Thermal electricity generation: Atmospheric emissions and associated health effects

Literature review for 2008-2013

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Prepared for:
Clean Air Strategic Alliance
Electricity Project Team

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Abbreviations

As:	arsenic
BC:	black carbon
BTEX:	benzene, toluene, ethylbenzene and xylene
CAPs:	concentrated ambient particles
CASA:	Clean Air Strategic Alliance
Cd:	cadmium
CO2:	carbon dioxide
CO:	carbon monoxide
EC:	elemental carbon
GHG:	greenhouse gas
HCl:	hydrochloric acid
HF:	hydrofluoric acid
Hg:	mercury
NOx:	nitrogen oxides
NOy:	nitrogen oxides and oxidation products
O3:	ozone
OC:	organic carbon
PAHs:	polycyclic aromatic hydrocarbons
Pb:	lead
PCB:	polychlorinated biphenyl
PM:	particulate matter
PM2.5:	particulate matter with an aerodynamic diameter 50% cut point of 2.5 μm
PM10:	particulate matter with an aerodynamic diameter 50% cut point of 10 μm
RDF:	refuse-derived fuel
SO2:	sulphur dioxide
TSP:	total solid particulate
UFP:	ultrafine particle
VOC:	volatile organic compound
WTE:	waste-to-energy

Executive Summary

This literature review was prepared for the Clean Air Strategic Alliance (CASA) Electricity Project Team as part of the 5-year review process of the *2003 Emissions Management Framework for the Alberta Electricity Sector*. The review presents a collection of recent white and grey literature abstracts (2008-2013) relating to the atmospheric emissions of thermal electricity generation and the associated health effects. The focus is on emissions of five priority substances (mercury (Hg), nitrogen oxides (NOx), sulphur dioxide (SO2), particulate matter (PM), and carbon dioxide/greenhouse gases (CO2, GHG)), as well as any other substances documented in recent literature. Fuel types of interest are those relevant to thermal electricity generation in Alberta: coal, oil, natural gas, shale, black liquor, biomass, municipal solid waste, refuse-derived fuel, sewage sludge, and recyclable waste.

The main objectives of this review are to: (i) Identify new information related to atmospheric emissions from thermal electricity generation and provide a list of abstracts; (ii) Identify new information related to health effects associated with thermal electricity generation emissions and provide a list of abstracts; and (iii) Critically evaluate and rank the health effects studies to provide an indication of the quality of the literature.

For the health effects studies, articles considered relevant were original epidemiology, animal, or *in vitro* studies evaluating the health impacts of atmospheric emissions from power plants. The literature search produced 63 white literature articles and 8 grey literature documents. Each of the health effects studies underwent an assessment of technical quality; 23 were ranked as high quality, 35 as moderate quality, and 13 as low quality.

For atmospheric emissions, articles were considered relevant if they measured emissions directly from power plant stacks, measured ambient pollutant concentrations near power plants, or presented past/future emission inventories of existing power plants. The literature search produced ~400 relevant white literature and ~80 relevant grey literature articles related to emissions.

The report provides a summary of the main findings and key studies for each pollutant, and presents a list of all recent abstracts identified by the literature search. Pollutants are categorized as '5 Priority Substances' (Hg, NOx, SO2, PM, CO2/GHG) and 'Non-Priority Substances'. The main non-priority substances captured by the literature search include PM components (elements, metals, ammonia, black carbon, elemental carbon, organic carbon, polycyclic aromatic hydrocarbons, sulphates, nitrates, and other ions), dioxins and furans, volatile organic compounds, acid gases, radionuclides, and amines/nitrosamines.

1. Introduction

1.1 Objectives

This literature review was prepared for the Clean Air Strategic Alliance (CASA) Electricity Project Team as part of the 5-year review process of the *2003 Emissions Management Framework for the Alberta Electricity Sector* (CASA, 2003). The review presents a collection of recent white and grey literature abstracts (2008-2013) relating to the atmospheric emissions of thermal electricity generation and the associated health effects.

Previous 5-year reviews for CASA were conducted in 2008 for atmospheric emissions and environmental effects (Swanson, 2008) as well as health effects (LeBlanc, 2008) related to thermal electricity generation.

The main objectives of this review are to:

I. Identify new information related to atmospheric emissions from thermal electricity generation and provide a list of abstracts;
II. Identify new information related to health effects associated with thermal electricity generation emissions and provide a list of abstracts;
III. Critically evaluate and rank the health effects studies to provide an indication of the quality of the literature included in the review.

The review will focus on emissions of five priority substances (mercury (Hg), nitrogen oxides (NOx), sulphur dioxide (SO2), particulate matter (PM), and carbon dioxide/greenhouse gases (CO2, GHG)), as well as any other substances documented in the recent literature.

1.2 Methodology

1.2.1 Literature search methods

White literature

Literature searches were conducted using 3 health and science databases: *Scopus*, *ISI Web of Science*, and *Pubmed*. These databases are commonly used in environmental health and science, cover a range of disciplines, and include links to related articles. A comparison of the characteristics of these databases can be found in a review by Falagas et al (2008). Searches were limited to English articles published between 2008 and 2013. Articles with advanced online publication dates in 2013 were also included.

The search strategy is provided in Table 1-1; search terms were tailored to each database based on the focus of each search (ie. health-focused, emission-focused, or a general search) and the type/number of articles generated. The number of studies related to power and electricity is enormous; therefore, the search strategy required significant tailoring to narrow the results to the most relevant articles. For all searches, the first row includes terms that are common synonyms for power plants or power generation. For the health-focused search (Table 1-1a), row 2 includes common health and epidemiology terms. For the emission-focused search (Table 1-1b), terms in row 2 are the fuel types of interest for this review, and row 3 identifies terms related to

atmospheric emissions and ambient air. Each search was narrowed further by excluding studies with terms listed in the 'NOT' row. These exclusion terms were words commonly found in studies generated by the literature search that were not relevant to the current review. For example, the term 'Fukushima' was used to exclude the large number of studies related to the 2011 Fukushima nuclear power plant incident. Likewise, the term 'gait' was used to exclude the numerous studies evaluating 'power generation' during walking and effect on gait.

References generated from each search were exported into reference management software. After removal of duplicates, the total number of studies generated by the 5 searches was ~6500. Given the broad nature of the topic, it was expected that the literature search would generate many studies that were not applicable to the literature review. However, performing the literature search in this manner (ie. of low specificity, high sensitivity) would maximize the number of suitable articles retrieved. This would provide a more thorough collection of articles and a better indication of the current state of knowledge. Any grey literature references (eg. book chapter, conference proceeding) found in the white literature search were included with the grey literature references.

Table 1-1. Literature search strategy for thermal electricity generation articles published in English between 2008 and 2013

	Search terms	Field	Database	Results
a. Health-focused search				
	1. Electrical generation, electricity generating, electricity generation, generating station(s), power generating, power generation, power plant(s), power sector, OR power station(s)	Abstract Keyword Title	*Scopus*	**1353**
AND	2. Adult(s), cancer, cardiovascular, child, children, cohort, disease, epidemiological, epidemiology, health, morbidity, mortality, population, respiratory, OR symptom(s)		*ISI Web of Science*	**1531**
NOT	3. Bacteria, fish, fuel cell, Fukushima, gait, life cycle analysis, life cycle assessment, microbial, nuclear, photovoltaic, OR soil	All Fields		
LIMIT TO	4. Article, book chapter, conference proceeding	-		
b. Emission-focused search				
	1. Electrical generation, electricity generating, electricity generation, generating station(s), power generating, power generation, power plant(s), power sector, OR power station(s)	Abstract Keyword Title	*Scopus*	**2526**
AND	2. Biogas, biomass, black liquor, coal, fossil fuel, fuel oil, gas oil, MSW, municipal solid waste, natural gas, recyclable, refuse-derived fuel, sewage sludge, OR wood		*ISI Web of Science*	**2584**
AND	3. Air quality, ambient air, ambient concentration(s), atmosphere, atmospheric, emission(s), plume, OR stack			
NOT	4. Bacteria, fish, fuel cell, Fukushima, gait, life cycle analysis, life cycle assessment, microbial, nuclear, optimization, photovoltaic, OR soil	All Fields		
LIMIT TO	5. Article, book chapter, conference proceeding	-		
c. General search				
	1. Electrical generation, electricity generating, electricity generation, generating station(s), power generating, power generation, power plant(s), power sector, OR power station(s)	All Fields	*Pubmed*	**1501**
NOT	2. Bacteria, fish, fuel cell, Fukushima, gait, microbial, nuclear, photovoltaic, OR soil			
		Total # of studies (after removal of duplicates)		**~6500**

Study Inclusion Criteria

Abstracts generated by the literature search were reviewed for relevance by a single reviewer. The screening process consisted of two phases: an initial scan of titles and abstracts (which eliminated a large number of articles), followed by a more detailed screening of abstracts and, if necessary, full texts. Fuel types of interest included those relevant to electricity generation in Alberta: coal, oil, natural gas, shale, black liquor, biomass, municipal solid waste (MSW), refuse-derived fuel (RDF), sewage sludge, and recyclable waste. Only studies that indicated the fuel was used specifically for generation of energy/power/electricity were included.

For health effects, articles considered relevant were original epidemiology, animal, or *in vitro* studies evaluating the health impacts of atmospheric emissions from power plants. Types of studies considered out of scope included occupational studies, cost-benefit analyses, and modeling studies that estimated health impacts based on emission data.

For atmospheric emissions, articles were considered relevant if they measured emissions directly from power plant stacks/flue gas (sampled downstream from all pollution control systems), measured ambient pollutant concentrations near power plants (eg. source apportionment or 'top down' studies), or presented past/future emission inventories of existing power plants (eg. 'bottom-up' studies).

Several study types related to emissions were considered out of scope for this review: assessments of pollution control technologies (eg. carbon capture materials, mercury abatement methods), assessments of optimal conditions for fuel combustion, development of new electricity generation techniques, laboratory testing of fuel combustion, analyses of fly ash or bottom ash samples collected from power plants, life cycle assessments, estimations of emissions from proposed installations, and estimations of potentially avoided CO2 emissions with the use of biomass over fossil fuels. Additionally, any 2008 studies that were included in the previous 5-year reviews (LeBlanc, 2008; Swanson, 2008) were excluded.

Supplementary searches

To ensure a more thorough collection of the literature, supplementary searches were conducted to obtain articles not found by the white literature search. The methods included citation sourcing of relevant articles and use of the 'related studies' function within the 3 databases. Several studies were found using the supplementary search methods, particularly source apportionment or emission inventory studies where power plants or electricity generation were only mentioned in the text.

Grey literature

The search for grey literature documents was conducted using websites of known health and environmental agencies. The websites searched were those used in the previous 5-year reviews (LeBlanc, 2008; Swanson, 2008), as well as any other agencies identified in recent studies or reports (Table 1-2). Original documents pertaining to health effects or emissions from thermal electricity generation were identified by searching each website for publications containing any of the following electricity-related terms: biomass, black liquor, coal, electrical, electricity, gas, municipal solid waste, oil, power, or refuse-derived fuel. Additionally, brief Google-based searches were conducted using agency names combined with the following search terms: electrical, electricity, power generation, or power plant. Criteria for study inclusion were the same as indicated above. In cases where annual or repeated reports were published by the same agency, only the most recent report was included.

Table 1-2. Agencies searched for documents relating to power plant emissions or health effects

Agency or Group	Country	Website
Agency for Toxic Substances and Disease Registry	USA	www.atsdr.cdc.gov
Alberta Health and Wellness	Canada	www.health.gov.ab.ca
Alberta Environment	Canada	www.environment.gov.ab.ca
Brookhaven National Laboratory	USA	www.bnl.gov
California Air Resources Board	USA	www.arb.ca.gov
Canadian Clean Power Coalition	Canada	www.canadiancleanpowercoalition.com
Canadian Council of Ministers of the Environment	Canada	www.ccme.ca
Clean Air Task Force	USA	www.catf.us
Commission for Environmental Cooperation	Canada, USA, Mexico	www.cec.org
Electric Power Research Institute	USA	www.epri.com
Energy Information Administration	USA	www.eia.gov/environment
Environment America	USA	www.environmentamerica.org
Environment Canada	Canada	www.ec.gc.ca
Environmental Integrity Project	USA	www.environmentalintegrity.org
Environmental Protection Agency	USA	www.epa.gov
European Commission - Environment	Europe	www.ec.europa.eu/environment; bookshop.europa.eu
Government of British Columbia	Canada	www.gov.bc.ca
Government of Ontario	Canada	www.gov.on.ca
Government of Saskatchewan	Canada	www.gov.sk.ca
Greenpeace	International	www.greenpeace.org
Health Canada	Canada	www.hc-sc.gc.ca
Health Effects Institute	USA	www.healtheffects.org
National Energy Technology Laboratory	USA	www.netl.doe.gov
National Council on Air and Stream Improvement	Canada, USA	www.ncasi.org
Natural Resources Canada	Canada	www.nrcan.gc.ca
New South Wales Health	Australia	www.health.nsw.gov.au
Ontario Clean Air Alliance	Canada	www.cleanairalliance.org
Ontario Power Generation	Canada	www.opg.com
Southwest Clean Air Agency	USA	www.swcleanair.org
Sustainable Energy & Economic Development	USA	www.seedcoalition.org
Texas Commission on Environmental Quality	USA	www.tceq.state.tx.us
Toronto Public Health	Canada	www.toronto.ca/health
World Health Organization	International	www.who.int
World Resources Institute	International	www.wri.org

1.2.2 Methods for criteria assessment of health effects studies

To provide an indication of the quality of the health effects literature, studies evaluating the health impacts of power plant emissions underwent an assessment of technical quality. The evaluation tool used was the *'Checklist for assessing the quality of quantitative studies*' developed by Kmet and colleagues at the Alberta Heritage Foundation for Medical Research (Kmet et al, 2004). With this tool, the quality of a variety of study designs (epidemiology, animal, and in vitro studies) can be assessed using the same 14-item checklist. The tool includes a guideline manual on how to appropriately evaluate each item. The use of the tool for animal and *in vitro* studies was not specifically addressed in the manual; however, in reviewing the criteria checklist, it was found that the questions could generally be applied to the evaluation of animal and *in vitro* studies.

The review form template is provided in Appendix A. Each item is scored based on the degree that which each specific criterion is met (yes=2, partial=1, no=0, or not applicable=n/a). A final score is derived by dividing the total number of points by the total points possible; the scores are then used to classify each study as low, moderate, or high quality, based on the rating system of Squires et al (2011).

In addition to the scoring, any apparent strengths and weaknesses of each study were also noted.

An assessment of criteria was completed for the 71 health effects studies only. Conducting a similar criteria evaluation for the ~500 emissions studies would require a considerable amount of time and resources, and thus was considered beyond the scope of this review.

1.2.3 Method uncertainties

Given the broad nature of the topic and the large amount of available literature regarding power plants and electricity generation, there is the potential that relevant articles may have been missed. All efforts were made to be thorough and obtain a comprehensive collection of all suitable studies; however, the literature search methods may not have identified all relevant material. The literature search may be limited by the search terms used and the capabilities of the database search engines. For the grey literature search, there is the potential that important agencies may have been missed. Additionally, grey literature documents were limited to those that were publicly available.

Due to time and resource constraints, the literature search and criteria assessment were performed by a single reviewer only. It is acknowledged that the use of a single reviewer for study selection and appraisal has the potential to introduce a reviewer bias. However, the reviewer has no stake in the results of this review and all attempts were made by the reviewer to remain objective throughout the process. It is hoped that reviewer bias is minimized by utilizing clearly-defined and transparent methods for study identification, selection, and appraisal.

1.3 Organization of document

A summary of the main findings and key studies for each pollutant is presented in Section 2. Sections 3 and 4 provide the list of abstracts for the 5 priority substances and non-priority substances, respectively. Evaluations of SO2 and NOx are often conducted together; therefore, data for these two substances are presented in the same sections (Sections 2.1.2 and 3.2). Studies that have evaluated multiple pollutants (which

typically include priority substances) are presented at the end of the priority substances section (Sections 2.1.5 and 3.5).

For each pollutant, health effects abstracts are presented first, followed by the emissions abstracts. Health effects abstracts are organized based on study quality ranking (*High quality*, *Moderate quality*, *Low quality*). Emissions abstracts are organized based on whether stack emissions or ambient concentrations were measured (*Measured emissions*, eg. 'top down' studies)) or modeled/inventoried based on estimations of emissions (*Modeled emissions*, eg. 'bottom up' studies).

For PM, many studies include a composition analysis of metals, elements, ions, and polycyclic aromatic hydrocarbons (PAHs). Studies focusing primarily on PM mass and source apportionment analyses are included in the 'Particular Matter' category (Sections 2.1.3 and 3.3); studies focusing on specific components of PM are included in the 'Particular Matter Components' category (Sections 2.2.1 and 4.1).

1.4 References

Clean Air Strategic Alliance (CASA) Electricity Project Team. 2003. An Emissions Management Framework for the Alberta Electricity Sector Report to Stakeholders. Edmonton, AB. Available at http://www.casahome.org/DesktopModules/Bring2mind/DMX/Download.aspx?EntryId=572&Command=Core_Download&PortalId=0&TabId=161.

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2. Summary of findings and key studies

For health effects studies, 63 white literature articles and 8 grey literature documents were found in the literature search. Overall, there were 54 epidemiology studies, 16 animal toxicology studies, and 1 *in vitro* study. Most of the studies were related to fossil fuels, with few studies evaluating the health impacts of biomass or MSW. For atmospheric emissions, ~400 relevant white literature and ~80 grey literature articles were found.

The following section provides a summary of the main findings and key studies for each pollutant. The key studies identified are those that were considered particularly relevant to CASA and emission management in Alberta.

2.1 Priority substances

2.1.1 Mercury

Health Effects

The literature search produced 4 health effects studies specifically evaluating power plant emissions of mercury (3 of moderate quality, 1 of low quality). A cross-sectional analysis conducted in China found hair levels of mercury to be higher in children living near thermal power plants (Park et al, 2008). Mixed results were observed in ecological analyses investigating correlations between mercury emissions and autism (Lewandowski et al, 2009; Palmer et al, 2009).

Emissions

Key studies evaluating ambient levels of mercury were found for Alberta (Mazur et al, 2009), Ontario (Deeds et al, 2013; Xu and Akhtar, 2010), and USA (de Foy et al, 2012; Kolker et al, 2010; Lyman and Sexauer Gustin, 2008; Weiss-Penzias et al, 2011). Of particular note are two studies measuring ambient mercury concentrations in Rochester, New York before, during and after the 4-month closure of a coal-fired power plant (Huang et al, 2010; Wang Y et al, 2013).

Several studies evaluated Hg speciation in stack flue gas (Shah et al, 2010; Wang SX et al, 2010), as well as Hg isotopic fractionation of stack flue gas (Sun et al, 2013). A key study conducted in Taiwan compared power plant emission rates to ambient mercury levels (Wu et al, 2012).

Recent studies also included the review of emission inventories for mercury (Canadian Council of Ministers of the Environment, 2013; Nelson et al, 2012; United Nations Environment Programme, 2013).

Table 2-1. Key health effects studies for mercury

Author, Year; (Ranking*)	Title	Page
Lewandowski et al, 2009; (M)	An evaluation of surrogate chemical exposure measures and autism prevalence in Texas	23

*Ranking: H: High quality; M: Moderate quality; L: Low quality. Details on ranking methodology provided in Section 1.2.2.

Table 2-2. Key emissions studies for mercury

2.1.2 Sulphur dioxide and nitrogen oxides

Health Effects

Six studies evaluating the health effects of NOx and SO2 from power plants were found in the literature search (2 high quality, 1 moderate quality, and 3 low quality studies). In a prospective cohort study of Israeli children, NOx and SO2 emissions from power plants were associated with poorer performance on lung function tests (Yogev-Baggio et al, 2010). Also in Israeli children, a cross-sectional study found power plant NOx emissions to correlate with respiratory symptoms, but not asthma or COPD (Amster et al, 2014).

In a time-series analysis conducted in New York State, Garcia et al (2011) found respiratory-related hospital admissions to be higher on days when air was transported from Midwest areas (where power plant emissions, particularly NOx and the resulting formation of O3, are known to be high).

Emissions

Relevant studies have focused on measurements of NOx from aircraft or satellites in the US and Canada (Duncan et al, 2013; Halla et al, 2011) or examining the nitrogen isotopic composition of NOx in stack emissions (Felix et al, 2012).

A recent air monitoring survey conducted in Grande Cache, Alberta, observed elevated levels of SO2 and NOx downwind from a coal-fired power plant; however, concentrations did not exceed the ambient air quality objectives (Alberta Environment, 2010).

Key studies also include those comparing measured ambient pollutant levels with estimated 'bottom up' levels for SO2 (Dresser and Huizer, 2011) and NOx (Pouliot et al, 2012). Likewise, others have compared aircraft or satellite measurements of SO2 and NOx with power plant inventory emission data (Fioletov et al, 2011; Kim et al, 2009; Russel et al, 2012; Zhou et al, 2012). In addition, several studies analyzed NOx emissions and the resulting formation of ozone in plumes (Brown et al, 2012; Schade et al, 2011).

Relevant modeling abstracts include four US studies that modeled air dispersion of NOx and reactive nitrogen (Pinder et al, 2011), NOx and O3 (Bergin et al, 2008; Gego et al, 2008), or NOy (NOx and oxidation products) and SO2 (Vijayaraghavan et al, 2009).

Table 2-3. Key health effects studies for sulphur dioxide and nitrogen oxides

Author, Year; (Ranking*)	Title	Page
Amster et al, 2014; (H)	Contribution of nitrogen oxide and sulfur dioxide exposure from power plant emissions on respiratory symptom and disease prevalence	52
Garcia et al, 2011; (M)	An evaluation of transported pollution and respiratory-related hospital admissions in the state of New York	54
Yogev-Baggio et al, 2010; (H)	Who is affected more by air pollution-sick or healthy? Some evidence from a health survey of schoolchildren living in the vicinity of a coal-fired power plant in Northern Israel	53

*Ranking: H: High quality; M: Moderate quality; L: Low quality. Details on ranking methodology provided in Section 1.2.2.

Table 2-4. Key emissions studies for sulphur dioxide and nitrogen oxides

Author, Year	Title	Page
Alberta Environment, 2010	Air quality monitoring: In the Grande Cache area, September 2008	200
Bergin et al, 2008	Single-source impact analysis using three-dimensional air quality models	71
Brown et al, 2012	Effects of NOx control and plume mixing on nighttime chemical processing of plumes from coal-fired power plants	58
Dresser and Huizer, 2011	CALPUFF and AERMOD model validation study in the near field: Martins Creek revisited	58
Duncan et al, 2013	The observed response of Ozone Monitoring Instrument (OMI) NO2 columns to NOx emission controls on power plants in the United States: 2005-2011	58
Felix et al, 2012	Nitrogen isotopic composition of coal-fired power plant NOx: influence of emission controls and implications for global emission inventories	59
Fioletov et al, 2011	Estimation of SO2 emissions using OMI retrievals	59
Gego et al, 2008	Modeling analyses of the effects of changes in nitrogen oxides emissions from the electric power sector on ozone levels in the eastern United States	72
Halla et al, 2011	Determination of tropospheric vertical columns of NO2 and aerosol optical properties in a rural setting using MAX-DOAS	60
Kim et al, 2009	NO2 columns in the western U.S. observed from space and simulated by a regional chemistry model and their implications in NOx emissions	62
Pinder et al, 2011	Trends in atmospheric reactive nitrogen for the Eastern United States	75
Pouliot et al, 2012	Quantification of emission factor uncertainty	65
Russel et al, 2012	Trends in OMI NO2 observations over the US: Effects of emission control technology and the economic recession	67
Schade et al, 2011	Rural southeast Texas air quality measurements during the 2006 Texas Air Quality Study	195
Vijayaraghavan et al, 2009	Export of reactive nitrogen from coal-fired power plants in the U. S.: Estimates from a plume-in-grid modeling study	76
Zhou et al, 2012	Observation and modeling of the evolution of Texas power plant plumes	69

2.1.3 Particulate matter

Health Effects

There were 16 health effects studies found specifically evaluating PM, all of which were ranked as moderate or high quality. For epidemiology studies, Zhou et al (2011) found power plants to be an important contributor to cardiorespiratory mortality in a PM source-apportionment analysis. Similarly, Sarnat et al (2008) observed a significant association between sulphate-rich secondary PM2.5 (formed mainly from primary power plant precursors) and respiratory emergency department visits.

The majority of PM health effects abstracts were toxicology studies exposing animals to various mixtures of power plant emissions. Diaz et al (2011) found PM mixtures containing secondary oxidized particles to be associated with changes in respiratory parameters in rats (eg. increased respiratory frequency, decreased peak expiratory flow). Exposures to the same oxidized PM mixtures also resulted in increased inflammation in

bronchoalveolar lavage fluid in healthy rats (Godleski et al, 2011) and ventricular arrhythmias in susceptible rats (Wellenius et al, 2011). Another group of studies assessed exposure of rats to concentrated ambient particles (CAPs) from polluted areas. Exposures to CAPs linked to power plant sources led to increased metals/elements in lung tissue (Morishita et al, 2009), enhanced allergic airway disease in asthmatic rats (Harkema et al, 2009; Wagner et al, 2012), and decreased heart rate in spontaneously hypertensive rats (Rohr et al, 2011).

Emissions

Several recent emission studies have focused towards assessing ultrafine particles (UFP, PM ≤ 0.1 μm)) downwind of coal-fired power plants (Jeong et al, 2010; Junkermann et al, 2011a,b). Also common were studies that performed elemental analyses of ambient PM samples to identify PM sources and estimate the contribution of each source to total PM mass (Cohen et al, 2012; Hibberd et al, 2013; Kolker et al, 2013; Martello et al, 2008; McGuire et al, 2011; Morishita et al, 2011a,b; Yerramilli et al, 2012). Alternatively, other investigators have utilized ambient PM measurements combined with emission inventory data to identify source contributions to atmospheric PM (Cherian et al, 2010; Hendriks et al, 2010).

Several studies focused on particle emissions of power plants utilizing non-fossil fuels. PM, particularly UFP and nanoparticles (PM ≤ 0.05 μm), have been measured in stack emissions of waste-to-energy (WTE) and woody biomass power plants (Buonanno et al, 2012; Cernuschi et al, 2012; Ozgen et al, 2012). Assessments of UFP in ambient air near WTE plants have also been conducted (Buonanno et al, 2010b).

A number of studies also made use of qualitative analyses to examine particles. Hinkley et al (2008) collected ambient UFP near coal-fired power plants and evaluated particle morphology using transmission electron microscope imaging. Similar morphological examinations were performed for PM10 samples from coal-fired power plants (Iordanidis et al, 2008b). Buonanno et al (2011) conducted a mineralogical and morphological analysis of UFP from MSW power plants; oxides (eg. calcium oxide), salts (eg. sodium chloride), and silicates (eg. chlorite) were the main inorganic minerals detected.

Table 2-5. Key health effects studies for particulate matter

Author, Year; (Ranking*)	Title	Page
Diaz et al, 2011; (H)	Toxicological evaluation of realistic emission source aerosols (TERESA)–power plant studies: assessment of breathing pattern	80
Godleski et al, 2011; (H)	Toxicological evaluation of realistic emission source aerosols (TERESA)-power plant studies: assessment of cellular responses	81
Harkema et al, 2009; (H)	Effects of concentrated ambient particles and diesel engine exhaust on allergic airway disease in Brown Norway rats	82
Morishita et al, 2009; (H)	Source-to-receptor pathways of anthropogenic PM2.5 in Detroit, Michigan: Comparison of two inhalation exposure studies	86
Rohr et al, 2011; (H)	Altered heart rate variability in spontaneously hypertensive rats is associated with specific particulate matter components in Detroit, Michigan	88
Sarnat et al, 2008; (H)	Fine particle sources and cardiorespiratory morbidity: An application of chemical mass balance and factor analytical source-apportionment methods	89

*Ranking: H: High quality; M: Moderate quality; L: Low quality. Details on ranking methodology provided in Section 1.2.2.

Table 2-6. Key emissions studies for particulate matter

Morishita et al, 2011a	Identification of ambient PM2.5 sources and analysis of pollution episodes in Detroit, Michigan using highly time-resolved measurements	117
Morishita et al, 2011b	Source identification of ambient PM2.5 for inhalation exposure studies in Steubenville, Ohio using highly time-resolved measurements	117
Ozgen et al, 2012	Nanoparticle emissions from a woody biomass power plant (15 Mw)	129
Yerramilli et al, 2012	An integrated WRF/HYSPLIT modeling approach for the assessment of PM2.5 source regions over the Mississippi Gulf Coast region	128

2.1.4 Carbon dioxide and greenhouse gases

Health Effects

Greenhouse gases (GHG) include CO2, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride. There were no studies found in the literature search that evaluated health effects of power plant CO2 or GHG emissions.

Emissions

Several studies have estimated ambient CO2 levels using aircraft (Krings et al, 2010; Thorpe et al, 2012) or satellite imagery (Bovensmann et al, 2010; Velazco et al, 2011). Others have focused on identifying the biogenic fraction of CO2 emissions from fossil fuel, biomass, and waste power plants (Calcagnile et al, 2011; Mohn et al, 2012; Palstra and Meijer, 2010). Another key study compared emissions of GHG from power plants utilizing wood chip fuel, refuse-derived fuel, and refused plastic fuel (Cho et al, 2012).

Government reports summarizing GHG emissions data from different sectors are available for Alberta, Canada, and the US (Alberta Environment and Sustainable Resource Development, 2013; Environment Canada, 2013; US Environmental Protection Agency, 2013). A number of CO2 emission inventory studies are also noted (Gurney et al, 2009, 2012; Petron et al, 2008).

Table 2-7. Key emissions studies for carbon dioxide and greenhouse gases

Author, Year	Title	Page
Alberta Environment and Sustainable Resource Development, 2013	Report on 2011 greenhouse gas emissions	143
Bovensmann et al, 2010	A remote sensing technique for global monitoring of power plant CO2 emissions from space and related applications	134
Calcagnile et al, 2011	Radiocarbon AMS determination of the biogenic component in CO2 emitted from waste incineration	135
Cho et al, 2012	Development of methane and nitrous oxide emission factors for the biomass fired circulating fluidized bed combustion power plant	135
Environment Canada, 2013	National Inventory Report 1990–2011: Greenhouse gas sources and sinks in Canada	145
Gurney et al, 2009	High resolution fossil fuel combustion CO2 emission fluxes for the United States	139

Author, Year	Title	Page
Gurney et al, 2012	Quantification of fossil fuel CO2 emissions on the building/street scale for a large U.S. city	140
Krings et al, 2010	MAMAP - a new spectrometer system for column-averaged methane and carbon dioxide observations from aircraft: retrieval algorithm and first inversions for point source emission rates	135
Mohn et al, 2012	Fossil and biogenic CO2 from waste incineration based on a yearlong radiocarbon study	137
Palstra and Meijer, 2010	Carbon-14 based determination of the biogenic fraction of industrial CO2 emissions - application and validation	137
Petron et al, 2008	High-resolution emissions of CO2 from power generation in the USA	141
Thorpe et al, 2012	Point source emissions mapping using the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)	138
US Environmental Protection Agency, 2013	Inventory of U.S. greenhouse gas emissions and sinks: 1990 – 2011	147
Velazco et al, 2011	Towards space based verification of CO2 emissions from strong localized sources: fossil fuel power plant emissions as seen by a CarbonSat constellation	137

2.1.5 Multiple pollutants

Health Effects

Thirty-one health effects studies were found that analyzed the impacts of emissions of multiple pollutants from power plants on nearby residents (4 high quality, 21 moderate quality, and 6 low quality studies).

Two large time-series ecological analyses examined the relationships between ambient pollutant levels and mortality before and after significant changes in power plant emissions. In Germany, Peters et al (2009) demonstrated associations between NO2, CO, O3, or UFP and daily mortality; their observations suggested that the substitution of natural gas for coal, among other air quality improvements, may have had a beneficial impact on pollution-related mortality. In a similar Hong Kong study, Wong et al (2012) found nickel and vanadium to correlate with respiratory-related mortality, and PM10 and SO2 to correlate with losses in life expectancy.

In New York, Liu et al (2012) observed increased rates of hospitalization for asthma, acute respiratory infection, and chronic obstructive pulmonary disease among subjects living in a ZIP code containing a fuel-fired power plant. Similarly, an Italian study found ambient concentrations of PM10 and NO2 to correlate with daily emergency visits and hospital admissions in elderly subjects living near a natural gas power plant (Di Ciaula, 2012). In Canada, a large multi-centre case-control analysis observed a weak association between breast cancer and residential proximity to thermal power plants (Pan et al, 2011).

Exposure of animals to simulated downwind coal combustion emissions found few outcomes to be significantly altered by exposure. Simulated coal combustion atmospheres had only subtle effects on some pulmonary outcomes (Barrett et al, 2011; Seagrave et al, 2008) and no major effects on cardiovascular

outcomes (Campen et al, 2010). Mauderly et al (2011) found coal combustion mixtures to be less toxic overall than diesel exhaust, gasoline exhaust, and wood smoke.

Emissions

The literature search produced several studies evaluating emissions of multiple pollutants in Alberta. An air monitoring survey of carbon monoxide (CO), PAH, NOx, SO2, total reduced sulphur, and total hydrocarbons was recently conducted near a power station in Three Creeks, Alberta (Alberta Environment, 2011). Alberta Environment (2008a) presented a summary of emission inventories for CO, PM2.5, NOx, and SO2 from the power generation sector in Alberta for the years 1990 through 2015. In a report assessing pulp mill emissions, Alberta Environment (2008b) discussed PM, NOx, SO2, and total reduced sulphur emissions from the recovery boilers (black liquor) and power boilers of 4 Alberta pulp mills.

Other studies considered relevant to this review include comparisons of ambient pollutant concentrations with power plant emission inventories (Brewer and Moore, 2009; He et al, 2013; Morgenstern et al, 2012; Peischl et al, 2010), comparisons of personal exposure measurements with pollutant levels in ambient air (Lioy et al, 2011), and comparisons of ambient pollutant concentrations between periods of power plant operation and plant closure (Jaffe and Reidmiller, 2009; Wang et al, 2011a,b). Additionally, ambient concentrations of several air pollutants have been measured in the vicinity of WTE facilities utilizing MSW (AECOM Inc, 2010; New Hampshire Department of Environmental Services, 2009).

Key studies also include assessments of stack emissions of multiple pollutants from power plants utilizing refuse derived fuel (Bulow, 2008), sewage sludge (Pudasainee et al, 2013), MSW (Environmental Integrity Project, 2011), residual fuel oil (Hays et al, 2009), and black liquor (Vakkilainen et al, 2010). In Denmark, a survey of stack emissions was conducted for 25 power plants utilizing fossil fuels, biogas, MSW, straw, or wood; revised emission factors were developed for more than 30 pollutants (Nielson et al, 2010).

Key modeling abstracts include studies evaluating air dispersion of pollutants based on power plant emission data (Lonsdale et al, 2012; Odman et al, 2009) and studies developing emission inventories for multiple pollutants (Wilson et al, 2008; Woo et al, 2008).

Table 2-8. Key health effects studies for multiple pollutants

Author, Year; (Ranking*)	Title	Page
Barrett et al, 2011; (M)	Effects of simulated downwind coal combustion emissions on pre-existing allergic airway responses in mice	155
Campen et al, 2010; (M)	A comparison of vascular effects from complex and individual air pollutants indicates a role for monoxide gases and volatile hydrocarbons	156
Di Ciaula et al, 2012; (M)	Emergency visits and hospital admissions in aged people living close to a gas-fired power plant	157
Liu et al, 2012; (M)	Association between residential proximity to fuel-fired power plants and hospitalization rate for respiratory diseases	160
Mauderly et al, 2011; (H)	Health effects of subchronic inhalation exposure to simulated downwind coal combustion emissions	148
Pan et al, 2011; (H)	Breast cancer risk associated with residential proximity to industrial plants in Canada	149

Author, Year; (Ranking*)	Title	Page
Peters et al, 2009; (H)	The influence of improved air quality on mortality risks in Erfurt, Germany	150
Seagrave et al, 2008; (M)	Oxidative stress, inflammation, and pulmonary function assessment in rats exposed to laboratory-generated pollutant mixtures	170
Wong et al, 2012; (H)	Impact of the 1990 Hong Kong legislation for restriction on sulfur content in fuel	152

*Ranking: H: High quality; M: Moderate quality; L: Low quality. Details on ranking methodology provided in Section 1.2.2.

Table 2-9. Key emissions studies for multiple pollutants

Author, Year	Title	Page
AECOM Inc, 2010	Report on the third operational phase air media sampling program – Winter 2008	199
Alberta Environment, 2011	A report on air quality monitoring conducted in the Three Creeks area (Phase II)	200
Alberta Environment, 2008a	Alberta air emissions trends and projections	219
Alberta Environment, 2008b	Technical and regulatory review and benchmarking of air emissions from Alberta's Kraft pulp mills	219
Brewer and Moore, 2009	Source contributions to visibility impairment in the southeastern and western United States	183
Bulow, 2008	Small decentralised thermal power stations for Refuse-Derived Fuel (RDF)	201
Environmental Integrity Project, 2011	Waste-to-energy: Dirtying Maryland's air by seeking a quick fix on renewable energy?	221
Hays et al, 2009	Physical and chemical characterization of residual oil-fired power plant emissions	187
He et al, 2013	Trends in emissions and concentrations of air pollutants in the lower troposphere in the Baltimore/Washington airshed from 1997 to 2011	187
Jaffe and Reidmiller, 2009	Now you see it, now you don't: Impact of temporary closures of a coal-fired power plant on air quality in the Columbia River Gorge National Scenic Area	188
Lioy et al, 2011	Personal and ambient exposures to air toxics in Camden, New Jersey	190
Lonsdale et al, 2012	The effect of coal-fired power-plant SO2 and NOx control technologies on aerosol nucleation in the source plumes	210
Morgenstern et al, 2012	Accountability analysis of title IV phase 2 of the 1990 Clean Air Act Amendments	192
New Hampshire Department of Environmental Services, 2009	Public health assessment: Ambient air quality in Claremont, Sullivan County, New Hampshire	203
Nielsen et al, 2010	Emission factors and emission inventory for decentralised CHP production	203
Odman et al, 2009	Quantifying the sources of ozone, fine particulate matter, and regional haze in the Southeastern United States	213
Peischl et al, 2010	A top-down analysis of emissions from selected Texas power plants during TexAQS 2000 and 2006	193
Pudasainee et al, 2013	Hazardous air pollutants emission from coal and oil-fired power plants	194
Vakkilainen et al, 2010	Grouping statistically emissions from a recovery boiler	204

Author, Year	Title	Page
Wang et al, 2011a	Effect of the shutdown of a coal-fired power plant on urban ultrafine particles and other pollutants	197
Wang et al, 2011b	Long-term study of urban ultrafine particles and other pollutants	197
Wilson et al, 2008	Emission projections for the U.S. Environmental Protection Agency Section 812 second prospective Clean Air Act cost/benefit analysis	215
Woo et al, 2008	Development of North American emission inventories for air quality modeling under climate change	216

2.2 Non-priority substances

2.2.1 Particulate matter components (elements, metals, polycyclic aromatic hydrocarbons)

Health Effects

PM components include elements, metals, ammonia, black carbon (BC), elemental carbon (EC), organic carbon (OC), polycyclic aromatic hydrocarbons (PAHs), sulphates, nitrates, and other ions.

The literature search produced 14 health effects studies evaluating PM components, with PAHs and metals being the primary focus (5 high quality, 6 moderate quality, and 3 low quality studies). For PAHs, a group of prospective analyses in China assessed the impact of exposure to PAH emissions from a coal-fired power plant on children's health. Maternal exposure to PAH (measured as ambient PAH or PAH-DNA adducts in umbilical cord blood) was associated with reduced head circumference and reduced neurobehavioral development in children (Perera et al, 2008; Tang et al, 2008, 2014). A follow-up analysis linked prenatal PAH exposure, in combination with prenatal environmental tobacco smoke exposure, to reduced cognitive function of children at age 5 (Perera et al, 2012).

For metals, subjects living near power plants were found to have elevated levels of arsenic, lead, and other metals in blood, urine, or hair samples (Chiang et al, 2008; Chojnacka et al, 2012; Liang et al, 2010). Additionally, prenatal exposure to power plant lead emissions was associated with reduced neurodevelopment at age 2 (Tang et al, 2008).

PM components were also assessed in a number of multiple pollutant studies (see Sections 2.1.5 and 3.5).

Emissions

Key studies of stack emissions have analyzed metals, elements, and PAHs (Huggins and Goodarzi, 2009), lanthanoids (Celo et al, 2012), and nickel species (Huggins et al, 2011). A recent study compared the components of PM (sulphates, metals, PAHs) in the flue gases of power plants burning wood fuel and fossil fuel (Kaivosoja et al, 2013).

In samples of ambient air, key studies evaluated arsenic and mercury species (Fang et al, 2011a,b, 2012), lanthanoids (Moreno et al, 2008, 2010), and levels of BC in Ontario and Quebec (Chan et al, 2011; Jeong et

al, 2013). Recent studies conducted in Pennsylvania and Taiwan assessed metals in both stack emissions and nearby ambient air (Pennsylvania Department of Health, 2009; Wang et al, 2010).

Relevant modeling abstracts include emission inventories of EC and OC in the US (Chow et al, 2011), and metals (Hg, Pb, Cd) in Europe (Pacyna et al, 2009).

Key PAH studies focused on evaluation of PAHs in ambient air (Han et al, 2011), assessment of ambient and personal exposure to PAH coupled with PAH source identification (Choi and Spengler, 2014), and measurement of PAH species in the flue gas of power plants utilizing coal or coal plus tree bark (Kong et al, 2013; Ross et al, 2011).

Table 2-10. Key health effects studies for particulate matter components (elements, metals, PAH)

Author, Year; (Ranking*)	Title	Page
Chiang et al, 2008; (M)	A comparison of elementary schoolchildren's exposure to arsenic and lead	230
Chojnacka et al, 2012; (M)	Effects of local industry on heavy metals content in human hair	231
Liang et al, 2011; (M)	Lead in children's blood is mainly caused by coal-fired ash after phasing out of leaded gasoline in Shanghai	233
Perera et al, 2008; (H)	Benefits of reducing prenatal exposure to coal-burning pollutants to children's neurodevelopment in China	226
Perera et al, 2012; (H)	Effects of prenatal polycyclic aromatic hydrocarbon exposure and environmental tobacco smoke on child IQ in a Chinese cohort	225
Tang et al, 2014; (H)	Air pollution effects on fetal and child development: A cohort comparison in China	227
Tang et al, 2008; (H)	Effects of prenatal exposure to coal-burning pollutants on children's development in China	228

*Ranking: H: High quality; M: Moderate quality; L: Low quality. Details on ranking methodology provided in Section 1.2.2.

Table 2-11. Key emissions studies for particulate matter components (elements, metals, PAH)

Author, Year	Title	Page
Celo et al, 2012	Concentration and source origin of lanthanoids in the Canadian atmospheric particulate matter: a case study	238
Chan et al, 2011	Time-resolved measurements of black carbon light absorption enhancement in urban and near-urban locations of southern Ontario, Canada	239
Choi and Spengler, 2014	Source attribution of personal exposure to airborne polycyclic aromatic hydrocarbon mixture using concurrent personal, indoor, and outdoor measurements	240
Chow et al, 2011	PM2.5 source profiles for black and organic carbon emission inventories	258
Fang et al, 2011a	Study of ambient air particle-bound As(p) and Hg(p) in dry deposition, total suspended particulates (TSP) and seasonal variations in central Taiwan	242
Fang et al, 2011b	Measurement of ambient air arsenic (As) pollutant concentration and dry deposition fluxes in central Taiwan	242
Fang et al, 2012	Measuring and modeling atmospheric arsenic pollutants, total As, As(III), and As(V), at five characteristic sampling sites	242

Author, Year	Title	Page
Han et al, 2011	Comparison of spatial and temporal variations in p-PAH, BC, and p-PAH/BC ratio in six US counties	244
Huggins and Goodarzi, 2009	Environmental assessment of elements and polyaromatic hydrocarbons emitted from a Canadian coal-fired power plant	245
Huggins et al, 2011	Determination of nickel species in stack emissions from eight residual oil-fired utility steam-generating units	245
Jeong et al, 2013	Identification of the sources and geographic origins of black carbon using factor analysis at paired rural and urban sites	246
Kaivosoja et al, 2013	Comparison of emissions and toxicological properties of fine particles from wood and oil boilers in small (20-25kW) and medium (5-10MW) scale	246
Kong et al, 2013	Emission and profile characteristic of polycyclic aromatic hydrocarbons in PM2.5 and PM10 from stationary sources based on dilution sampling	247
Moreno et al, 2008	Lanthanoid geochemistry of urban atmospheric particulate matter	249
Moreno et al, 2010	Variations in vanadium, nickel and lanthanoid element concentrations in urban air	249
Pacyna et al, 2009	Changes of emissions and atmospheric deposition of mercury, lead, and cadmium	259
Pennsylvania Department of Health, 2009	Health consultation: First Energy Corporation, Bruce Mansfield power plant, Shippingport, Beaver County, Pennsylvania.	257
Ross et al, 2011	Formation and emission of polycyclic aromatic hydrocarbon soot precursors during coal combustion	250
Wang et al, 2010	Characteristics of heavy metals emitted from a heavy oil-fueled power plant in northern Taiwan	254

2.2.2 Dioxins and furans (and other polybrominated/polychlorinated substances)

Health Effects

No health studies were found that evaluated dioxins, furans, or other polychlorinated or polybrominated substances from power plants.

Emissions

Studies evaluating polychlorinated substances have primarily focused on emission of dioxins and furans (Hsieh et al, 2009; Wang et al, 2009), with some studies also focusing on polychlorinated biphenyls and naphthalenes (Bogdal et al, 2014; Mari et al, 2008b).

One research group assessed emissions of polybrominated dioxins, furans, and diphenyl ethers in flue gas (Tu et al, 2011; Wang et al, 2010) and ambient air (Tu et al, 2012).

Table 2-12. Key emissions studies for dioxins, furans, and other polybrominated/polychlorinated substances

Author, Year	Title	Page
Bogdal et al, 2014	Emissions of polychlorinated biphenyls, polychlorinated dibenzo-p-dioxins, and polychlorinated dibenzofurans during 2010 and 2011 in Zurich, Switzerland	263
Hsieh et al, 2009	Cluster analysis for polychlorinated dibenzo-p-dioxins and dibenzofurans concentrations in southern Taiwan	264
Mari et al, 2008b	Air concentrations of PCDD/Fs, PCBs and PCNs using active and passive air samplers	265
Tu et al, 2011	Distribution of polybrominated dibenzo-p-dioxins and dibenzofurans and polybrominated diphenyl ethers in a coal-fired power plant and two municipal solid waste incinerators	266
Tu et al, 2012	Monitoring and dispersion modeling of polybrominated diphenyl ethers (PBDEs) in the ambient air of two municipal solid waste incinerators and a coal-fired power plant	266
Wang YF et al, 2009	Emissions of polychlorinated dibenzo-p-dioxins and dibenzofurans from a heavy oil-fueled power plant in northern Taiwan	267
Wang LC et al, 2010	Emission estimation and congener-specific characterization of polybrominated diphenyl ethers from various stationary and mobile sources	267

2.2.3 Other pollutants (volatile organic compounds, acid gases, radionuclides, amines/nitrosamines)

Health Effects

Two moderate quality cross-sectional studies were found that specifically examined the health impacts of volatile organic compounds (VOCs) from power plants. Peluso et al (2013) and Rusconi et al (2011) compared ambient VOC concentrations with levels of VOC-related DNA adducts (malondialdehyde-deoxyguanosine adducts induced by reactive oxygen species) in children residing near an industrial complex in Italy housing an oil power plant, oil refinery, and petrochemical park. Ambient levels of benzene and ethylbenzene were highest near the industrial complex and lowest in the control area. No other VOCs were measured; however, the investigators indicated that formaldehyde, toluene, and xylenes were also produced by industries in the complex. Both studies demonstrated an increase in levels of VOC-related DNA adducts in nasal mucosa epithelium in children living near the industrial complex compared to children living in the control area.

No studies were found that evaluated health impacts of acid gases (halides), radionuclides, or amine/ nitrosamine emissions from power plants.

Emissions

For VOCs, Durrenberger et al (2008) measured ambient VOC concentrations in Texas at multiple sites near an industrial area involved with oil and natural gas production, chemical production, and electric power generation. The chemical analysis identified 15 VOCs that were regularly found at higher concentrations; the most abundant species included butane, ethane, ethylene, isobutane, isopentane, pentane, propane, and

toluene. In South Korea, Pudasainee et al (2010) measured VOCs in emissions from coal and oil-fired power plants; the major VOCs were identified as 1,2-dichloroethane, benzene, carbon tetrachloride, chloroform, and trichloroethylene.

Liu et al (2012) evaluated the VOC composition of stack emissions and ambient air at a MSW power plant in China. There were 25 different VOC species detected in the stack including 7 aromatic compounds, 4 oxygen-containing organic compounds, 8 alkanes, 5 halocarbons and 1 olefin. Aromatic compounds were the dominant VOCs in the stack exhaust, followed by chlorinated VOCs, and alkanes. Aromatic compounds and alkanes were the most abundant VOCs in ambient air. In a source fingerprint analysis, chlorobenzene and tetrachoroethylene were identified as unique molecular markers for the MSW power plant. Benzene, toluene, ethylbenzene and xylene (BTEX) were also recognized as indicators of MSW incineration, but were not considered to be unique to power plants.

Regarding acid gases, the Environmental Integrity Project (2011, 2013) presented inventory data for total acid gas emissions (hydrochloric acid (HCl), hydrofluoric acid (HF), and hydrogen cyanide) for power plants in the US. Additionally, Wu et al (2010) measured HCl, HF, and hydrobromic acid in the flue gas of a coal-fired power plant. For radionuclides, key studies measured ambient radon concentrations near coal-fired power plants in Turkey and Greece (Aytekin et al, 2008; Manousakas et al, 2010).

Recently, amines and nitrosamines have been the focus of studies evaluating emissions from power plants equipped with amine-based CO2 capture, a newer carbon capture technology. Key studies have analyzed amines in flue gas and modeled emissions of amines and nitrosamines from power plants utilizing amine-based CO2 capture (de Koeijer et al, 2013; Fujita et al, 2013; Karl et al, 2011; Zhang et al, 2014).

Table 2-13. Key health effects studies for volatile organic compounds

Author, Year; (Ranking*)	Title	Page
Peluso et al, 2013; (M)	Malondialdehyde-deoxyguanosine and bulky DNA adducts in schoolchildren resident in the proximity of the Sarroch industrial estate on Sardinia Island, Italy	164
Rusconi et al, 2011; (M)	Asthma symptoms, lung function, and markers of oxidative stress and inflammation in children exposed to oil refinery pollution	166

*Ranking: H: High quality; M: Moderate quality; L: Low quality. Details on ranking methodology provided in Section 1.2.2.

Table 2-14. Key emissions studies for other substances (radionuclides, volatile organic compounds, halides, amines/nitrosamines)

Author, Year	Title	Page
Aytekin et al, 2008	Radon measurements in the Catalagzi Thermal Power Plant, Turkey	271
de Koeijer et al, 2013	Health risk analysis for emissions to air from CO2 Technology Centre Mongstad	274
Durrenberger et al, 2008	Evaluation of VOC concentrations in Victoria, Texas	272
Environmental Integrity Project, 2011	America's top power plant toxic air polluters	262
Environmental Integrity Project, 2013	The toxic ten: Top power plant emissions of mercury, toxic metals, and acid gases in 2011	221

3. List of abstracts – 5 priority substances

3.1 Mercury

3.1.1 Mercury - health effects

Lewandowski TA, Bartell SM, Yager JW, Levin L. 2009. An evaluation of surrogate chemical exposure measures and autism prevalence in Texas. Journal of Toxicology and Environmental Health A 72(24): 1592-1603.

Funding Agency: Electric Power Research Institute	
Study Location: Texas	**Study Design:** Ecological
Fuel Type: Coal	**Chemicals:** Hg

Abstract: There is currently considerable discussion in the scientific community as well as within the general public concerning the role mercury (Hg) exposures may play in the apparent increased incidence of neurodevelopmental disorders (particularly autism) in children. Although the primary focus of this debate has focused on ethylmercury from vaccinations, linkage to other sources of Hg has been proposed. An ecologic association between 2001 Toxic Release Inventory (TRI; www.epa.gov/tri) data for Hg and 2000-2001 school district autism prevalence was previously reported in Texas. Evaluations using industrial release data as surrogate exposure measures may be problematic, particularly for chemicals like Hg that have complex environmental fates. To explore the robustness of TRI-based analyses of the Hg-autism hypothesis in Texas, a detailed analysis was undertaken examining the extent of the ecological relationship during multiple years and examining whether surrogate exposure measures would yield similar conclusions. Using multilevel Poisson regression analysis and data obtained from a number of publicly available databases, it was found that air Hg release data were significantly associated with autism prevalence in Texas school districts when considering data for 2001 and 2002 (2001: RR = 4.45, 95% CI = 1.60-12.36, 2002: RR = 2.70, 95% CI = 1.17-6.15). Significant associations were not found using data from 2003 to 2005. A significant association was not observed when considering air Hg data for 2000 or 2001 and school district autism prevalence data for 2005-2006 or 2006-2007, an analysis allowing for a 5-yr time period between presumed exposure and entry into the public school system (2000: RR = 1.03, 95% CI = 0.59-1.83, 2001: RR = 0.94, 95% CI = 0.59-1.47). Significant associations were not observed for any year nor for the time lagged analyses when censored autism counts were replaced by threes instead of zeros. An evaluation of TRI air emissions data for several other pollutants did not find significant associations except for nickel (RR = 1.71, 1.12-2.60), which has no history of being associated with neurodevelopmental disorders. An evaluation using downwind location from coal-fired power plants as the exposure surrogate variable also did not yield statistically significant results. The analysis suggests Hg emissions are not consistently associated with autism prevalence in Texas school districts. The lack of consistency across time may be the result of the influence of a more significant factor which remains unidentified. Alternatively, it may be that the significant association observed in 2001 and 2002 does not represent a true causal association.

Strengths and Limitations:

Strengths: Large sample size. Objective outcome measure (autism counts per school district). Considered 5- and 6-year latencies between exposure and outcome. Accounted for some demographic factors for each school district (eg. race, wealth). Considered Hg-related fish consumption advisories in each county.
Limitations: Hypothesis-generating study. Weak exposure assessment (emission inventories and upwind/ downwind of power plant). No ambient pollutant measurements. No individual data. Potential for confounding (eg. urbanicity). Potential ecological bias.

Study Score and Ranking:

0.75; Moderate

Palmer RF, Blanchard S, Wood R. 2009. Proximity to point sources of environmental mercury release as a predictor of autism prevalence. Health and Place 15(1): 18-24.

Funding Agency: Not stated	
Study Location: Texas	**Study Design:** Ecological
Fuel Type: Coal	**Chemicals:** Hg

Abstract: The objective of this study was to determine if proximity to sources of mercury pollution in 1998 were related to autism prevalence in 2002. Autism count data from the Texas Educational Agency and environmental mercury release data from the Environmental Protection Agency were used. We found that for every 1000 pounds of industrial release, there was a corresponding 2.6% increase in autism rates ($p<.05$) and a 3.7% increase associated with power plant emissions ($P<.05$). Distances to these sources were independent predictors after adjustment for relevant covariates. For every 10 miles from industrial or power plant sources, there was an associated decreased autism Incident Risk of 2.0% and 1.4%, respectively ($p<.05$). While design limitations preclude interpretation of individual risk, further investigations of environmental risks to child development issues are warranted.

Strengths and Limitations:

Strengths: Large sample size. Objective outcome measure (autism counts per school district in education system database). Considered ~5-year latency between exposure and outcome. Accounted for some demographic factors for each school district (eg. race, wealth).
Limitations: Hypothesis-generating study. Weak exposure assessment (emission inventories and distance between power plant and school district). No ambient pollutant measurements. No individual data. Potential for confounding. Potential ecological bias.

Study Score and Ranking:

0.75; Moderate

Park HJ, Kim DS, Moon JS, Yang W, Son BS. 2008. Mercury level in hair of primary school children in Korea and China. Molecular and Cellular Toxicology 4(3): 235-245.

Funding Agency: Not stated	
Study Location: China, Korea	**Study Design:** Cross-sectional
Fuel Type: N/A	**Chemicals:** Hg

Abstract: Exposure to mercury was assessed in 125 Korean (Gwangju and Busan) and 373 Chinese primary school students (Xinguang village, Goumen town) using hair mercury analysis from November 2006 to September 2007. The geometric mean concentration of mercury was higher among Korean children with recording 0.73 μg/g compared to Chinese children of 0.12 μg/g, which indicated statistically difference ($P<0.01$). The mean concentration of Korean children living near incineration facilities was higher by recording 0.76 μg/g while the average concentration of their counterpart in Korea reached 0.69 μg/g. In case of Chinese children, those who are living near power plants showed higher level with posting 0.16 μg/g while the others recorded 0.10 μg/g ($P< 0.01$). Intake of fish was found to be related to hair mercury level. In case of Korean children, those with high fish intake recorded 0.79 μg/g in terms of the geometric mean concentration while the others with low fish intake posted 0.61 μg/g. Among Chinese children, those who often eat fish recorded 0.13 μg/g compared to the others with low fish intake of 0.11 μg/g. On the other hand, amalgam dental fillings have limited influence on mean hair mercury level. As for vaccination, within a month of vaccination, the geometric mean concentration of Korean children reached 0.76 μg/g, and in case of 15 days after injection, the level was 1.20 μg/g. In China, the level of children at one month after receiving injection stood at 0.15 μg/g while the level within 15 days was 0.13 μg/g. Multiple regression analysis showed that BMI, passive smoking, and fish consumption are closely related to hair mercury level among the Korean subjects. In China, hair mercury level was affected by age, location, passive smoking, fish consumption, and vaccination. Explanatory power was 21.6% with $R^2=0.216$.

Strengths and Limitations:

Strengths: Objective outcome measure. Considered several sources of Hg exposure (eg. diet, water, fillings, vaccinations, passive smoking).
Limitations: Relatively small sample size. Weak assessment of exposure. No measurement of ambient Hg levels. Not known if investigators blinded to exposure status (particularly for analysis of Hg in hair). Multiple regression models only explained ~12-22% of variation in hair Hg levels.

Study Score and Ranking:

0.62; Moderate

Blanchard KS, Palmer RF, Stein Z. 2011. The value of ecologic studies: Mercury concentration in ambient air and the risk of autism. Reviews on Environmental Health 26(2): 111-118.

Funding Agency: Not stated	
Study Location: Texas	**Study Design:** Ecological
Fuel Type: Coal	**Chemicals:** Hg

Abstract: Ecologic studies of the spatial relationship between disease and sources of environmental contamination can help to ascertain the degree of risk to populations from contamination and to inform legislation to ameliorate the risk. Population risks associated with persistent low-level mercury exposure have recently begun to be of concern and current reports implicate environmental mercury as a potential contributor in the etiology of various developmental and neurodegenerative diseases including autism and Alzheimer' s disease. In this demonstration of preliminary findings, we demonstrate for Bexar County Texas and Santa Clara County California, the hypothesis that the spatial structure of the occurrence of autism has a positive co-variation with the spatial structure of the distribution of mercury in ambient air. The relative risk of autism is greater in the geographic areas of higher levels of ambient mercury. We find that the higher levels of ambient mercury are geographically associated with point sources of mercury emission, such as coal-fired power plants and cement plants with coal-fired kilns. Although this does not indicate a cause, these results should not be dismissed, but rather seen as a preliminary step for generating a hypothesis for further investigation.

Strengths and Limitations:

Strengths: Objective measure of health outcome (autism counts per school district in education system database). Considered 6-year latency between exposure and outcome.
Limitations: Hypothesis-generating study. Weak exposure assessment (modeled ambient Hg level in school district). Sample size not stated. No individual data. Did not account for any potential confounders. Potential ecological bias.

Study Score and Ranking:

0.46; Low

3.1.2 Mercury - measured emissions (flue gas or ambient air)

White literature

Chen L, Liu M, Xu Z, Fan R, Tao J, Chen D et al. 2013. Variation trends and influencing factors of total gaseous mercury in the Pearl River Delta - A highly industrialised region in South China influenced by seasonal monsoons. Atmospheric Environment 77: 757-66.

Abstract: Studies on atmospheric mercury in the Pearl River Delta (PRD) region are important because of the economic relevance of this region to China, because of its economic developmental pattern and because it is a highly industrialised area influenced by the strong seasonal monsoons. Total gaseous mercury (TGM), meteorological parameters and criteria pollutant concentrations were measured at Mt. Dinghu (DH, a regional monitoring site) and Guangzhou (GZ, an urban monitoring site) in the PRD region from October 2009 to April 2010 and from November 2010 to November 2011, respectively. The ranges of daily average TGM concentrations at the DH and GZ sites were 1.87–29.9 ng m−3 (5.07 ± 2.89 ng m−3) and 2.66–11.1 ng m−3 (4.60 ± 1.36 ng m−3), respectively, which were far more significant than the background values in the Northern Hemisphere (1.5–1.7 ng m−3), suggesting that the atmosphere in the PRD has suffered from mercury pollution. Similar TGM seasonal distributions at the two sites were observed, with a descending order of spring, winter, autumn and summer. The different seasonal monsoons were the dominant factor controlling the seasonal variability of the TGM, with variations in the boundary layer and oxidation also possibly partially contributing. Different diurnal patterns of the TGM at two sites were observed. TGM levels during the daytime were higher than those during the nighttime and were predominantly influenced by mountain and valley winds at the DH site, whereas the opposite trend was evident at the GZ site, which was primarily influenced by the boundary-layer height and O3 concentration. During the monitoring period, the correlations between the daily TGM levels and the SO2 and NO2 levels at the DH site were significant ($r = 0.36$, $p < 0.001$; $r = 0.29$, $p < 0.001$), suggesting that coal-fired emission is an important source of mercury for this regional monitoring site. At the GZ site, the correlations between the daily TGM level and the NO, NO2, CO levels were significant ($r = 0.501$, $p < 0.001$; $r = 0.579$, $p < 0.001$; $r = 0.358$, $p < 0.001$). However, TGM was partially correlated with SO2, suggesting that the combined vehicle emissions and coal combustion were the dominant mercury sources for this urban monitoring site. The TGM distribution figure, which related to the wind-rose pattern and the distribution figure of emission sources, indicated significant contributions from anthropogenic emission sources.

Chen SJ, Lo CT, Fang GC, Huang CS. 2012. Particulate-bound mercury (Hg[p]) size distributions in central Taiwan. Environmental Forensics 13: 98-104.

Abstract: This study focuses on particulate-bound Hg (Hg[p]) composition (ng/g) (defined as ng/g), concentrations (ng/m3) and dry deposition (ng/m2*min) variations for PM18, PM10, PM2.5, and PM1.0. Three characteristic sampling sites collected 1-day ambient suspended particles during November and December 2010 using MOUDI-100S4 samplers. Additionally, Hg(p) size distributions are also characterized. Composition variations of Hg(p) in PM18 were in the order of 0.158 ± 0.055 ng/g (Quan-xing sampling site) > 0.086 ± 0.097 ng/g (Hung-kuang sampling site) > 0.083 ± 0.065 ng/g (Gao-mei sampling site). Further, composition variations of Hg(p) in PM10 were in the order of 0.115 ± 0.038 ng/g (Quan-xing site) > 0.107 ± 0.080 ng/g (Gao-mei site) > 0.103 ± 0.060 ng/g (Hung-kuang site). Composition variations of Hg(p) in PM2.5 were in the order of 0.885 ± 0.423 ng/g (Quan-xing site) > 0.458 ± 0.105 ng/g (Gao-mei site) > 0.372 ± 0.157 ng/g (Hung-kuang site). Finally, composition variations of Hg(p) in PM1.0 were in the order of 0.913 ± 0.441 ng/g (Quan-xing site) > 0.698 ± 0.293 ng/g (Hung-kuang site) > 0.508 ± 0.270 ng/g (Gao-mei site). The Hg(p) size distribution peaked at 1.0 μm at the Quan-xin site, and the lowest average Hg(p) size distribution was 18 μm at the Hung-kung site. The main possible sources for atmospheric particulate-bound mercury Hg(p) were likely from transportation, chemical plant and fossil fuel combustion (Fang et al., 2011). In addition to the above findings, other possible nearby sources at Taichung Thermal Power Plant (TTPP) and Central Taiwan Science Park (CTSP) were: steel industry, electronic industry, plastic industry, chemical industry, basic metal manufacturing, machinery manufacturing, coal products and petroleum. Our sampling sites were in the regions of all of the above sources.

Cordoba P, Maroto-Valer M, Ayora C, Perry R, Rallo M, Font O et al. 2012. Unusual speciation and retention of Hg at a coal-fired power plant. Environmental Science and Technology 46(14): 7890-7.

Abstract: An unusual and different speciation of Hg in the outgoing gaseous stream of the flue gas desulfurization (OUT-FGD) system was revealed at two Spanish power plants (PP1 and PP2) equipped with a forced oxidation wet FGD system with water recirculation to the scrubber. At PP1 and PP2, a high proportion of Hg escapes from the electrostatic precipitator in gaseous form, Hg(2+) (75-86%) being the species that enters the FGD. At PP1 Hg(0) (71%) was the prevalent Hg OUT-FGD species, whereas at PP2 Hg(2+) was the prevalent Hg OUT-FGD species in 2007 (66%) and 2008 (87%). The unusual speciation of gaseous Hg OUT-FGD and the different Hg retentions between 2007 and 2008 at PP2 were attributable to the evaporation of HgCl(2) particles from the aqueous phase of gypsum slurry in the OUT-FGD gas and the Al additive used at PP2, respectively. The Al additive induced the retention of Hg as HgS in the 2007 FGD gypsum, thus reducing gaseous emissions of Hg in the OUT-FGD gas.

de Foy B, Wiedinmyer C, Schauer JJ. 2012. Estimation of mercury emissions from forest fires, lakes, regional and local sources using measurements in Milwaukee and an inverse method. Atmospheric Chemistry and Physics 12(19): 8993-9011.

Abstract: Gaseous elemental mercury is a global pollutant that can lead to serious health concerns via deposition to the biosphere and bio-accumulation in the food chain. Hourly measurements between June 2004 and May 2005 in an urban site (Milwaukee, WI) show elevated levels of mercury in the atmosphere with numerous short-lived peaks as well as longer-lived episodes. The measurements are analyzed with an inverse model to obtain information about mercury emissions. The model is based on high resolution meteorological simulations (WRF), hourly back-trajectories (WRF-FLEXPART) and a chemical transport model (CAMx). The hybrid formulation combining back-trajectories and Eulerian simulations is used to identify potential source regions as well as the impacts of forest fires and lake surface emissions. Uncertainty bounds are estimated using a bootstrap method on the inversions. Comparison with the US Environmental Protection Agency's National Emission Inventory (NEI) and Toxic Release Inventory (TRI) shows that emissions from coal-fired power plants are properly characterized, but emissions from local urban sources, waste incineration and metal processing could be significantly under-estimated. Emissions from the lake surface and from forest fires were found to have significant impacts on mercury levels in Milwaukee, and to be underestimated by a factor of two or more.

Deeds DA, Banic CM, Lu J, Daggupaty S. 2013. Mercury speciation in a coal-fired power plant plume: An aircraft-based study of emissions from the 3640 MW Nanticoke Generating Station, Ontario, Canada. Journal of Geophysical Research D: Atmospheres 118(10): 4919-35.

Abstract: Coal-fired power plants are one of the principal sources of mercury to the atmosphere. The form this mercury takes is the predominant factor determining its fate after emission. Recent ground-level field and modeling studies suggest that oxidized mercury in stack emissions is converted into elemental mercury in the plume. We present here aircraft-based plume mercury measurements taken by Environment Canada in 2000 at the Nanticoke Generating Station as part of the Health Canada Toxic Substances Research Initiative Metals in the Environment Research Network. Although the average mercury speciation observed in the Nanticoke plume (82% Hg0, 13% Hg(II)(g), 5% Hg (P), by mass) appears to be distinct from the average mercury speciation in the Nanticoke stacks (53% Hg0, 43% Hg(II) (g), 4% Hg(P)), we find that the in-plume elemental mercury concentrations as a whole can be explained by plume dilution after emission. The discrepancy between in-stack and in-plume Hg(II) concentrations is statistically significant, yet is not associated with a transformation of Hg(II) to Hg0. Sampling biases associated with the differing techniques used to measure Hg(II) in-stack and in-plume may reconcile the concentration discrepancy without invoking novel chemical reactions or physical processes. Although the mercury speciation of the Nanticoke plume influences local mercury deposition, the majority of the mercury emitted is transported out of the surrounding area.

Friedli HR, Arellano AF,Jr., Geng F, Cai C, Pan L. 2011. Measurements of atmospheric mercury in Shanghai during September 2009. Atmospheric Chemistry and Physics 11: 3781-8.

Abstract: We report on total gaseous mercury (TGM) measurements made in Pudong, Shanghai in August/September 2009. The average TGM was 2.7 +/- 1.7 ng m(-3). This represents about 90% of the total atmospheric mercury. This is an underestimate for an annual-mean concentration because the meteorology in September favored predominantly easterly oceanic air, replaced in other seasons by airflow from industrial areas. The observed TGM follows a pattern seen in other cities around the world: a background elevated over mean hemispheric background (1.5 ng m(-3)), and pollution plumes of different magnitude and duration, interspersed with very sharp spikes of high concentration (60 ng m(-3)). The September 2009 Shanghai measurements are lower than those reported for most other Chinese cities and Mexico City, and similar to concentrations found in some Asian and in North American cities. Such comparisons are tenuous because of differences in season and year of the respective measurements. Our results should not be used for regulatory purposes. We find that the observed TGM are most likely coming from coal fired power plants, smelters and industrial sources, based on its high correlation with NOx, SO2, CO and wind directions.

Hsi HC, Lee HH, Hwang JF, Chen W. 2010. Mercury speciation and distribution in a 660-megawatt utility boiler in Taiwan firing bituminous coals. Journal of the Air and Waste Management Association (1995) 60(5): 514-22.

Abstract: Mercury speciation and distribution in a 660-MW tangential-fired utility boiler in Taiwan burning Australian and Chinese bituminous coal blends was investigated. Flue gases were simultaneously sampled at the selective catalytic reduction (SCR) inlet, the SCR outlet, the electrostatic precipitator (ESP) outlet, and the stack. Samplings of coal, lime, bottom ash/slag, fly ash, and gypsum slurry were also conducted. Results indicated that flue gases at the inlet to SCR contained a great potion of particle-bound mercury (Hg(p)), 59-92% of the total mercury. Removal of mercury was not observed for the SCR system. However, repartitioning of mercury species across the SCR occurred that significantly increased the portion of elemental mercury (Hg0) to up to 29% and oxidized mercury (Hg2+) to up to 33% in the SCR outlet gas. Overreporting of Hg(p) at the inlet of SCR may cause the observed repartitioning; the high ammonia/nitric oxide circumstance in the SCR unit was also speculated to cause the mercury desorption from ash particles and subsequent reentrance into the gas phase. ESP can remove up to 99% of Hg(p), and wet flue gas desulfurization (FGD) can remove up to 84% of Hg2+. Mercury mass balances were calculated to range between 81 and 127.4%, with an average of 95.7% wherein 56-82% was in ESP fly ash, 8.7-18.6% was retained in the FGD gypsum, and 6.2-26.1% was emitted from the stack. Data presented here suggest that mercury removal can be largely enhanced by increasing the conversion of Hg0 into Hg(p) and Hg2+.

Huang J, Choi HD, Hopke PK, Holsen TM. 2010. Ambient mercury sources in Rochester, NY: results from Principle Components Analysis (PCA) of Mercury Monitoring Network Data. Environmental Science and Technology 44(22): 8441-5.

Abstract: Continuous atmospheric measurements of speciated mercury (Hg) (elemental mercury (Hg(0)), reactive gaseous mercury (RGM), and particulate mercury (Hgp)) were made in Rochester, NY from Dec 2007 to May 2009. Continuous measurements of ozone (O3), sulfur dioxide (SO2), carbon monoxide (CO), particulate matter (PM2.5), and meteorological data were also available. A principle components analysis (PCA) of 3886 observations of 13 variables for the period identified six major factors. Melting snow was observed to be a source of Hg(0) in winters. Positive correlations between RGM and O3 in the spring and summer may be indicative of Hg(0) oxidation. RGM concentrations increased simultaneously with SO2 suggesting the influence of coal fired power plants (CFPP). The fifth factor (F5) containing O3 (high negative loading), CO (positive loading), Hg(0) and Hg(p) (positive), and/or RGM (negative) was identified as a mobile source which was usually observed during morning rush hours (6:00-9:00 a.m.). The concentrations of the three mercury species from the direction of the CFPP were significantly reduced following the shutdown of this source.

Kim JH, Pudasainee D, Yoon YS, Son SU, Seo YC. 2010. Studies on speciation changes and mass distribution of mercury in a bituminous coal-fired power plant by combining field data and chemical equilibrium calculation. Industrial and Engineering Chemistry Research 49: 5197-203.

Abstract: Transformation of mercury compounds in combustion flue gas and overall mercury mass balance in a typical bituminous coal-fired power plant were studied. Upon decreasing temperature and interaction with flue gas components, oxidized mercury increased across an electrostatic precipitator. A major fraction of particulate mercury was removed in the electrostatic precipitator, and oxidized mercury was removed in wet flue gas desulfurization. Hg was mainly speciated into elemental form in the stack emission. The measurement of mercury in a real facility and equilibrium calculation showed that coal composition, operating conditions, and flue gas components were the major factors affecting mercury emission and speciation. A reliable overall Hg mass balance was obtained from the field measurement. Mercury mainly entered from coal, and lime/limestone feeding was distributed in electrostatic precipitator fly ash (57.6−64.3%), gypsum (4.5 −12.9%), effluents (0.5−1.9%), and stack emission (15.2−27.0%). Further, the mass distribution and speciation of mercury in the power plant with simulated coal mixture feeds could be predicted with a chemical equilibrium code in combination with the measured results at the commercial plant.

Kim KH, Shon ZH, Nguyen HT, Jung K, Park CG, Bae GN. 2011. The effect of man made source processes on the behavior of total gaseous mercury in air: a comparison between four urban monitoring sites in Seoul Korea. Science of the Total Environment 409(19): 3801-11.

Abstract: Concentrations of total gaseous mercury (TGM) were measured continuously at four urban residential locations (G (Guro-gu); N (Nowon-gu); S (Songpa-gu); and Y (Yongsan-gu)) in Seoul, Korea from 2004 to 2009. The mean concentrations of Hg at these sites were found on the order of N (3.98+/-1.68 ng m(-3)), S (3.87+/-1.56 ng m(-3)), G (3.80+/-1.60 ng m(-3)), and Y (3.36+/-1.55 ng m(-3)). Evidence indicates that the spatial distribution of Hg should be affected by the combined effects of both local anthropogenic (incineration facilities and thermal power plants) and natural (soil) emission sources in association with the meteorological parameters. Inspection of the Hg temporal patterns indicates the co-existence of contrasting seasonal patterns between the central site Y (winter dominance) and all other outbound sites near city borders (summer dominance). The long-term trend of Hg, if examined by combining our previous studies and the present one, shows that Hg levels in this urban area declined gradually across decadal periods despite slight variabilities in spatial scale: (1) above 10 ng m(-3) in the late 1980s, (2) ~5 ng m(-3) in the late 1990s, and (3) ~3 ng m(-3) toward the late 2000s. The results of the principal component analysis along with observed differences in seasonal patterns (between study sites) suggest that Hg distributions between different urban sites are greatly distinguishable with strong source signatures at each individual site.

Kim KH, Yoon HO, Brown RJC, Jeon EC, Sohn JR, Jung K et al. 2013. Simultaneous monitoring of total gaseous mercury at four urban monitoring stations in Seoul, Korea. Atmospheric Research 132–133: 199-208.

Abstract: The monitoring of total gaseous mercury (TGM) concentrations together with other trace gases and meteorological parameters was made at hourly intervals over 2-year period (1 January 2010 to 31 December 2011) at four urban monitoring sites: Guro-gu (G), Nowon-gu (N), Songpa-gu (S), and Yongsan-gu (Y) in Seoul, Korea. The mean concentrations of TGM at these sites were found to span the range of 3.28 (Y) to 3.47 ng m-3 (N). Inspection of the seasonal patterns indicates that the maximum concentrations (ng m-3) occur at different times of year across the four sites: winter at N (3.67 ± 1.77), fall at S (3.64 ± 1.12), summer at G (3.61 ± 1.51), and spring at Y (3.40 ± 1.26). The long-term trend in Hg concentrations, when also considering data sets from previous studies, suggests modest reductions in concentrations at all four sites, from 2.89 to 4.49 ng m-3 in 2004 and from 2.49 to 3.42 ng m-3 in 2011.

Kolker A, Olson ML, Krabbenhoft DP, Tate MT, Engle MA. 2010. Patterns of mercury dispersion from local and regional emission sources, rural Central Wisconsin, USA. Atmospheric Chemistry and Physics 10: 4467-76.

Abstract: Simultaneous real-time changes in mercury (Hg) speciation- reactive gaseous Hg (RGM), elemental Hg (HgA degrees), and fine particulate Hg (Hg-PM2.5), were determined from June to November, 2007, in ambient air at three locations in rural Central Wisconsin. Known Hg emission sources within the airshed of the monitoring sites include: 1) a 1114 megawatt (MW) coal-fired electric utility generating station; 2) a Hg-bed chlor-alkali plant; and 3) a smaller (465 MW) coal-burning electric utility. Monitoring sites, showing sporadic elevation of HgA degrees, Hg-PM2.5, and RGM were positioned at distances of 25, 50 and 100 km northward of the larger electric utility. Median concentrations of HgA degrees, Hg-PM2.5, and RGM were 1.3-1.4 ng m-3, 2.6-5.0 pg m-3, and 0.6-0.8 pg m-3, respectively. A series of RGM events were recorded at each site. The largest, on 23 September, occurred under prevailing southerly winds, with a maximum RGM value (56.8 pg m-3) measured at the 100 km site, and corresponding elevated SO2 (10.4 ppbv; measured at 50 km site). The finding that RGM, HgA degrees, and Hg-PM2.5 are not always highest at the 25 km site, closest to the large generating station, contradicts the idea that RGM decreases with distance from a large point source. This may be explained if: 1) the 100 km site was influenced by emissions from the chlor-alkali facility or by RGM from regional urban sources; 2) the emission stack height of the larger power plant promoted plume transport at an elevation where the Hg is carried over the closest site; or 3) RGM was being generated in the plume through oxidation of HgA degrees. Operational changes at each emitter since 2007 should reduce their Hg output, potentially allowing quantification of the environmental benefit in future studies.

Lopez-Anton MA, Diaz-Somoano M, Diaz L, Martinez-Tarazona MR. 2011. Avoiding mercury emissions by combustion in a Spanish circulating fluidized-bed combustion (CFBC) plant. Energy and Fuels 25: 3002-8.

Abstract: This work evaluates the behavior of mercury in an industrial circulating fluidized-bed combustion plant (CFBC) of 50 MW situated in Oviedo, Spain. The results showed that mercury was not emitted in the gas phase in significant amounts, thereby proving this technology as an effective means of preventing mercury emissions. Most of the mercury (85-97%) was retained in the fly ashes. The proportion of mercury emitted in the gas phase was on the order of 0.2-0.3 μg m-3, whereas only 0.02 ng m-3 at most was emitted in the particulate matter. An evaluation of the fly ash fractions separated from the hoppers of the electrostatic precipitator showed the highest proportion of mercury to be present in the fly ashes with the lowest particle size and the highest carbon content. However, this mercury proved to be stable when subjected to leachability tests.

Lyman SN, Sexauer Gustin M. 2008. Speciation of atmospheric mercury at two sites in northern Nevada, USA. Atmospheric Environment 42: 927-39.

Abstract: Gaseous elemental mercury (Hg0), reactive gaseous mercury (RGM), and mercury bound to particles (Hgp) were measured during seasonal 1- or 2-week data collection campaigns at two Mercury Deposition Network sites (NV02 and NV99) in northern Nevada, USA. The sites are rural but are located in an area of diverse natural and anthropogenic mercury sources that include undisturbed and mining mercury-disturbed enriched substrates, coal-fired power plants, ore processing facilities, and industrial facilities. Concentrations of Hg0 averaged over all campaigns were 3.0±1.7 ng m−3 at NV02 and 2.5±3.1 ng m−3 at NV99, higher than has been reported for other rural sites. Hg0 concentrations at the sites were found to be influenced by both local substrate emission and transport from regional source areas. Concentrations of RGM and Hgp were within ranges reported for other rural sites (13±18 and 9±7 pg m−3 at NV02, 7±8 and 13±12 pg m−3 at NV99, respectively). Mercury wet deposition rates measured over 3 years (2003–2005) were similar to other sites in the arid West (3.0±0.7 μg m−2 yr−1 at NV02, 3.9±0.4 μg m−2 yr−1 at NV99).

Mazur M, Mintz R, Lapalme M, Wiens B. 2009. Ambient air total gaseous mercury concentrations in the vicinity of coal-fired power plants in Alberta, Canada. Science of the Total Environment 408(2): 373-81.

Abstract: The Lake Wabamun area, in Alberta, is unique within Canada as there are four coal-fired power plants within a 500 km(2) area. Continuous monitoring of ambient total gaseous mercury (TGM) concentrations in the Lake Wabamun area was undertaken at two sites, Genesee and Meadows. The data were analyzed in order to characterise the effect of the coal-fired power plants on the regional TGM. Mean concentrations of 1.57 ng/m3 for Genesee and 1.50 ng/m3 for Meadows were comparable to other Canadian sites. Maximum concentrations of 9.50 ng/m3 and 4.43 ng/m3 were comparable to maxima recorded at Canadian sites influenced by anthropogenic sources. The Genesee site was directly affected by the coal-fired power plants with the occurrence of northwest winds, and this was evident by episodes of elevated TGM, NOx and SO2 concentrations. NOx/TGM and SO2/TGM ratios of 21.71 and 19.98 μg/ng, respectively, were characteristic of the episodic events from the northwest wind direction. AERMOD modeling predicted that coal-fired power plant TGM emissions under normal operating conditions can influence hourly ground-level concentrations by 0.46-1.19 ng/m3. The effect of changes in coal-fired power plant electricity production on the ambient TGM concentrations was also investigated, and was useful in describing some of the episodes.

Sexauer Gustin M, Weiss-Penzias PS, Peterson C. 2012. Investigating sources of gaseous oxidized mercury in dry deposition at three sites across Florida, USA. Atmospheric Chemistry and Physics 12(19): 9201-19.

Abstract: During 2009–2010, the State of Florida established a series of air quality monitoring stations to collect data for development of a statewide total maximum daily load (TMDL) for mercury (Hg). At three of these sites, located near Ft. Lauderdale (DVE), Pensacola (OLF), and Tampa Bay (TPA), passive samplers for the measurement of air Hg concentrations and surrogate surfaces for measurement of Hg dry deposition were deployed. While it is known that Hg in wet deposition in Florida is high compared to the rest of the United States, there is little information on Hg dry deposition. The objectives of the work were to: (1) investigate the utility of passive sampling systems for Hg in an area with low and consistent air concentrations as measured by the Tekran® mercury measurement system, (2) estimate dry deposition of gaseous oxidized Hg, and (3) investigate potential sources. This paper focuses on Objective 3. All sites were situated within 15 km of 1000 MW electricity generating plants (EGPs) and major highways. Bi-weekly dry deposition and passive sampler Hg uptake were not directly correlated with the automated Tekran® system measurements, and there was limited agreement between these systems for periods of high deposition. Using diel, biweekly, and seasonal Hg observations, and ancillary data collected at each site, the potential sources of Hg deposited to surrogate surfaces were investigated. With this information, we conclude that there are three major processes/sources contributing to Hg dry deposition in Florida, with these varying as a function of location and time of year. These include: (1) in situ oxidation of locally and regionally derived Hg facilitated by mobile source emissions, (2) indirect and direct inputs of Hg from local EGPs, and (3) direct input of Hg associated with long range transport of air from the northeastern United States. Based on data collected with the surrogate surface sampling system, natural background dry deposition for Florida is estimated to be 0.03 ng m−2 h−1. Deposition associated with mobile sources is 0.10 ng m−2 h−1 at TPA and DVE, and 0.03 ng m−2 h−1 at OLF. Long range transport contributes 0.8 ng m−2 h−1 in the spring. At DVE ~0.10 ng m−2 h−1 is contributed directly or indirectly from local point sources. We also suggest based on the data collected with the Tekran® and passive sampling systems that different chemical forms of GOM are associated with each of these sources.

Shah P, Strezov V, Nelson PF. 2010. Speciation of mercury in coal-fired power station flue gas. Energy and Fuels 24: 205-12.

Abstract: Mercury is a potentially toxic trace metal. Mercury exists naturally in coal in very low concentrations, having been incorporated during the coalification process. Consequently, coal-fired power stations are a major anthropogenic source of mercury because of the large quantity of coal used for electricity generation. In the environment, mercury transforms into methylmercury, a potential neurotoxin,

bioaccumulates in aquatic biota, and subsequently, enters the food chain. The subsequent environmental fate and ability to capture mercury prior to emission are dependent upon its different physicochemical forms and oxidation states, known as speciation. In this work, speciation of mercury was conducted at five different coal power stations across Australia (one in New South Wales, three in Western Australia, and one in Queensland) by the Ontario Hydro sampling and analysis method. The total Hg concentrations in the emissions of these plants were found to be in the range of 1.9−5.6 μg Nm−3. Particle-bound mercury HgP occurred in very low proportions of 0.3−3.7%, while variable proportions of Hg0 and HgII were observed. Kinetic calculations were performed assuming a homogeneous system to understand role of the chlorine/mercury ratio of feed coal in the oxidation of mercury during power station combustion. Results from this study are compared to previous work published in the literature and discussed with respect to operating parameters of the power station.

Shi YJ, Deng S, Zhang F, Zhang C, Cao Q, Liu Y et al. 2013. Effect of flue gas pollution control devices on mercury emission from coal-fired power plants. Advanced Materials Research 726-731: 2160-4.

Abstract: Coal-fired power plant is one of the largest sources of mercury emitted into the atmosphere artificially. In the paper, more intensive investigations were performed in 27 power plants for observing distribution of mercury at all the effluents. Mass balance of mercury was figured out from the emission data and analysis results of mercury at all the in- and out-streams. The results show that, concentrations of mercury emitted from stack gas equipped with air pollution control devices (APCDs) range between 0.6734 and 14.4312 μg/m3 with coal mercury content lower than 0.20mg/kg. FGD gypsum mercury is about 2~10 times as that of in coal. The average mercury removal efficiency by ESP is only about 29.36% while ESP +wFGD and dry-FGD+FF about 68.72% and 81.51% separately. Therefore, it is necessary to enhance the existing APCDs, wash and mix coal to Hg co-removal for coal-fired power plants.

Stergarsek A, Horvat M, Kotnik J, Tratnik J, Frkal P, Kocman D et al. 2008. The role of flue gas desulphurisation in mercury speciation and distribution in a lignite burning power plant. Fuel 87: 3504-12.

Abstract: The present study was conducted on a lignite burning thermal power plant which combines five power units totalling of 775 MW with a yearly consumption of about 4 million tons of lignite. All units are currently connected to two wet limestone FGD plants. Unit 4 and 5 were initially investigated in 1999 when unit 5 was operated without an FGD. All units differ in boiler type, producer, power and age. A mass balance for mercury and 39 trace and major elements was estimated in two units under different operational conditions. Due to its global relevance attention was devoted to emissions of Hg, where speciation of various Hg compounds was also measured in the flue gases. A great difference in the emissions of gas phase mercury was found depending upon the different gas cleaning technologies. One of the major problems in this initial investigation stage was that in the total mass balance 37% of Hg was missing in unit 5 operating without an FGD and 74% in the case of unit 4 with an FGD. Therefore a new study was conducted in 2007 in order to account for possible errors in the mass balance estimation. This time, units 1-4, which are connected to the same FGD plant, were included in the study, as unit 5 was connected to a new FGD system. The new study revealed that the mercury content in lignite was almost the same as in 1999, but the differences in concentrations and mass flows were significantly different. The deficit of Hg in flue gases observed in 1999 on unit 5 can be explained by errors in measuring the gas flow rates. Hg in various fly ash samples differed significantly and was dependant on the content of unburned carbon, sulphide content, and specific surface area determined by the BET method. The distribution of mercury species in flue gases was dependent on the boiler type, as demonstrated by the degree of Hg oxidation (20% and 44% of Hg(II) in units 5 and 4, respectively). Emission of mercury was reduced from about 80% to 12% of total Hg introduced with coal, by the installation of a wet limestone FGD with forced oxidation. Mercury speciation in stack gas after the FGD was similar in 1999 and 2007, with about 4% of Hg(II), 94-96% of Hg(0) and the remaining bound to particles. Removal efficiency of Hg species from flue gas in the FGD was 89% for total Hg, 99% for Hg(II), 98% for particulate Hg and 76% for Hg(0). The latter value is very high and indicates that a wet FGD may also efficiently remove Hg(0) under favourable FGD conditions. One of the very important findings is that gypsum is the major sink (about 80%) of Hg. Hg binds more efficiently to finer particles in gypsum, e.g. in

12% of the finest fraction retains about 63% of mercury, which indicates that the separation of the gypsum fractions may offer one possible efficient way of Hg control. The results also showed that in mass balance calculations a representative gypsum samples are essential, and the deficit in 1999 is most probably attributed to non-representative sampling on account of its in-homogeneity. Among other trace elements the distribution of volatile As, Br, and Se were also followed, showing that Se and Br are enriched along with Hg in the FGD products.

Sun R, Heimbuerger LE, Sonke JE, Liu G, Amouroux D, Berail S. 2013. Mercury stable isotope fractionation in six utility boilers of two large coal-fired power plants. Chemical Geology 336: 103-11.

Abstract: Coal-fired utility boiler (CFUB) emissions of mercury (Hg) represent the largest anthropogenic Hg source to the atmosphere. Hg stable isotope signatures in coal have been shown to vary among coal deposits and coal basins. There is therefore a substantial interest in tracing CFUB Hg emissions at local, regional and global scales. However, CFUB operating conditions, Hg capture technologies and post-emission Hg transformations may potentially alter the original feed coal Hg isotope signatures. Here we investigate Hg isotopic fractionation between feed coal and coal combustion products in six utility boilers of two large power plants in Huainan City, Anhui Province, China. We observe identical trends in all six boilers: relative to feed coal with delta Hg-202 ranging from -0.67 to -0.18 parts per thousand, oxidized Hg species in bottom ash and fly ash are enriched in the lighter isotopes with delta Hg-202 from -1.96 to -0.82 parts per thousand. Flue gas desulphurization by-product gypsum shows delta Hg-202 from -0.99 to -0.47 parts per thousand. No mass independent fractionation was observed during the transport and transformation of Hg inside the boilers. An isotope mass balance suggests that gaseous stack Hg emissions are enriched by up to 0.3 parts per thousand in the heavier Hg isotopes relative to feed coal and that the enrichment depends on the Hg capture technology. The observation that oxidized Hg species are enriched in the lighter isotopes suggests that oxidized and reduced forms of Hg in stack emission carry different isotope signatures. This has implications for near-field and far-field Hg emission tracing.

Tao Y, Zhuo Y, Zhang L, Chen C, Xu X. 2010. Mercury transformation across various air pollution control devices in a 200 MW coal-fired boiler of China. Asia-Pacific Journal of Chemical Engineering 5: 756-62.

Abstract: An onsite investigation of the mercury emission from a Chinese 200 MW pulverized coal (PC) boiler equipped with various air pollution control devices (APCDs) was conducted by using the Ontario Hydro method (OHM). The mercury mass balance was +4.6% of the input coal mercury for the whole system. Small amounts of mercury were detected in the bottom ash; nearly 90% of the mercury in PC was removed by the existing APCDs, i.e. selective catalytic reduction unit (SCR) and electrostatic precipitator (ESP) followed by fabric filters (FFs) baghouse, and flue gas desulfurization system (FGD). The concentration of oxidized mercury (converted from the elemental form) in the flue gas increased from 14% before SCR to 75% after SCR. Hence, the mercury removal efficiency of ESP and FGD was significantly improved when compared to the removal rates found in previous field measurement. This study demonstrates that the conversion of elemental mercury into the oxidized forms significantly improves the overall mercury removal efficiency of conventional APCDs, and most of the mercury emitted after FGD was in the elemental form.

Wang J, Wang W, Xu W, Wang X, Zhao S. 2011a. Mercury removals by existing pollutants control devices of four coal-fired power plants in China. Journal of Environmental Sciences (China) 23(11): 1839-44.

Abstract: The mercury removals by existing pollution control devices and the mass balances of mercury in four coal-fired power plants of China were carried out based on a measurement method with the aluminum matrix sorbent. All the plants are equipped with a cold-side electrostatic precipitator (ESP) and a wet flue gas desulfurization (FGD) in series. During the course of coal stream, the samples, such as coal, bottom ash, fly ash, gypsum and flue gas, were collected. The Hg concentrations in coals were measured by CVAAS after appropriate preparation and acid digestion. Other solid samples were measured by the RA-915+ Zeeman Mercury Spectrometer. The vapor phase Hg was collected by a sorbent trap from flue gas and then measured

using CVAAS followed by acid leaching. The mercury mass balances were estimated in this study were 91.6%, 77.1%, 118% and 85.8% for the four power plants, respectively. The total Hg concentrations in the stack gas were ranged from 1.56-5.95 μg/m3. The relative distribution of Hg in bottom ash, ESP, WFGD and stack discharged were ranged between 0.110%-2.50%, 2.17%-23.4%, 2.21%-87.1%, and 21.8%-72.7%, respectively. The distribution profiles were varied with the coal type and the operation conditions. The Hg in flue gas could be removed by ESP and FGD systems with an average removal efficiency of 51.8%. The calculated average emission factor was 0.066 g/ton and much lower than the results obtained ten years ago.

Wang J, Xu W, Wang X, Wang W. 2011b. Measurement of mercury in flue gas based on an aluminum matrix sorbent. The Scientific World Journal 11: 2469-79.

Abstract: The measurement of total mercury in flue gas based on an economical aluminum matrix sorbent was developed in this paper. A sorbent trap consisted of three tubes was employed to capture Hg from flue gas. Hg trapped on sorbent was transferred into solution by acid leaching and then detected by CVAAS. Hg adsorbed on sorbent was recovered completely by leaching process. The 87.7% recovery of Hg in flue gas by tube 1 and tube 2 was obtained on the equipment of coal combustion and sampling in lab. In order to evaluate the ability to recover and accurately quantify Hg(0) on the sorbent media, the analytical bias test on tube 3 spiked with Hg(0) was also performed and got the average recovery of 97.1%. Mercury measurements based on this method were conducted for three coal-fired power plants in China. The mercury in coal is distributed into bottom ash, electrostatic precipitator (ESP) ash, wet flue gas desulfurization (WFGD) reactant, and flue gas, and the relative distribution varied depending on factors such as the coal type and the operation conditions of plants. The mercury mass balances of three plants were also calculated which were 91.6%, 77.1%, and 118%, respectively. The reliability of this method was verified by the Ontario Hydro (OH) method either in lab or in field.

Wang SX, Zhang L, Li GH, Wu Y, Hao JM, Pirrone N et al. 2010. Mercury emission and speciation of coal-fired power plants in China. Atmospheric Chemistry and Physics 10: 1183-92.

Abstract: Comprehensive field measurements are needed to understand the mercury emissions from Chinese power plants and to improve the accuracy of emission inventories. Characterization of mercury emissions and their behavior were measured in six typical coal-fired power plants in China. During the tests, the flue gas was sampled simultaneously at inlet and outlet of Selective Catalytic Reduction (SCR), electrostatic precipitators (ESP), and flue gas desulfurization (FGD) using the Ontario Hydro Method (OHM). The pulverized coal, bottom ash, fly ash and gypsum were also sampled in the field. Mercury concentrations in coal burned in the measured power plants ranged from 17 to 385 μg/kg. The mercury mass balances for the six power plants varied from 87 to 116% of the input coal mercury for the whole system. The total mercury concentrations in the flue gas from boilers were at the range of 1.92-27.15 μg/m3, which were significantly related to the mercury contents in burned coal. The mercury speciation in flue gas right after the boiler is influenced by the contents of halogen, mercury, and ash in the burned coal. The average mercury removal efficiencies of ESP, ESP plus wet FGD, and ESP plus dry FGD-FF systems were 24%, 73% and 66%, respectively, which were similar to the average removal efficiencies of pollution control device systems in other countries such as US, Japan and South Korea. The SCR system oxidized 16% elemental mercury and reduced about 32% of total mercury. Elemental mercury, accounting for 66-94% of total mercury, was the dominant species emitted to the atmosphere. The mercury emission factor was also calculated for each power plant.

Wang Y, Duan Y, Yang L, Zhao C, Shen X, Zhang M et al. 2009. Experimental study on mercury transformation and removal in coal-fired boiler flue gases. Fuel Processing Technology 90: 643-51.

Abstract: This paper reported mercury speciation and emissions from five coal-fired power stations in China. The standard Ontario Hydro Method (OHM) was used into the flue gas mercury sampling before and after fabric filter (FF)/electrostatic precipitator (ESP) locations in these coal-fired power stations, and then various mercury speciation such as Hg0, Hg2+ and HgP in flue gas, was analyzed by using EPA method. The solid samples such as coal, bottom ash and ESP ash, were analyzed by DMA 80 based on EPA Method 7473. Through analysis the mercury speciation varied greatly when flue gas went through FF/ESP. Of the total mercury in flue gas, the concentration of Hg2+ is in the range of 0.11–14.76 μg/N m3 before FF/ESP and

0.02–21.20 μg/N m3 after FF/ESP; the concentration of Hg0 ranges in 1.18–33.63 μg/N m3 before FF/ESP and 0.77–13.57 μg/N m3 after FF/ESP, and that of HgP is in the scope of 0–12.11 μg/N m3 before FF/ESP and 0–0.54 μg/N m3 after FF/ESP. The proportion of Hg2+ ranges from 4.87%–50.93% before FF/ESP and 2.02%–75.55% after FF/ESP, while that of Hg0 is between 13.81% – 94.79% before FF/ESP and 15.69%–98% after FF/ESP, with that of HgP is in the range of 0%–45.13% before FF/ESP and 0%–11.03% after FF/ESP. The mercury in flue gas mainly existed in the forms of Hg0 and Hg2+. The concentrations of chlorine and sulfur in coal and flue gas influence the species of Hg that are formed in the flue gas entering air pollution control devices. The concentrations of chlorine, sulfur and mercury in coal and the compositions of fly ash had significant effects on mercury emissions.

Wang Y, Duan Y, Yang L, Zhao C, Xu Y. 2010. Mercury speciation and emission from the coal-fired power plant filled with flue gas desulfurization equipment. Canadian Journal of Chemical Engineering 88: 867-73.

Abstract: Mercury speciation and emission from two Chinese coal-fired power stations equipped with flue gas desulfurization device were investigated. Research results reveal that Hg(0) is the main form in the flue gas in Plant 1; Hg(2+) is the main form in the flue gas in Plant 2. Most of mercury was emitted to the atmosphere, which was about 77-98%, and the elemental mercury released to atmosphere ranged 73-94% approximately. A pot of mercury is adsorbed by bottom ash, electrostatic precipitator (ESP) ash, and gypsum in Plant 1. However, most mercury, the scale of which is 75-83.2%, is collected by ESP ash, and only 7.0-12.2% mercury is emitted to the atmosphere in Plant 2. The mercury removal by NID semi-desulfurization system is higher than wet flue gas desulfurization (WFGD) desulfurization system.

Wang Y, Huang J, Hopke PK, Rattigan OV, Chalupa DC, Utell MJ et al. 2013. Effect of the shutdown of a large coal-fired power plant on ambient mercury species. Chemosphere 92(4): 360-7.

Abstract: In the spring of 2008, a 260MWe coal-fired power plant (CFPP) located in Rochester, New York was closed over a 4 month period. Using a 2-years data record, the impacts of the shutdown of the CFPP on nearby ambient concentrations of three Hg species were quantified. The arithmetic average ambient concentrations of gaseous elemental mercury (GEM), gaseous oxidized mercury (GOM), and particulate mercury (PBM) during December 2007-November 2009 were 1.6 ngm(-3), 5.1 pgm(-3), and 8.9 pgm(-3), respectively. The median concentrations of GEM, GOM, and PBM significantly decreased by 12%, 73%, and 50% after the CFPP closed (Mann-Whitney test, $p<0.001$). Positive Matrix Factorization (EPA PMF v4.1) identified six factors including O3-rich, traffic, gas phase oxidation, wood combustion, nucleation, and CFPP. When the CFPP was closed, median concentrations of GEM, GOM, and PBM apportioned to the CFPP factor significantly decreased by 25%, 74%, and 67%, respectively, compared to those measured when the CFPP was still in operation (Mann-Whitney test, $p<0.001$). Conditional probability function (CPF) analysis showed the greatest reduction in all three Hg species was associated with northwesterly winds pointing toward the CFPP. These changes were clearly attributable to the closure of the CFPP.

Weiss-Penzias PS, Gustin MS, Lyman SN. 2011. Sources of gaseous oxidized mercury and mercury dry deposition at two southeastern US sites. Atmospheric Environment 45: 4569-79.

Abstract: Wet deposition measurements have shown that relative to other parts of the US, the southeastern region has the highest mercury (Hg) inputs. The source of this Hg has been investigated by multiple researchers and is suggested to be derived from local, regional and global sources. Here we focus on trying to understand potential sources of Hg to this area during periods dominated by dry gaseous oxidized mercury (GOM) deposition. Dry deposition of GOM to a surrogate surface was measured in conjunction with speciated atmospheric Hg, and ancillary parameters from September 2007 through September 2008 at two sites located within 25 km of coal-fired power plants (CFPPs) near Yorkville. CA, and Pensacola, FL Mean weekly GOM dry deposition, daily GOM, and daily sulfur dioxide (SO2) concentrations were significantly (P 98th percentile), were also associated with NOy/SO2 ratios that were within 25% of that reported for the local CFPPs (N = 27 of 33 at Yorkville, N = 18 of 26 at Pensacola). During these events, termed Category 1, mean GOM/SO2 enhancement ratios were 2.4 +/- 0.1 and 2.3 +/- 0.1 pg m-3 ppb(-1) for Yorkville and Pensacola, respectively (range = 0.5 to 5.5). The remaining events at both sites (termed Category 2) displayed

significantly lower SO2 concentrations, yet GUM concentrations were not significantly different compared to Category 1 events. The potential sources of GOM during the Category 2 events at OLF were investigated using gridded frequency distributions (GFD) of 72-h atmospheric back trajectories. During these periods there was a greater component of air mass transport from the free troposphere, and less precipitation along the trajectory paths compared to GFDs for Category 1 events. GFDs developed for the weeks when GUM dry deposition was in the upper quartile at both sites simultaneously revealed a similar pattern to the GEDs of Category 2 GUM concentration events, that is, greater free tropospheric transport and relatively little precipitation. Although dry deposition inputs are thought to represent <15% of total annual Hg deposition in this region, we suggest that a significant portion of this Hg could be derived from sources outside the local area.

Wu C, Cao Y, Dong Z, Cheng C, Li H, Pan W. 2010. Evaluation of mercury speciation and removal through air pollution control devices of a 190 MW boiler. Journal of Environmental Sciences (China) 22(2): 277-82.

Abstract: Air pollution control devices (APCDs) are installed at coal-fired power plants for air pollutant regulation. Selective catalytic reduction (SCR) and wet flue gas desulfurization (FGD) systems have the co-benefits of air pollutant and mercury removal. Configuration and operational conditions of APCDs and mercury speciation affect mercury removal efficiently at coal-fired utilities. The Ontario Hydro Method (OHM) recommended by the U.S. Environmental Protection Agency (EPA) was used to determine mercury speciation simultaneously at five sampling locations through SCR-ESP-FGD at a 190 MW unit. Chlorine in coal had been suggested as a factor affecting the mercury speciation in flue gas; and low-chlorine coal was purported to produce less oxidized mercury (Hg2+) and more elemental mercury (Hg0) at the SCR inlet compared to higher chlorine coal. SCR could oxidize elemental mercury into oxidized mercury when SCR was in service, and oxidation efficiency reached 71.0%. Therefore, oxidized mercury removal efficiency was enhanced through a wet FGD system. In the non-ozone season, about 89.5%-96.8% of oxidized mercury was controlled, but only 54.9%-68.8% of the total mercury was captured through wet FGD. Oxidized mercury removal efficiency was 95.9%-98.0%, and there was a big difference in the total mercury removal efficiencies from 78.0% to 90.2% in the ozone season. Mercury mass balance was evaluated to validate reliability of OHM testing data, and the ratio of mercury input in the coal to mercury output at the stack was from 0.84 to 1.08.

Wu H, Qiu JR, Tang SL, Liu H, Wang QH, Zeng HC. 2010. Mercury and halides emissions from 200 MW pulverized coal combustion boiler. Asia-Pacific Journal of Chemical Engineering 5: 281-6.

Abstract: Mercury emission from coal-fired power plants is the major industrial source of mercury pollution in China. For a better understanding about the coal combustion Hg emission in China, a field measurement was conducted on a 200 MW pulverized coal fired boiler. Halides being proved to be mercury transformation participators, the U.S. EPA (Environmental Protection Agency) recommended Ontario Hydro method (OHM) and EPA Method 26A were adopted to determine the speciation of Hg and halides in postcombustion flue gases, respectively. Results indicated that, as the flue gas cooling down, the percentage of oxidized mercury in total gas phase mercury (Hg2+(g)/HgT(G)) increased from 41% to about 74% across the electrostatic precipitator (ESP) outlet. Oxidized mercury (Hg2+(g)) was more apt to be absorbed onto the fly ash. The main halides measured in flue gas were HF and HCl, while the concentrations of Cl2 and HBr were extremely low and no Br2 was detected in flue gas. Analysis indicated that acid flue gas components, such as HCl, HF, SO2 and NO, showed a certain extent of promotion on Hg oxidation. The measured mercury emission factor (EMF) in this test was 5.63 g/1012J (13.1 lb/1012Btu).

Wu YL, Rahmaningrum DG, Lai YC, Tu LK, Lee SJ, Wang LC et al. 2012. Mercury emissions from a coal-fired power plant and their impact on the nearby environment. Aerosol and Air Quality Research 12: 643-50.

Abstract: This study investigated Hg emissions from a coal-fired power plant (CFPP) and their impact on the nearby environment. Atmospheric Hg concentrations were measured at sampling sites near a CFPP located in central Taiwan from November 2008 to March 2011. The mean gaseous and particulate Hg concentrations

were 2.59-4.12 ng/m3 and 105-182 pg/m3, respectively, with gaseous Hg predominant at all sites (approximately 96% of the total atmospheric Hg). The seasonal variations of both gaseous and particle Hg concentrations in the atmosphere showed a similar pattern, with the highest concentrations in the cold season and the lowest in warm season. The mean emission factor of 13.1 mg/ton was found for the CFPP burning bituminous coal, with an electrostatic precipitator (ESP), flue gas desulfurization (FGD), and selective catalytic reduction (SCR) in series as air pollution control devices (APCDs). This figure was significantly lower than that measured at various power facilities, probably due to different fuel type, APCDs configuration, and flue gas condition. The modeling of the Industrial Source Complex Short Term (ISCST) revealed that the contribution of the CFPP to ambient atmospheric Hg was minimal (less than 1%).

Xu X, Akhtar US. 2010. Identification of potential regional sources of atmospheric total gaseous mercury in Windsor, Ontario, Canada using hybrid receptor modeling. Atmospheric Chemistry and Physics 10: 7073-83.

Abstract: Windsor (Ontario, Canada) experiences trans-boundary air pollution as it is located on the border immediately downwind of industrialized regions of the United States of America. A study was conducted in 2007 to identify the potential regional sources of total gaseous mercury (TGM) and investigate the effects of regional sources and other factors on seasonal variability of TGM concentrations in Windsor. TGM concentration was measured at the University of Windsor campus using a Tekran(R) 2537A Hg vapour analyzer. An annual mean of 2.02+/-1.63 ng/m3 was observed in 2007. The average TGM concentration was high in the summer (2.48+/-2.68 ng/m3) and winter (2.17+/-2.01 ng/m3), compared to spring (1.88+/-0.78 ng/m3) and fall (1.76+/-0.58 ng/m3). Hybrid receptor modeling potential source contribution function (PSCF) was used by incorporating 72-h backward trajectories and measurements of TGM in Windsor. The results of PSCF were analyzed in conjunction with the Hg emissions inventory of North America (by state/province) to identify regions affecting Windsor. In addition to annual modeling, seasonal PSCF modeling was also conducted. The potential source region was identified between 24-61 degrees N and 51-143 degrees W. Annual PSCF modeling identified major sources southwest of Windsor, stretching from Ohio to Texas. The emissions inventory also supported the findings, as Hg emissions were high in those regions. Results of seasonal PSCF modeling were analyzed to find the combined effects of regional sources, meteorological conditions, and surface re-emissions, on seasonal variability of Hg concentrations. It was found that the summer and winter highs of atmospheric Hg can be attributed to areas where large numbers of coal fired power plants are located in the USA. Weak atmospheric dispersion due to low winds and high re-emission from surfaces due to higher temperatures also contributed to high concentrations in the summer. In the winter, the atmospheric removal of Hg was slow, but strong winds led to more dispersion, resulting in lower concentrations than the summer. Future studies could use smaller grid sizes and refined emission inventories, for more accurate analysis of source-receptor relationship of atmospheric Hg.

Zhang L, Zhuo Y, Chen L, Xu X, Chen C. 2008. Mercury emissions from six coal-fired power plants in China. Fuel Processing Technology 89: 1033-40.

Abstract: Mercury emission field measurements based on the Ontario Hydro Method (OHM) were conducted for six coal-fired power plants in China. The mercury mass balances for the six power plants varied from 100.3% to 139.5% of the input coal mercury for the whole system. About 0.02%–1.2% of the mercury remained in the bottom ash. In the first five power plants equipped with pulverized coal boiler, most of the mercury was emitted from the stack to the atmosphere. The plants with Electrostatic Precipitator (ESP) system emitted more Hg0 than Hg2+, while the plants with the Fabric Filter (FF) emitted less Hg0 than Hg2+. Virtually all of the HgP enter the ESP or the FF was removed. The FF systems had better Hg0 and Hg2+ removal efficiencies than the ESP systems. The flue gas desulfurization (FGD) system removed up to 78.0% of Hg2+ and only 3.14% of Hg0 in the flue gas, while 8.94% of the original mercury in the coal was removed by the FGD system. The average mercury removal efficiencies of the ESP systems was 11.5%, that of the FF systems was 52.3% and that of the combined ESP + FGD system was 13.7%, much lower than the average removal efficiencies of pollution control device systems in US plants which have been used in previous studies of Chinese mercury emission inventory. Hg0, rather than Hg2+ as assumed in previous estimates, has been found to be the dominant species emitted in the atmosphere. The average emission factor was found to be 4.70 g/TJ (10.92 bl/Tbtu), which is much higher than for US plants burning bituminous

coals due to the high mercury content in the Chinese coal and the low mercury removal efficiency of air pollution control devices of power plants.

Zhu J, Wang T, Talbot R, Mao H, Hall CB, Yang X et al. 2012. Characteristics of atmospheric Total Gaseous Mercury (TGM) observed in urban Nanjing, China. Atmospheric Chemistry and Physics 12: 12103-18.

Abstract: Long-term continuous measurements of total gaseous mercury (TGM = gaseous elemental mercury (GEM) + reactive gaseous mercury (RGM)) were conducted simultaneously along with meteorological variables and a suite of trace gases at an urban site in Nanjing, China from 18 January to 31 December 2011. Measurements were conducted using a high resolution mercury vapor analyzer (Tekran 2537B) with 5-min time resolution. The average concentration of TGM was 7.9 ± 7.0 ng m−3 with a range of 0.8–180 ng m−3 over the study period. TGM concentrations followed a typical lognormal pattern dominated by a range of 3–7 ng m−3, which was significantly higher than the continental background values (~1.5 ng m−3) in Northern Hemisphere. The mean seasonal TGM concentrations decreased in the following order: summer, spring, fall, and winter. This seasonal pattern was quite different from measurements at most other sites around the world. We attributed high monthly average concentrations to the re-volatilization of deposited mercury during the warm season due to high temperatures and greater solar radiation. Previous modeling studies suggested that Nanjing and the surrounding region have the largest Chinese natural emissions during the summer. Positive correlations between temperature, solar radiation, and TGM concentration combined with no correlation between CO and TGM in summer provide a strong indication that natural sources are important in Nanjing while most sharp peaks were caused by anthropogenic sources. TGM concentrations in Nanjing exhibited a noticeable diurnal pattern with a sharp increase after sunrise and peak of greater than 8 ng m−3 during 7–10 a.m. local time. Further, seasonally averaged diurnal cycles of TGM exhibited considerably different patterns with the largest variation in spring and insignificant fluctuations in winter. Using HYSPLIT backwards trajectories from six clusters, it was indicated that the highest TGM concentrations, 11.9 ng m−3, was derived from local air masses. The cleanest air masses, with an average TGM concentration of 4.7 and 5.9 ng m−3, were advected from the north via fast transport facilitated by sweeping synoptic flows.

Grey literature

Bencardino M, Sprovieri F, Pirrone N. 2013. Large industrial point sources in Italy: a focus on mercury concentrations resulting from three seasonal ship-borne measurements. In: Proceedings of the 16th International Conference on Heavy Metals in the Environment, 23005.

Abstract: In Italy there are 25 Large Industrial Point Sources whose mercury emissions in air exceed the established threshold of 10 kg year(-1). Many of these mercury point sources, mostly distributed along the Italian coastal area, are located at sites qualified as National Interest Rehabilitation Sites because of documented contamination in qualitative and/or quantitative terms and of potential health impact. Atmospheric mercury emissions related to Italian Large Industrial Point Sources, with a value of 1.04 Mg.yr(-1) for 2007, have a not negligible contribution, accounting, on their own, for more than 10% of the total mercury emissions resulting from all activity sectors at a national level. Among others, thermal power stations, pig iron and steel as well as basic inorganic chemical production, result to be the main contributing industrial activities. In order to assess how mercury species concentrations and distribution in the Marine Boundary Layer (MBL) change with vicinity to large industrial sites, measurements of atmospheric mercury were performed during three oceanographic campaigns aboard the Research Vessel (R.V.) Urania of the Italian CNR. Collection of GEM, GOM and PBM was conducted across the Adriatic sea, during autumn 2004 (27th of October to 12th of November) and summer 2005 (17th to 29th of June), and across the Tyrrhenian sea during autumn 2007 (12th of September to 1st October). Analysis were carried out with reference to the period in which the R. V. Urania has stopped close to the main Italian industrial contaminated sites. Explorative statistical parameters of atmospheric mercury species were computed over each single stop-period and then compared with the overall cruise campaign measurements. Results are herein presented and discussed.

Bland A, Newcomer J, Kephart A, Schmidt V, Butcher G. 2008. Emissions, Monitoring, and Control of Mercury from Subbituminous Coal-Fired Power Plants - Phase II. WRI-08-R012, US Department of Energy, West Virginia. Available at http://www.osti.gov/scitech/servlets/purl/993829.

Abstract: *No abstract available.*

Excerpt from Executive Summary:
[Western Research Institute (WRI), in conjunction with Western Farmers Electric Cooperative (WFEC), has teamed with Clean Air Engineering of Pittsburgh PA to conduct a mercury monitoring program at the WEFC Hugo plant in Oklahoma. Sponsored by US Department of Energy Cooperative Agreement DE-FC-26-98FT40323, the program included the following members of the Subbituminous Energy Coalition (SEC) as co-sponsors: Missouri Basin Power Project; DTE Energy; Entergy; Grand River Dam Authority; and Nebraska Public Power District. This research effort had five objectives: (1) determine the mass balance of mercury for subbituminous coal-fired power plant; (2) assess the distribution of mercury species in the flue gas (3) perform a comparison of three different Hg test methods; (4) investigate the long-term (six months) mercury variability at a subbituminous coal-fired power plant; and (5) assess operation and maintenance of the Method 324 and Horiba CEMS utilizing plant personnel.]

Bullock D, Johnson S. 2011. Electric Generating Utility Mercury Speciation Profiles for the Clean Air Mercury Rule. EPA-454/R-11-010, US Environmental Protection Agency, North Carolina. Available at http://www.epa.gov/ttnchie1/emch/speciation/EGU_Hg_speciation_summary_CAMR.pdf.

Abstract: *No abstract available.*

Excerpt from Introduction:
[The U.S. Environmental Protection Agency (EPA) is preparing for finalizing the National Emission Standards for Hazardous Air Pollutants from Coal- and Oil-Fired Electric Utility Steam Generating Units (EGUs) under Clean Air Act (CAA or the Act) section 112(d) (referred to as the Mercury and Air Toxics Standards [MATS]). A key piece to several aspects of the rule documentation includes emission inventory estimates for this sector at the facility and national resolutions. Associated with the emission inventory estimates is the application of mercury speciation profiles that were developed from the 1999 information collection request (ICR) data used to support development of the Clean Air Mercury Rule (CAMR).
This memorandum describes the general process followed in the development of the mercury speciation profiles. The development of the mercury speciation profiles can generally be divided into three major elements: (1) collecting the speciated mercury data, (2) grouping the data into "bins," and (3) developing the average mercury speciation profiles for each bin.]

Lu P, Li C, Wu J, Pan WP. 2009. Emissions of mercury and other trace elements from a coal-fired power plant. In: Proceedings of the International Conference on Power Engineering 2009, 195-200.

Abstract: This paper provides details concerning emissions of mercury and other trace elements conducted at a coal-fired power plant with SCR and wet FGD. Mercury emission concentration and its speciation were measured with Ontario Hydro Method (OHM) and Semi-continuous emission monitor (SCEM). The emission of trace elements was determined by EPA method 29. Mercury mass balance and partitioning of trace elements were analyzed based on the analyses of solid samples (such as: coal, bottom ash, fly ash, and flue gas desulphurization (FGD) slurry) and concentration of trace elements in the flue gas. The results indicated that total mercury (Hg(T), sum of Hg(0), Hg(2+), and Hg(P)) remained relatively constant along the flue gas path before passing through FGD. The ratio of Hg(2+) to Hg(VT) increased from 45.7% to 83.3% after flue gas passed through SCR. Hg monitoring methods of OHM and SCEM agreed that over 95% of Hg in flue gas was in oxidized form before FGD. The mercury removal efficiency of FGD was more than 96%. A better ratio of Hg output to Hg input (within the range of 0.8 to 1.2) was obtained while Hg content in ashes reached a dateable level. The emission concentration of each element was very low, and the change of the gaseous phase compositions of the selected trace elements was found insignificantly throughout the flue

gas path. Mercury and Selenium are almost fully released in the gaseous phase. The main proportion of other trace elements is bound with the fly ash and collected in the electrostatic precipitator (ESP).

Wu J, Zhang Y, Pan W, He P, Ren J, Shen M et al. 2009. Experimental research on mercury emission and its speciation in the flue gas from coal-fired power station. In: Proceedings of the International Conference on Energy and Environment Technology, Vol 3, 332-5.

Abstract: Mercury is harmful to our health and environment, so research on mercury emission from coal-fired power station, the main source of anthropogenic mercury emission, is very important. In this paper, mercury emission and speciation in the flue gas from a coal-fired power station was measured by three methods, i.e., OHM (Ontario Hydro method), Hg SCEM (semi-continuous emission monitors), and EPA Appendix K (carbon trap method). The effects of boiler load, flue gas characteristics on mercury emission and its speciation were analyzed. Mercury mass balance was calculated based on the analyses of mercury contents in coal, pyrite, bottom ash, fly ash, FGD (flue gas desulphurization) slurry, and flue gas at FGD inlet and stack. The results indicate that data by the three methods have good consistency within acceptable range. The total mercury emission increases with the increasing of mercury content in fuel and boiler load. The percentages of elemental mercury in the flue gas at FGD inlet and stack are around 26%-48% and 70%-85% respectively. Wet FGD would capture more than 80% of oxidized mercury.

Zhao Z. 2010. Mass balance of mercury before and after coal combustion. In: Proceedings of the 3rd International Conference on Environmental Technology and Knowledge Transfer, 179-82.

Abstract: Mercury has caused significant adverse impacts on human health and the environment. And, coal-fired power production is clearly the largest global source of atmospheric mercury emissions. In this paper, taken CCS power plant as an example, the mass balance of mercury before and after coal combustion is researched. The feed coal, bottom ash, and fly ash samples were collected by experienced technician, and, the flue gas was sampled by Ontario Hydro Method. The ultimate analysis of feed coal was tested, and the mercury content in feed coal, bottom ash, fly ash, and flue gas samples were determined. The mercury input of feed coal, the mercury output of bottom ash, fly ash, and flue gas were respectively calculated. The ratio of output to input was about 1.07, and this result revealed that all the mercury data of feed coal, bottom ash, fly ash and the flue gas were reasonably reliable.

3.1.3 Mercury - modeled emissions (emission inventories)

White literature

Chakraborty LB, Qureshi A, Vadenbo C, Hellweg S. 2013. Anthropogenic mercury flows in India and impacts of emission controls. Environmental Science and Technology 47(15): 8105-13.

Abstract: India is a major emitter of mercury, a pollutant of global importance. However, quantitative information on mercury flows in the country is lacking. Here, we quantify major transfer pathways for anthropogenic mercury, its emissions to the environment (air, water, soil), and storage in consumer products and anthropogenic sinks (e.g., landfills) in India in the period 2001-2020, and evaluate the potential influence of six pollution control measures. Total mercury emissions in India were approximately 415 tonnes in 2001, 310 tonnes in 2010, and are projected to rise to 540 tonnes in 2020. In 2010, 76% of these emissions went to the atmosphere. The most important emission sources to atmosphere are coal power plants and zinc production. Pesticides were the most important source for emissions to soil in 2005 and dental amalgam in later years. Mercury stocks in products rose from 700 tonnes in 2001 to 1125 tonnes in 2010, and in landfills and ash-made structures (e.g., embankments) from 920 tonnes in 2001 to 1450 tonnes in 2010. These stocks are expected to rise further and may be regarded as stored toxicity, which may become a concern in the future. Total mercury emissions can be reduced by about 50% by combining pollution control measures that target different mercury emission sources.

Dabrowski JM, Ashton PJ, Murray K, Leaner JJ, Mason RP. 2008. Anthropogenic mercury emissions in South Africa: Coal combustion in power plants. Atmospheric Environment 42: 6620-6.

Abstract: South Africa is regarded as a country with the 2nd highest mercury (Hg) emissions in the World. This assumption is based on estimates of total Hg emissions derived primarily from gold mining and coal combustion. The potential sources of Hg to the South African environment were assessed by focussing particularly on coal combustion at the country's coal-fired power plants. Mercury emission estimates were based on the total amount of coal burned in all power plants per year (112.3 Mt y(-1)), the Hg content Of South African coals (0.2 ppm) and the emission control devices used in each power plant. Results indicate that Hg emissions arising from South Africa's coal-fired power plants (ranging between 2.6 and 17.6 tonnes y(-1), with an estimated average emission of 9.8 tonnes y(-1)) are significantly lower than suggested in the literature (approximately 50 tonnes y(-1)). The calculated emission factor (ranging between 0.02 and 0.16 g Hg tonne(-1) coal burned) and per capita estimates (0.24 g Hg person(-1) y(-1) R-1, where R is the fraction of total electricity generated from coal) fall within the range of values reported for Hg inventories derived in other countries and indicate that Hg emission estimates for coal-fired power plants presented in this paper are more reliable than those published previously.

Kim JH, Park JM, Lee SB, Pudasainee D, Yong-Chil Seo YC. 2010. Anthropogenic mercury emission inventory with emission factors and total emission in Korea. Atmospheric Environment 44(23): 2714-21.

Abstract: Mercury emissions concentrations, emission factors, and the total national emission from major anthropogenic sources in Korea for the year 2007 were estimated. Uncontrolled and controlled mercury emission factors and the total emission from each source types are presented. The annual national mercury emission from major anthropogenic sources for the year 2007, on average was 12.8 ton which ranged from 6.5 to 20.2 ton. Averaged emissions of elemental, oxidized, and particulate mercury were estimated at 8.25 ton, 3.69 ton, and 0.87 ton, respectively. Due to the removal of a major portion of particulate and oxidized mercury species, elemental mercury was dominant in stack emission. About 54.8% of mercury emission was contributed by industrial sources, 45.0% by stationary combustion sources and 0.02% by mobile sources. Thermal power plants, oil refineries, cement kilns and incinerators (municipal, industrial, medical, sewage sludge) were the major mercury emitters, contributing about 26%, 25%, 21% and 20%, respectively to the total mercury emission. Other sources (crematory, pulp and paper manufacturing, nonferrous metals manufacturing, glass manufacturing) contributed about 8% of the total emission. Priority should be given in controlling mercury emissions from coal-fired power plants, oil refineries, cement kilns and waste incinerators. More measurements including natural and re-emission sources are to be carried out in the future in order to have a clear scenario of mercury emission from the country and to apply effective control measures.

Lee SS, Keener TC. 2008. Dispersion modeling of mercury emissions from coal-fired power plants at Coshocton and Manchester, Ohio. Ohio Journal of Science 108: 65-9.

Abstract: Mercury emissions from coal-fired power plants are estimated to contribute to approximately 46% of the total U. S. anthropogenic mercury emissions and required to be regulated by maximum achievable control technology (MACT) standards. Dispersion modeling of mercury emissions using the AERMOD model and the Industrial Source Complex Short Term (ISCST3) model was conducted for two representative coal-fired power plants at Coshocton and Manchester, Ohio. Atmospheric mercury concentrations, dry mercury deposition rates, and wet mercury deposition rates were predicted in a 5 x 5 km area surrounding the Conesville and JM Stuart coal-fired power plants. In addition, the analysis results of meteorological parameters showed that wet mercury deposition is dependent on precipitation, but dry mercury deposition is influenced by various meteorological factors.

Masekoameng KE, Leaner J, Dabrowski J. 2010. Trends in anthropogenic mercury emissions estimated for South Africa during 2000–2006. Atmospheric Environment 44(25): 3007-14.

Abstract: Recent studies suggest an increase in mercury (Hg) emissions to the global environment, particularly as a result of anthropogenic activities. This has prompted many countries to complete Hg

emission inventories, based on country-specific Hg sources. In this study, information on annual coal consumption and Hg-containing commodities produced in South Africa, was used to estimate Hg emissions during 2000–2006. Based on the information, the UNEP toolkit was used to estimate the amount of Hg released to air and general waste from each activity; using South Africa specific and toolkit based emission factors. In both atmospheric and solid waste releases, coal-fired power plants were estimated to be the largest contributors of Hg emissions, viz. 27.1 to 38.9 tonnes y-1 in air, and 5.8 to 7.4 tonnes y-1 in waste. Cement production was estimated to be the second largest atmospheric Hg emission contributor (2.2–3.9 tonnes y-1), while coal gasification was estimated to be the second largest Hg contributor in terms of general waste releases (2.9–4.2 tonnes y-1). Overall, there was an increase in total atmospheric Hg emissions from all activities, estimated at ca. 34 tonnes in 2000, to 50 tonnes in 2006, with some fluctuations between the years. Similarly, the total Hg emissions released to general waste was estimated to be 9 tonnes in 2000, with an increase to 12 tonnes in 2006.

Nelson PF, Morrison AL, Malfroy HJ, Cope M, Lee S, Hibberd ML et al. 2012. Atmospheric mercury emissions in Australia from anthropogenic, natural and recycled sources. Atmospheric Environment 62: 291-302.

Abstract: The United Nations Environment Programme (UNEP) has begun a process of developing a legally binding instrument to manage emissions of mercury from anthropogenic sources. The UNEP Governing Council has concluded that there is sufficient evidence of significant global adverse impacts from mercury to warrant further international action; and that national, regional and global actions should be initiated as soon as possible to identify populations at risk and to reduce human generated releases. This paper describes the development of, and presents results from, a comprehensive, spatially and temporally resolved inventory of atmospheric mercury emissions from the Australian landmass. Results indicate that the best estimate of total anthropogenic emissions of mercury to the atmosphere in 2006 was 15 ± 5 tonnes. Three industrial sectors contribute substantially to Australian anthropogenic emissions: gold smelting (~50%, essentially from a single site/operation), coal combustion in power plants (~15%) and alumina production from bauxite (~12%). A diverse range of other sectors contribute smaller proportions of the emitted mercury, but industrial emissions account for around 90% of total anthropogenic mercury emissions. The other sectors include other industrial sources (mining, smelting, and cement production) and the use of products containing mercury. It is difficult to determine historical trends in mercury emissions given the large uncertainties in the data. Estimates for natural and re-emitted emissions from soil, water, vegetation and fires are made using meteorological models, satellite observations of land cover and soil and vegetation type, fuel loading, fire scars and emission factors which account for the effects of temperature, insolation and other environmental variables. These natural and re-emitted sources comfortably exceed the anthropogenic emissions, and comprise 4–12 tonnes per year from vegetation, 70–210 tonnes per year from soils, and 21–63 tonnes per year from fires.

Pirrone N, Cinnirella S, Feng X, Finkelman RB, Friedli HR, Leaner J et al. 2010. Global mercury emissions to the atmosphere from anthropogenic and natural sources. Atmospheric Chemistry and Physics 10(13): 5951-64.

Abstract: This paper provides an up-to-date assessment of global mercury emissions from anthropogenic and natural sources. On an annual basis, natural sources account for 5207 Mg of mercury released to the global atmosphere, including the contribution from re-emission processes, which are emissions of previously deposited mercury originating from anthropogenic and natural sources, and primary emissions from natural reservoirs. Anthropogenic sources, which include a large number of industrial point sources, are estimated to account for 2320 Mg of mercury emitted annually. The major contributions are from fossil-fuel fired power plants (810 Mg yr−1), artisanal small scale gold mining (400 Mg yr−1), non-ferrous metals manufacturing (310 Mg yr−1), cement production (236 Mg yr−1), waste disposal (187 Mg yr−1) and caustic soda production (163 Mg yr−1). Therefore, our current estimate of global mercury emissions suggests that the overall contribution from natural sources (primary emissions+re-emissions) and anthropogenic sources is nearly 7527 Mg per year, the uncertainty associated with these estimates are related to the typology of emission sources and source regions.

Rafaj P, Bertok I, Cofala J, Schoepp W. 2013. Scenarios of global mercury emissions from anthropogenic sources. Atmospheric Environment 79: 472-9.

Abstract: This paper discusses the impact of air quality and climate policies on global mercury emissions in the time horizon up to 2050. Evolution of mercury emissions is based on projections of energy consumption for a scenario without any global greenhouse gas mitigation efforts, and for a 2 degrees C climate policy scenario, which assumes internationally coordinated action to mitigate climate change. The assessment takes into account current air quality legislation in each country, as well as provides estimates of maximum feasible reductions in mercury through 2050. Results indicate significant scope for co-benefits of climate policies for mercury emissions. Atmospheric releases of mercury from anthropogenic sources under the global climate mitigation regime are reduced in 2050 by 45% when compared to the case without climate measures. Around one third of world-wide co-benefits for mercury emissions by 2050 occur in China. An annual Hg-abatement of about 800 tons is estimated for the coal combustion in power sector if the current air pollution legislation and climate policies are adopted in parallel.

Romanov A, Sloss L, Jozewicz W. 2012. Mercury emissions from the coal-fired energy generation sector of the Russian Federation. Energy and Fuels 26: 4647-54.

Abstract: This paper presents results from the United Nations Environment Programme (UNEP)-coordinated project, "Reducing Mercury Emissions from Coal Combustion in the Energy Sector", implemented in the Russian Federation in 2009-2010. A profile of the coal-fired power sector of the Russian Federation, which includes some 120 power plants, is provided and analyzed. Information on consumption and main characteristics of coals from major and minor coal basins burnt for energy generation is presented. The paper also demonstrates results of model and experimental mercury emission factor development for selected high-installed capacity power plants of 1.9 and 3.8 GW located in the European and Asian parts of the Russian Federation. Mercury emissions are projected to increase by 2030 largely based on projected national energy consumption and mercury content of coal feedstocks. Remaining challenges to improve data quality and considerations for further research are outlined.

Streets DG, Zhang Q, Wu Y. 2009. Projections of global mercury emissions in 2050. Environmental Science and Technology 43(8): 2983-8.

Abstract: Global Hg emissions are presented for the year 2050 under a variety of assumptions about socioeconomic and technology development. We find it likely that Hg emissions will increase in the future. The range of 2050 global Hg emissions is projected to be 2390-4860 Mg, compared to 2006 levels of 2480 Mg, reflecting a change of -4% to +96%. The main driving force for increased emissions is the expansion of coal-fired electricity generation in the developing world, particularly Asia. Our ability to arrest the growth in Hg emissions is limited by the relatively low Hg removal efficiency of the current generation of emission control technologies for coal-fired power plants (flue-gas desulfurization). Large-scale deployment of advanced Hg sorbent technologies, such as Activated Carbon Injection, offers the promise of lowering the 2050 emissions range to 1670-3480 Mg, but these technologies are not yet in commercial use. The share of elemental Hg in total emissions will decline from today's levels of ~65% to ~50-55% by 2050, while the share of divalent Hg will increase. This signals a shift from long-range transport of elemental Hg to local deposition of Hg compounds - though emissions of both species could increase under the worst case.

Tian H, Wang Y, Cheng K, Qu Y, Hao J, Xue Z et al. 2012. Control strategies of atmospheric mercury emissions from coal-fired power plants in China. Journal of the Air and Waste Management Association 62(5): 576-86.

Abstract: Atmospheric mercury (Hg) emission from coal is one of the primary sources of anthropogenic discharge and pollution. China is one of the few countries in the world whose coal consumption constitutes about 70% of total primary energy, and over half of coals are burned directly for electricity generation. Atmospheric emissions of Hg and its speciation from coal-fired power plants are of great concern owing to their negative impacts on regional human health and ecosystem risks, as well as long-distance transport. In this paper, recent trends of atmospheric Hg emissions and its species split from coal-fired power plants in

China during the period of 2000-2007 are evaluated, by integrating each plant's coal consumption and emission factors, which are classified by different subcategories of boilers, particulate matter (PM) and sulfur dioxide (SO2) control devices. Our results show that the total Hg emissions from coal-fired power plants have begun to decrease from the peak value of 139.19 t in 2005 to 134.55 t in 2007, though coal consumption growing steadily from 1213.8 to 1532.4 Mt, which can be mainly attributed to the co-benefit Hg reduction by electrostatic precipitators/fabric filters (ESPs/FFs) and wet flue gas desulfurization (WFGD), especially the sharp growth in installation of WFGD both in the new and existing power plants since 2005. In the coming 12th five-year-plan, more and more plants will be mandated to install De-NOx (nitrogen oxides) systems (mainly selective catalytic reduction [SCR] and selective noncatalytic reduction [SNCR]) for minimizing NOx emission, thus the specific Hg emission rate per ton of coal will decline further owing to the much higher co-benefit removal efficiency by the combination of SCR + ESPs/FFs + WFGD systems. Consequently, SCR + ESPs/FFs + WFGD configuration will be the main path to abate Hg discharge from coal-fired power plants in China in the near future. However, advanced specific Hg removal technologies are necessary for further reduction of elemental Hg discharge in the long term. Implications: Controlling of atmospheric Hg discharge from coal-fired power plants have aroused great concerns for its adverse impacts on regional environment and human health risks, as well as long-distance transportation. It is of great significance for Chinese decision makers to be aware of the current status of Hg emissions from coal-fired power plants, so that the regulations and policies regarding Hg abatement can be made that are cost-effective and feasible implementation. This study provides the recent trend of atmospheric Hg emissions from coal-fired power plants, and accordingly proposes the preliminary comprehensive Hg control strategies suggestion in the future, which will be helpful for relevant policy making to minimize the harmful risks on environment and human health in China.

Vijayaraghavan K, Karamchandani P, Seigneur C, Balmori R, Chen SY. 2008. Plume-in-grid modeling of atmospheric mercury. Journal of Geophysical Research - Atmospheres 113, D24.

Abstract: An existing plume-in-grid model for ozone and particulate matter, which provides an explicit treatment of stack plumes embedded within a three-dimensional grid-based Eulerian air quality model, is extended to include a comprehensive treatment of mercury (Hg) processes. The model is applied to the continental United States to investigate the subgrid-scale effects associated with Hg emissions from large elevated point sources on atmospheric Hg concentrations and deposition. The top thirty Hg-emitting power plants in the U. S. were selected for explicit plume-in-grid treatment. Two new processes are included in the Hg chemical mechanism: the gas-phase adsorption of reactive gaseous mercury (RGM)on atmospheric particulate matter and the reduction of RGM to elemental Hg by sulfur dioxide. The plume-in-grid treatment results in improved performance for Hg wet deposition over a purely Eulerian grid-based model, partial correction of overpredictions of wet deposition downwind of coal-fired power plants in the northeastern U. S., and decreases of approximately 10% in simulated dry and wet deposition over large parts of the eastern U. S., with larger decreases near the plants selected for plume-in-grid treatment. On average, 23% of ambient RGM is modeled to adsorb on atmospheric particulate matter.

Wang S, Zhang L, Wu Y, Ancora MP, Zhao Y, Hao J. 2010. Synergistic mercury removal by conventional pollutant control strategies for coal-fired power plants in China. Journal of the Air and Waste Management Association 60(6): 722-30.

Abstract: China's 11th 5-yr plan has regulated total sulfur dioxide (SO2) emissions by installing flue gas desulfurization (FGD) devices and shutting down small thermal power units. These control measures will not only significantly reduce the emission of conventional pollutants but also benefit the reduction of mercury emissions from coal-fired power plants. This paper uses the emission factor method to estimate the efficiencies of these measures on mercury emission abatement. From 2005 to 2010, coal consumption in power plants will increase by 59%; however, the mercury emission will only rise from 141 to 155 t, with an increase of 10%. The average emission rate of mercury from coal burning will decrease from 126 mg Hg/t of coal to 87 mg Hg/t of coal. The effects of the three desulfurization measures were assessed and show that wet FGD will play an important role in mercury removal. Mercury emissions in 2015 and 2020 are also projected under different policy scenarios. Under the most probable scenario, the total mercury emission in

coal-fired power plants in China will decrease to 130 t by 2020, which will benefit from the rapid installation of fabric filters and selective catalytic reduction.

Wang S, Zhang L, Zhao B, Meng Y, Hao J. 2012. Mitigation potential of mercury emissions from coal-fired power plants in China. Energy and Fuels 26: 4635-42.

Abstract: With the rapid increase of coal consumption in China, the mercury emissions from coal-fired power plants have drawn global attention. In this study, a literature review on the mercury content of coal in China and the mercury removal efficiencies of particulate matter, SO2, and NOx control devices was conducted thoroughly. A probabilistic emission factor model was established to develop the mercury emission inventory for coal-fired power plants in China. The best estimate for total mercury emissions from coal-fired power plants in China was 96.5 tons (P50) in 2008, with the confidence interval from 57.3 tons (P10) to 183.0 tons (P90). The synergetic mercury removal benefit from the SO2 control measures during 2005-2008 was 33.9 tons. Two energy scenarios and three pollution control scenarios were developed to forecast the future trend of mercury emissions in China. The change of the energy structure and energy saving will play an important role in the mercury emission reduction in the next 2 decades. Under the current energy consumption pattern and air pollution control policies, the mercury emissions would increase to 196 tons in 2020. The installation of selective catalytic reduction (SCR) will result in 75 tons of mercury emission reduction during 2008-2020. Under the current energy consumption pattern and extended emission controls, the mercury emission in 2030 is 47% lower than that in 2020, because of the widespread application of SCR and the application of fabric filter (FF) and mercury-specific control technologies. Further reduction can be contributed by the enhancement of mercury-specific control technologies. Through the implementation of energy policies with accelerated control technologies, the mercury emission in 2030 can be decreased by 71% from the level of 2008, which shows the significant mitigation potential of mercury emissions from coal-fired power plants in China in the future.

Wu Y, Streets DG, Wang SX, Hao JM. 2010. Uncertainties in estimating mercury emissions from coal-fired power plants in China. Atmospheric Chemistry and Physics 10: 2937-46.

Abstract: A detailed multiple-year inventory of mercury emissions from anthropogenic activities in China has been developed. Coal combustion and nonferrous metals production continue to be the two leading mercury sources in China, together contributing similar to 80% of total mercury emissions. However, many uncertainties still remain in our knowledge of primary anthropogenic releases of mercury to the atmosphere in China. In situations involving large uncertainties, our previous mercury emission inventory that used a deterministic approach could produce results that might not be a true reflection of reality; and in such cases stochastic simulations incorporating uncertainties need to be performed. Within our inventory, a new comprehensive sub-module for estimation of mercury emissions from coal-fired power plants in China is constructed as an uncertainty case study. The new sub-module integrates up-to-date information regarding mercury content in coal by province, coal washing and cleaning, coal consumption by province, mercury removal efficiencies by control technology or technology combinations, etc. Based on these detailed data, probability-based distribution functions are built into the sub-module to address the uncertainties of these key parameters. The sub-module incorporates Monte Carlo simulations to take into account the probability distributions of key input parameters and produce the mercury emission results in the form of a statistical distribution. For example, the best estimate for total mercury emissions from coal-fired power plants in China in 2003 is 90.5 Mg, with the uncertainty range from 57.1 Mg (P10) to 154.6 Mg (P90); and the best estimate for elemental mercury emissions is 43.0 Mg, with the uncertainty range from 25.6 Mg (P10) to 75.7 Mg (P90). The results further indicate that the majority of the uncertainty in mercury emission estimation comes from two factors: mercury content of coal and mercury removal efficiency.

Zhang L, Wang S, Meng Y, Hao J. 2012. Influence of mercury and chlorine content of coal on mercury emissions from coal-fired power plants in China. Environmental Science and Technology 46(11): 6385-92.

Abstract: China is the largest mercury emitter in the world and coal combustion is the most important mercury source in China. This paper updates the coal quality database of China and evaluates the mercury removal efficiency of air pollution control devices (APCDs) based on 112 on-site measurements. A submodel was developed to address the relationship of mercury emission factor to the chlorine content of coal. The mercury emissions from coal-fired power plants (CFPPs) in China were estimated using deterministic mercury emission factor model, nonchlorine-based and chlorine-based probabilistic emission factor models, respectively. The national mercury emission from CFPPs in 2008 was calculated to be 113.3 t using the deterministic model. The nonchlorine-based probabilistic emission factor model, which addresses the log-normal distribution of the mercury content of coal, estimates that the mercury emission from CFPPs is 96.5 t (P50), with a confidence interval of 57.3 t (P10) to 183.0 t (P90). The best estimate by the chlorine-based probabilistic emission factor model is 102.5 t, with a confidence interval of 71.7 to 162.1 t. The chlorine-based model addresses the influence of chlorine and reduces the uncertainties of mercury emission estimates.

Zhao Y, Xue FM, Wang H, Hao SQ, Shao Y. 2013. Estimate of mercury emissions from coal-fired power station in China during the "twelfth five-year". Advanced Materials Research 807-809: 77-80.

Abstract: The input and output amount of the total mercury in coal-fired power stations was calculated in the year of 2010 and 2015. By 2015 the emissions of mercury discharged from coal-fired power plant to the atmosphere will reduce, the mercury contented in the solid waste will increase, and the amount of mercury in the waste water will be flat compared with the year of 2010.

Zheng J, Ou J, Mo Z, Yin S. 2011. Mercury emission inventory and its spatial characteristics in the Pearl River Delta region, China. 412: 214-22.

Abstract: A 3 km x 3 km gridded mercury emission inventory in the Pearl River Delta (PRD) region for 2008 was compiled from the best available emission factors and official statistical data. The inventory presented a comprehensive estimation of anthropogenic mercury sources and roughly estimated the emissions from natural sources. The total mercury emissions in the PRD region for the year of 2008 are estimated to be 17,244 kg, of which 85% released as Hg(0), 11% as Hg(2+), and 4% as Hg(P). Anthropogenic activities are dominant sources, accounting for 91% of the total emissions, while natural sources constitute the remaining emissions. Ranking by cities, Foshan produces the largest mercury emissions, followed by Dongguan, Guangzhou and Jiangmen. Coal combustion, municipal solid waste (MSW) incineration, fluorescent lamp and battery production are dominant contributors, responsible for 28%, 21%, 19% and 16% of the anthropogenic emissions, respectively. The high contribution of MSW incineration results from the rapid growth of MSW incineration in this region, reflecting a new trend of mercury emissions in China, especially in the fast developing regions. This implies the urgent need for further investigation of mercury emissions and the importance of controlling mercury emissions from MSW incineration.

Zysk J, Wyrwa A, Pluta M. 2011. Emissions of mercury from the power sector in Poland. Atmospheric Environment 45: 605-10.

Abstract: Poland belongs to the European Union countries with the highest mercury emissions. This is mainly related to coal combustion. This paper presents estimates of mercury emissions from power sector in Poland. In this work, the bottom-up approach was applied and over 160 emission point sources were analysed. For each, the characteristics of the whole technological chain starting from fuel quality, boiler type as well as emission controls were taken into account. Our results show that emissions of mercury from brown coal power plants in 2005 were nearly four times greater than those of hard coal power plants. These estimates differ significantly from national statistics and some possible reasons are discussed. For the first time total mercury emissions from the Polish power sector were differentiated into its main atmospheric forms: gaseous elemental (GEM), reactive gaseous (RGM) and particulate-bound mercury. Information on emission source location and the likely vertical distribution of mercury emissions, which can be used in modelling of atmospheric dispersion of mercury is also provided.

Grey Literature

Canadian Council of Ministers of the Environment. 2013. Canada-wide Standards for Mercury Emissions from Coal-fired Electric Power Generation Plants: 2010 Progress Report. PN 1488. Available at http://www.ccme.ca/assets/pdf/pn_1488_cws_mercury_coal_2010_prgrs_rpt_e.pdf.

Abstract: *No abstract available.*

Excerpt from Introduction:
[This report presents information on the attainment of 2010 emissions caps under the Canada-wide Standards for Mercury Emissions from Coal-fired Electric Power Generation Plants. Only those jurisdictions with coal-fired electric power generation plants are required to report. More information on the Canada-wide standards for mercury may be found on the CCME website at www.ccme.ca. In 2006 the Canadian Council of Ministers of the Environment (CCME) endorsed Canada-wide Standards (CWS) for Mercury Emissions from Coal-fired Electric Power Generation Plants. The CWS set targeted caps for each signatory jurisdiction for the year 2010. In 2010 there were 1461.66 kilograms of mercury emitted in total from coal-fired power generation plants in signatory jurisdictions. In 2003, the coal-fired electric power generation sector emitted an estimated 2,695 kilograms of mercury from an estimated 3,725 kilograms of mercury in coal burned. Under the CWS for Mercury Emissions from Coal-fired Electric Power Generation Plants all jurisdictions are to have met their emissions caps by 2010. Several jurisdictions have not yet been able to reduce emissions to the level of the caps, despite best efforts. Those jurisdictions that have not met their cap have articulated the means by which they will meet their 2010 cap in 2011. The CWS is scheduled for review by 2012. Because several jurisdictions are not yet in achievement of the standard, this review has been postponed.]

Environmental Integrity Project. 2011. Dirty Kilowatts, America's Top Power Plant Mercury Polluters. Austin, Texas. Available at http://www.environmentalintegrity.org/news_reports/documents/dirtykilowatts-top50mercurypowerplantreport.pdf.

Abstract: *No abstract available.*
Excerpt from Introduction:
[As this report demonstrates, many U.S. coal-fired power plants continue to emit mercury at remarkably high levels, even while other electric power companies and states have demonstrated that reductions of toxic emissions are readily achievable through available pollution controls, such as sorbent injection, baghouses, sulfur dioxide scrubbers, and selective catalytic reduction. The best performers are proof that mercury and other toxic emissions can be cleaned up.]
[This report is based on emissions data self-reported by the electric power industry to the U.S. EPA's Toxics Release Inventory (TRI), and accessible to the public at http://www.epa.gov/tri/. All data is based on 2010 annual reported emissions, the most recent data available, from a total of 452 electric utilities across the United States, including Puerto Rico. The data in this report was last updated by EPA on September 26, 2011.
The majority of the 452 power plants that reported mercury emissions in 2010 are traditional coal-fired power plants, although some plants also burn petroleum coke (a byproduct of oil refining) or coal waste products. In total, these 452 power plants reported a combined 66,000 pounds, or 33 tons, of mercury air emissions released into the atmosphere in 2010.]

Houyoux M, Strum M. 2011. Memorandum: Emissions Overview: Hazardous Air Pollutants in Support of the Final Mercury and Air Toxics Standard. EPA-454/R-11-014. US Environmental Protection Agency, North Carolina. Available at http://www.epa.gov/mats/pdfs/20111216EmissionsOverviewMemo.pdf.

Abstract: *No abstract available.*

Excerpt from Introduction:
[The purpose of this document is to summarize the mercury (Hg) and non-Hg Hazardous Air Pollutants (HAP) emissions from U.S. electric generating utilities (EGUs) associated with the final Mercury and Air Toxics Standard (MATS). This information includes both background information about these pollutants as well as emissions totals from several emissions cases developed for the final MATS. In this memo, we summarize current HAP emissions estimates from U.S. EGUs, the estimates used in the national scale Hg risk assessment (Hg Risk TSD) for years 2005 and 2016, and the estimates for the future impact of the rule when fully implemented (in 2016).]

Leaner JJ, Dabrowski JM, Mason RP, Resane T, Richardson M, Ginster M, et al. 2009. Mercury emissions from point sources in South Africa. In: Pirrone N, Mason R (*Eds*), Mercury Fate and Transport in the Global Atmosphere; Emissions, Measurements and Models (pp 113-130). New York: Springer Science and Business Media, LLC.

Abstract: As a first step towards assessing Hg levels in a systematic approach in South Africa, representatives from the South African government, academia, research councils and key industries recently initiated a South African Mercury Assessment (SAMA) Programme (Leaner et al., 2006). The SAMA Programme has undertaken some limited Hg inventory development and monitoring studies in South Africa. The preliminary results of those studies and that of Hg monitoring undertaken at Cape Point's Global Atmospheric Watch Station (Baker et al., 2002), are discussed in this paper.

Madsen T, Randall L. 2011. America's Biggest Mercury Polluters; How Cleaning Up the Dirtiest Power Plants Will Protect Public Health. Environment America Research and Policy Center. Available at http://www.environmentamerica.org/sites/environment/files/reports/AME-Biggest-Mercury-Polluters---WEB.pdf.

Abstract: *No abstract available.*

Excerpt from Executive Summary:

[Power plants continue to release large amounts of toxic pollutants, including mercury, into our air. In 2010, two-thirds of all airborne mercury pollution in the United States came from the smokestacks of coal-fired power plants. In other words, power plants generate more airborne mercury pollution than all other industrial sources combined.
Mercury is a potent neurotoxicant. Mercury exposure during critical periods of brain development can contribute to irreversible deficits in verbal skills, damage to attention and motor control, and reduced IQ.
In 2011, the U.S. Environmental Protection Agency (EPA) developed the first national standards limiting mercury and other toxic air pollution from existing coal- and oil-fired power plants. Implementing these standards will protect public health.
Coal-fired power plants are a major source of airborne mercury pollution.
-The Big Brown Steam Electric Station and Lignite Coal Mine in Fairfield, Texas, emitted 1,610 pounds of mercury pollution into our air in 2010, the most of any industrial facility in the nation.
-This amount is significant because mercury is so potent. Distributed over a wide area, just fractions of an ounce of mercury can contaminate local and regional water bodies, making resident fish unsafe to eat. All 50 states currently have advisories warning women and children not to eat local fish due to mercury contamination.
-Of the top 10 biggest mercury-polluting power plants in the country, six are located in Texas, with one each in Alabama, Louisiana, Missouri and Ohio. Table ES-1 lists these top 10 biggest mercury polluters.
-Among all states nationwide, Texas ranked first in terms of overall airborne mercury pollution produced by power plants in 2010.Ohio ranked second, followed by Pennsylvania in third.
-Just five companies were responsible for more than one-third of all power plant mercury emissions in 2010, led by American Electric Power with 6,200 pounds.]

Mukherjee AB, Bhattacharya P, Sarkar A, Zevenhoven R. 2009. Mercury emissions from industrial sources in India and its effects in the environment. In: Pirrone N, Mason R (*Eds*), Mercury Fate and Transport in the Global Atmosphere; Emissions, Measurements and Models (pp 81-11). New York: Springer Science and Business Media, LLC.

Abstract: This study describes the atmospheric mercury (Hg) emissions from industrial sources in India for the years 2000 to 2004. In India emission inventories of Hg and other trace elements from anthropogenic sources have been largely neglected, although the GDP (Gross Domestic Products growth) has touched 9.6% at the beginning of the 21st century. In coal production India is the third largest in the world, whereas Indian cement and brick production have reached second place in the world. With increased industrial development, acute pollution problems have been identified in the subcontinent. There is no consistent earlier information for Hg emissions to the environment for any sectors of industry. This paper may be the first road map in which we have tried to find out the total emission of Hg from a wide range of sources, e.g. from coal combustion to clinical thermometers broken during production or packing. There is a lack of basic data and in an attempt to correct this, emission factors suitable for Asian countries have been selected to complete this study. Before this document, there were some efforts in Europe to develop emission inventories for Hg from coal combustion or chlor-alkali plants for India. In this study it was found that total atmospheric emission from industrial sources has decreased from 321 Mg in 2000 to 253 Mg in 2004 due to a switch for the membrane cell process in the chlor-alkali industry. In 2004 the largest part of the Hg emissions stemmed from coal combustion in thermal power plants. Hg-cell technology had been used earlier in chlorine and sodium hydroxide production, as a result of which Hg concentration in terrestrial and aquatic species are nowadays quite high in coastal areas. India can thus be referred to as a mercury "hot spot". We have received limited information on emissions of Hg from industrial sources in India. Estimates are based on emission factors and the values taken from the literature. Against a background of limited data and information, this paper gives an overview of Hg emissions in India and of the recent steps undertaken by authorities to curb the emissions of Hg and its subsequent trans-boundary movement in the global environment.

Stamper V, Copeland C, Williams M, Spencer T. 2012. Poisoning the Great Lakes: Mercury Emissions from Coal-Fired Power Plants in the Great Lakes Region. Natural Resources Defense Council. Available at http://www.nrdc.org/air/files/poisoning-the-great-lakes.pdf.

Abstract: *No abstract available.*

Excerpt from Executive Summary:
[Mercury emitted into the air from coal-fired power plants is by far the leading man-made source of mercury deposition into the Great Lakes and the lakes, rivers, and streams of the Great Lakes region. While other such plants outside the region contribute to the problem, the report highlights the top 25 mercury polluting coal-fired plants in the Great Lakes States. The U.S. Environmental Protection Agency (EPA) recently issued nationwide rules to require coal-fired power plants to limit airborne mercury emissions and other toxic air pollutants by 2015. The technologies to meet the EPA's mercury limits are widely available and effective. A significant fraction of mercury and other air toxics can be removed by air pollution controls already installed or soon to be installed at many power plants. These technologies could reduce sulfur dioxide and other particle-forming pollutants enough to meet soot and smog standards. Other technology that would achieve additional reductions in mercury by removing at least 90 percent or more of the mercury in coal is readily available.]

United Nations Environment Programme. 2013. Global Mercury Assessment 2013: Sources, Emissions, Releases and Environmental Transport. UNEP Chemicals Branch, Geneva, Switzerland. Available at http://www.unep.org/PDF/PressReleases/GlobalMercuryAssessment2013.pdf.

Abstract: *No abstract available.*

Excerpt from Executive Summary:

[This summary report and the accompanying Technical Background Report for the Global Mercury Assessment 2013 are developed in response to Decision 25/5, paragraph 36 of the Governing Council of the United Nations Environment Programme (UNEP), that: Requests the Executive Director, in consultation with Governments, to update the 2008 report entitled "Global Atmospheric Mercury Assessment: Sources, Emissions and Transport," for consideration by the Governing Council/Global Ministerial Environment Forum at its twenty-seventh session. The report provides the most recent information available on worldwide atmospheric mercury emissions, releases to the aquatic environment, and the transport and fate of mercury in the global environment. The report emphasizes emissions to air from human (anthropogenic) activities, but includes releases to water because the aquatic environment is the main route of exposure to humans and wildlife.]
[A large amount of coal is burned around the world to generate electricity, to run industrial plants, and for in-home heating and cooking. Coal burning emitted some 475 tonnes of mercury in 2010, the majority of which is from power generation and industrial use. The estimate of emissions from other coal burning (including domestic and residential burning) is lower than that reported in the previous global assessment, due to differences in estimates of the amounts and mercury content of coal burned in these uses. Use of coal for power generation and industry is increasing, especially in Asia. However, wider use of air pollution controls and more stringent regulations in several countries, together with improved combustion efficiency, have reduced emissions from coal-burning power plants, helping to offset most of the increase arising from higher coal consumption.]

Vinyard S, Randall L. 2011. Dirty Energy's Assault on our Health: Mercury. Environment America Research and Policy Center. Available at http://www.environmentamerica.org/sites/environment/files/reports/Mercury-Report.pdf.

Abstract: *No abstract available.*

Excerpt from Executive Summary:
[Our dependence on oil and coal-fired power plants has broad detrimental impacts on our health and our environment. Power plants represent America's single biggest source of air pollution, affecting our waterways, destroying ecosystems, and polluting the air we breathe. Pollution from coal-fired power plants in particular contributes to four of the five leading causes of mortality in the United States: heart disease, cancer, stroke, and chronic respiratory diseases. Dirty Energy's Assault on our Health is a series of reports examining the numerous threats that power plants pose to our environment and our health. Each segment in the series focuses on a different pollutant emitted by power plants. This report looks at the health and environmental impacts of mercury pollution from power plants.]

3.2 Sulphur dioxide and nitrogen oxides

3.2.1 SO2 and NOx - health effects

Amster ED, Haim M, Dubnov J, Broday DM. 2014. Contribution of nitrogen oxide and sulfur dioxide exposure from power plant emissions on respiratory symptom and disease prevalence. Environmental Pollution 186: 20-28.

Funding Agency: Council for International Exchange of Scholars Fulbright program (US-Israel Educational Foundation), Association of Towns for Environmental Protection (Israel), Ministry of Health and Ministry of Environmental Protection (Israel), Technion Center of Excellence in Exposure Science and Environmental Health	
Study Location: Israel	**Study Design:** Cross-sectional
Fuel Type: Coal	**Chemicals:** NOx, SO2

Abstract: This study investigates the association between exposure to ambient NOx and SO2 originating from power plant emissions and prevalence of obstructive pulmonary disease and related symptoms. The Orot Rabin coal-fired power plant is the largest power generating facility in the Eastern Mediterranean. Two novel methods assessing exposure to power plant-specific emissions were estimated for 2244 participants who completed the European Community Respiratory Health Survey. The "source approach" modeled emissions traced back to the power plant while the "event approach" identified peak exposures from power plant plume events. Respiratory symptoms, but not prevalence of asthma and COPD, were associated with estimates of power plant NOx emissions. The "source approach" yielded a better estimate of exposure to power plant emissions and showed a stronger dose-response relationship with outcomes. Calculating the portion of ambient pollution attributed to power plants emissions can be useful for air quality management purposes and targeted abatement programs.

Strengths and Limitations:

Strengths: Pollutant data from 20 monitoring stations and air dispersion modeling were used to estimate individual exposure level. Considered contribution of power plant and non-power plant sources to pollution levels. Controlled for potential confounders.
Limitations: Moderate participation rate of 69%. Health outcome self-reported. Potential reporting bias. The authors noted that there was minimal control for socio-economic variables due to incomplete data.

Study Score and Ranking:

0.83; High

Yogev-Baggio T, Bibi H, Dubnov J, Or-Hen K, Carel R, Portnov BA. 2010. Who is affected more by air pollution-sick or healthy? Some evidence from a health survey of schoolchildren living in the vicinity of a coal-fired power plant in Northern Israel. Health and Place 16(2): 399-408.

Funding Agency: Not stated	
Study Location: Israel	**Study Design:** Prospective cohort
Fuel Type: Coal	**Chemicals:** NOx, SO2

Abstract: Objective: To evaluate the effects of exposure to air pollution by NOx and SO2 on the development of pulmonary function of children, characterized by different health status. Methods: A cohort of 1181 schoolchildren from the 2nd to 5th grades, residing near a major coal-fired power plant in the Hadera district of Israel, were subdivided into three health status groups, according to the diagnosis given by a physician at the beginning of the study period in 1996: (a) healthy children; (b) children experiencing chest symptoms, and (c) children with asthma or spastic bronchitis. Pulmonary Function Tests (PFTs) were performed twice (in 1996 and 1999) and analyzed in conjunction with air pollution estimates at the children's places of residence and several potential confounders-height, age, gender, parental education, passive smoking, housing density, length of residence in the study area and proximity to the main road. Results: A significant negative association was found between changes in PFT results and individual exposure estimates to air pollution, controlled for socio-demographic characteristics of children and their living conditions. A sensitivity analysis revealed a decrease in the Forced Expiratory Volume during the First Second (FEV1) of about 19.6% for children with chest symptoms, 11.8% for healthy children, and approximately 7.9% for children diagnosed with asthma. Results of a sensitivity test for the Forced Vital Capacity (FVC) were found to be similar. Conclusion: Exposure to air pollution appeared to have had the greatest effect on children with chest symptoms. This phenomenon may be explained by the fact that this untreated symptomatic group might experience the most severe insult on their respiratory system as a result of exposure to ambient air pollution, which is reflected by a considerable reduction in their FEV1 and FVC. Since asthmatic children have lower baseline and slower growth rates, their PFT change may be affected less by exposure to air pollution, reflecting a well known relationship between pulmonary function change and height growth, according to which age-specific height is very similar for preadolescent children, but shifts upward with age during the growth spurt.

Strengths and Limitations:

Strengths: Subjects followed for 3 years. Pollutant data from 12 monitoring stations and air dispersion modeling were used to estimate exposure level at the home of each child. Objective outcome measure. Controlled for potential confounders.

Limitations: 21% of subjects lost to follow-up. Expected pulmonary function predicted from growth rate and accuracy may vary between subjects. Not known if the investigators performing the lung function tests were blinded to health status/exposure status.

Study Score and Ranking:

0.88; High

Garcia VC, Gego E, Lin S, Pantea C, Rappazzo K, Wootten A, Trivikrama Rao S. 2011. An evaluation of transported pollution and respiratory-related hospital admissions in the state of New York. Atmospheric Pollution Research 2(1): 9-15.

Funding Agency: Not stated (US EPA?)	
Study Location: New York	**Study Design:** Time-series
Fuel Type: N/A	**Chemicals:** NOx, O3

Abstract: Human exposure to air pollution transported from the Midwest is evaluated in eight New York State (NYS) regions over ten summers (1997 - 2006) for association with respiratory-related hospital admissions. Days when pollution is transported into the Northeastern United States (U.S.) were identified by using back-trajectories from the eight regions. These back-trajectories help identify predominant meteorological patterns associated with "polluted" air parcels (originating in the Midwest where power plant emissions are known to be relatively high) and "clean" air parcels (originating from the North where pollution is known to be relatively low). Ambient ozone concentrations measurements were used to validate the classification of "polluted" and "clean" air parcels. These classifications were then used to define the days of high- versus low-exposure for populations residing within each region. The results of this analysis indicate that the risk of being hospitalized for respiratory-related illness in NYS is greater on those days when air is transported from the Midwest as compared to days when air is transported from the North. Using a refined method to examine air parcels moving through a boundary drawn around high-emitting power plants in the Midwestern U.S. resulted in stronger associations across more regions (significant odds ratios ranging from 1.06 to 1.16 for the entire study time period for six of the eight NYS regions). An assessment of temperature and its impact on the odds ratio calculation in the New York City metropolitan region indicates that temperature alone does not explain the increased association between air pollution and respiratory-related hospital admissions.

Strengths and Limitations:

Strengths: Analyzed data over 10 summers, which included periods before and after implementation of a NOx regulation. Assessed 8 regions in the state. Used two different approaches to model pollution transport.
Limitations: Did not measure co-pollutants such as PM or SO2. Did not assess various time lags. The study focused on pollution transported from other areas, and results may have been influenced by local pollution. No individual data, however, the authors indicated that the influence of these factors was controlled by the design of the analysis.

Study Score and Ranking:

0.79; Moderate

Garcia VC, Gego E, Jones R, Lin S, Pantea CI, Rao ST, Wootten A. 2010. Examining the impact of regional-scale air quality regulations on human health outcomes. Proceedings of the 30th NATO/SPS International Technical Meeting on Air Pollution Modelling and Its Application, 545-548.

Funding Agency: Not stated	
Study Location: New York	**Study Design:** Time-series
Fuel Type: N/A	**Chemicals:** NOx, O3

Abstract: The NOx State Implementation Plan Call was issued by the U.S. Environmental Protection Agency to reduce the emissions of nitrogen oxides from the electric power sector to curtail the regional transport of the secondarily-formed pollutant, ozone. As emission control actions often come at a significant economic cost, it is important to understand whether such regulations have reduced air pollution and improved public health and the environment as originally anticipated. In this paper, we examine the relationships among meteorological transport patterns, ozone concentration levels and respiratory-related hospital admissions across New York State using trajectory analysis and other spatial and statistical approaches. Preliminary results from this analysis are presented in the paper.

Strengths and Limitations:

Strengths: Analyzed data over 8 summers, which included periods before and after implementation of a NOx regulation. Objective outcome measure.
Limitations: Minimal description of study methods. No individual data. Sample size not provided. Ambient pollutant levels not provided. Crude analysis only (did not control for confounding factors). Conference proceeding.

Study Score and Ranking:

0.33; Low

Lin S, Jones R, Pantea C, Garcia VC, Rao ST, Hwang SA, Kim N. 2010. Impact of the NOx SIP Call on respiratory hospitalizations in New York State. Proceedings of the 30th NATO/SPS International Technical Meeting on Air Pollution Modelling and Its Application, 549-552.

Funding Agency: Not stated	
Study Location: New York	**Study Design:** Time-series
Fuel Type: N/A	**Chemicals:** NOx, O3

Abstract: Asthma is a serious public health problem in New York State (NYS), affecting 8.4% (370,000) children and 7.6% (more than 1.1 million) adults. Asthma burden in New York's urban areas is consistently higher than the national average, with marked differences in prevalence and severity by socio-economic strata. Poor air quality from traffic pollution and other sources has consistently been linked to asthma morbidity. More specifically, nitrogen oxides, criteria pollutants which serve as a precurser to ozone, have been implicated as a player in respiratory irritation. This study investigated whether the U.S. Environmental Protection Agency-mandated NOx State Implementation Plan (NOx SIP) in NYS, aiming to reduce nitrogen oxide emissions from major sources during the summer months, had an impact on hospitalizations for asthma and other respiratory illnesses. More specifically, hospital admissions due to respiratory diseases (1997-2006) were compared during the period before the legislation, during the period of partial NOx SIP implementation, and post-implementation.

Strengths and Limitations:

Strengths: Analyzed data over 10 summers, which included periods before and after implementation of a NOx regulation. Objective outcome measure. Assessed 8 regions in the state.
Limitations: Limited individual data. Sample size not provided. Ambient pollutant levels not provided. Results not reported in detail. Conference proceeding.

Study Score and Ranking:

0.50; Low

Mohorovic L, Petrovic O, Haller H, Micovic V. 2010. Pregnancy loss and maternal methemoglobin levels: an indirect explanation of the association of environmental toxics and their adverse effects on the mother and the fetus. International Journal of Environmental Research and Public Health 7(12): 4203-4212.

Funding Agency: Not stated	
Study Location: Croatia	**Study Design:** Retrospective
Fuel Type: Coal	**Chemicals:** NOx, SO2

Abstract: The aim of this epidemiologic study was to point out a relationship between the exposure to products of coal combustion, and complications in pregnancy where one third of causes of stillbirth are still unknown. In the town of Labin (Croatia) a coal-powered thermoelectric power plant is the single major air polluter. We compared the records of miscarriages, premature births and stillbirths in two periods: the control and the exposure period. Data on reproductive loss was based on the records of pregnant women visiting for regular monthly pregnancy checkups. At the time of the epidemiological prospective study, 260 women (n = 138 in the clean period and n = 122 in the dirty period) were considered representative. The data were processed using Chi square and correlation tests. The frequencies of miscarriages and stillbirths were significantly lower in the control than in the exposure period ($p < 0.05$). Methemoglobinemia and stillbirths recorded over the "exposure" period are significantly higher than in the "control" period ($p = 0.0205$). The level of methemoglobin in the bloodstream is an worthy biomarker, predictor and precursor of environmental toxics' adverse effects on the mother and fetus, and can indirectly explain the unrecognized level of fetal methemoglobin. Methemoglobin and heme, having prooxidant properties, also cause the early and late endothelial dysfunction of vital organs. Despite our retrospective epidemiological study findings, we emphasize that the rate of reproductive loss represents a hypothetical risk, which needs to be confirmed with further fetal clinical and anatomopatholgical researches about the effects of methemoglobin catabolism products on the fetal CNS.

Strengths and Limitations:

Strengths: Use of maternal blood methemoglobin and sulfmethemoglobin as biomarkers of exposure; these levels correlated with ambient SO2 concentrations.
Limitations: Relatively small sample size. No information given regarding subjects (eg. age, socioeconomic factors). Did not control for potential confounders. Control and exposure periods were in different seasons.

Study Score and Ranking:

0.42; Low

3.2.2 SO2 and NOx - measured emissions (flue gas or ambient air)

White literature

Brown SS, Dube WP, Karamchandani P, Yarwood G, Peischl J, Ryerson TB et al. 2012. Effects of NOx control and plume mixing on nighttime chemical processing of plumes from coal-fired power plants. Journal of Geophysical Research-Atmospheres 117, D7.

Abstract: Coal-fired electric power plants produce a large fraction of total U. S. NOx emissions, but NOx from this sector has been declining in the last decade owing to installation of control technology. Nighttime aircraft intercepts of plumes from two different Texas power plants (Oklaunion near Wichita Falls and W. A. Parish near Houston) with different control technologies demonstrate the effect of these reductions on nighttime NOx oxidation rates. The analysis shows that the spatial extent of nighttime-emitted plumes to be quite limited and that mixing of highly concentrated plume NOx with ambient ozone is a determining factor for its nighttime oxidation. The plume from the uncontrolled plant had full titration of ozone through 74 km/2.4 h of downwind transport that suppressed nighttime oxidation of NO2 to higher oxides of nitrogen across the majority of the plume. The plume from the controlled plant did not have sufficient NOx to titrate background ozone, which led to rapid nighttime oxidation of NO2 during downwind transport. A plume model that includes horizontal mixing and nighttime chemistry reproduces the observed structures of the nitrogen species in the plumes from the two plants. The model shows that NOx controls not only reduce the emissions directly but also lead to an additional overnight NOx loss of 36-44% on average. The maximum reduction for 12 h of transport in darkness was 73%. The results imply that power plant NOx emissions controls may produce a larger than linear reduction in next-day, downwind ozone production following nighttime transport.

Dresser AL, Huizer RD. 2011. CALPUFF and AERMOD model validation study in the near field: Martins Creek revisited. Journal of the Air and Waste Management Association 61(6): 647-59.

Abstract: This paper describes a near-field validation study involving the steady-state, U.S. Environmental Protection Agency (EPA) guideline model AERMOD and the nonsteady-state puff model CALPUFF. Relative model performance is compared with field measurements collected near Martins Creek, PA-a rural, hilly area along the Pennsylvania-New Jersey border. The principal emission sources in the study were two coal-fired power plants with tall stacks and buoyant plumes. Over 1 yr of sulfur dioxide measurements were collected at eight monitors located at or above the two power plants' stack tops. Concurrent meteorological data were available at two sites. Both sites collected data 10 m above the ground. One of the sites also collected sonic detection and ranging measurements up to 420 m above ground. The ability of the two models to predict monitored sulfur dioxide concentrations was assessed in a four-part model validation. Each part of the validation applied different criteria and statistics to provide a comprehensive evaluation of model performance. Because of their importance in regulatory applications, an emphasis was placed on statistics that demonstrate the model's ability to reproduce the upper end of the concentration distribution. On the basis of the combined results of the four-part validation (i.e., weight of evidence), the performance of CALPUFF was judged to be superior to that of AERMOD.

Duncan BN, Yoshida Y, de Foy B, Lamsal LN, Streets DG, Lu Z et al. 2013. The observed response of Ozone Monitoring Instrument (OMI) NO2 columns to NOx emission controls on power plants in the United States: 2005-2011. Atmospheric Environment 81: 102-11.

Abstract: We show that Aura Ozone Monitoring Instrument (OMI) nitrogen dioxide (NO2) tropospheric column data may be used to assess changes of the emissions of nitrogen oxides (NOx) from power plants in the United States, though careful interpretation of the data is necessary. There is a clear response for OMI NO2 data to NOx emission reductions from power plants associated with the implementation of mandated emission control devices (ECDs) over the OMI record (2005–2011). This response is scalar for all intents and purposes, whether the reduction is rapid or incremental over several years. However, it is variable among the power plants, even for those with the greatest absolute decrease in emissions. We document the primary causes of this variability, presenting case examples for specific power plants.

Felix JD, Elliott EM, Shaw SL. 2012. Nitrogen isotopic composition of coal-fired power plant NOx: influence of emission controls and implications for global emission inventories. Environmental Science and Technology 46(6): 3528-35.

Abstract: Despite the potential use of delta(15)N as a tracer of NOx source contributions, prior documentation of delta(15)N of various NOx emission sources is exceedingly limited. This manuscript presents the first measurements of the nitrogen isotopic composition of NOx (delta(15)N-NOx) emitted from coal-fired power plants in the U.S. at typical operating conditions with and without the presence of selective catalytic reduction (SCR) and selective noncatalytic reduction (SNCR) technology. To accomplish this, a novel method for collection and isotopic analysis of coal-fired stack NOx emission samples was developed based on modifications of a historic U.S. EPA stack sampling method. At the power plants included in this study, large differences exist in the isotopic composition of NOx emitted with and without SCRs and SNCRs; further the isotopic composition of power plant NOx is higher than that of other measured NOx emission sources confirming its use as an environmental tracer. These findings indicate that gradual implementation of SCRs at power plants will result in an industry-wide increase in delta(15)N values of NOx and NOy oxidation products from this emission source.

Fioletov VE, McLinden CA, Krotkov N, Moran MD, Yang K. 2011. Estimation of SO2 emissions using OMI retrievals. Geophysical Research Letters 38: 21.

Abstract: Satellite sulfur dioxide (SO2) measurements from the Ozone Monitoring Instrument (OMI) satellite sensor, averaged over a period of several years, were compared with emissions inventories for major US sources. Low- and high-spatial frequency filtration was applied to OMI data to reduce the noise and bias to enhance and reveal weak SO2 signals that are otherwise not readily apparent. Averaging a large number of individual observations enables the study of SO2 spatial distributions near larger SO2 emissions sources with an effective resolution superior to that of an individual OMI observation and even to obtain rough estimates of the emissions level from those sources. It is demonstrated that individual sources (or multiple sources within 50 km) with annual SO2 emissions greater than about 70 kT y(-1) produce a statistically significant signal in 3-year averaged OMI data. A correlation of 0.93 was found between OMI SO2 integrated around the source and the annual SO2 emission rate for the sources greater than 70 kT y(-1). OMI SO2 data also indicate a 40% decline in SO2 values over the largest US coal power plants between 2005-2007 and 2008-2010, a value that is consistent with the reported 46% reduction in annual emissions due to the implementation of new SO2 pollution control measures over this period.

Ghude SD, Fadnavis S, Beig G, Polade SD, van der A RJ. 2008. Detection of surface emission hot spots, trends, and seasonal cycle from satellite-retrieved NO2 over India. Journal of Geophysical Research-Atmospheres 113, D20, D20305.

Abstract: Tropospheric NO2 concentrations derived from spaceborne measurements of Global Ozone Monitoring Experiment (GOME) on board ERS 2 and Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY) on board Envisat, respectively, for the time period of 1996-2006 have been used to identify major NO2 emission hot spots, trends, and seasonal cycle over different regions of India. Emission hot spots are observed over the locations of thermal power plants and over major urban and industrial regions. A multifunctional regression model has been used to analyze the trends and seasonal cycle over these emission hot spots. Increasing trends of similar to 1.65 +/- 0.52% a(-1) have been observed for NO2 over India. The fast growing industrial regions of Mumbai and Delhi show increasing trends of similar to 2.1 +/- 1.1 and similar to 2.4 +/- 1.2% a(-1), respectively. Seasonal variations of tropospheric NO2 concentrations show a maximum during winter-summer (December-May) and a minimum during the monsoon seasons (June-September). The observed seasonal cycle in satellite-derived NO2 agrees well with the surface-level observations of NOx.

Ghude SD, Kulkarni SH, Jena C, Pfister GG, Beig G, Fadnavis S et al. 2013. Application of satellite observations for identifying regions of dominant sources of nitrogen oxides over the indian subcontinent. Journal of Geophysical Research D: Atmospheres 118(2): 1075-89.

Abstract: We used SCIAMACHY (10:00 LT) and OMI (13:30 LT) tropospheric NO2 columns to study diurnal and seasonal patterns in NO2 concentrations over India. Using characteristics of seasonal variability in tropospheric NO2 columns, we present a simple methodology to identify the dominant NOx source category for specific regions in India. Regions where the dominant source category is classified as biomass burning are found generally to agree with the ATSR fire count distribution. Relating OMI NO2 columns to surface NOx emission, we find that biomass burning emission account for an average flux of 1.55×10^{11} molecules cm^{-2} s^{-1} during the peak burning period. Furthermore, extrapolating this estimated flux to the total burned area for the year 2005, biomass burning is estimated to account for 72 Gg of N emissions. Additional analysis of fire events in Northeast India shows a marked increase in TES retrieved O3 concentrations, suggesting significant photochemical ozone formation during the peak biomass burning period. Regions where the dominant source type was categorized as anthropogenic are in good agreement with the distribution of major industrial regions and urban centers in India. Tropospheric NO2 columns over these anthropogenic source regions increased by 3.8% per year between 2003 and 2011, which is consistent with the growth in oil and coal consumption in India. The OMI-derived surface NO2 mixing ratios are indirectly validated with the surface in situ measurements (correlation r = 0.85, n = 88) obtained from the air quality monitoring network in Delhi during August 2010 to January 2011. Most of the OMI-derived surface NO2 values agree with surface-based measurements, supporting the direct utility of OMI observation for emission estimates. Finally, we use OMI NO2 columns to estimate NOx emissions for selected large cites and major thermal power plants in India and compare these estimates with the INTEX-B and EDGAR emission inventory. We find that, for a few locations, OMI-derived emission show fair agreement; however, for many locations, NOx emissions differ from INTEX-B and EDGAR inventories.

Gu D, Wang Y, Smeltzer C, Liu Z. 2013. Reduction in NO(x) emission trends over China: regional and seasonal variations. Environmental Science and Technology 47(22): 12912-9.

Abstract: We analyzed satellite observations of nitrogen dioxide (NO2) columns by the Ozone Monitoring Instrument (OMI) over China from 2005 to 2010 in order to estimate the top-down anthropogenic nitrogen oxides (NOx) emission trends. Since NOx emissions were affected by the economic slowdown in 2009, we removed one year of abnormal data in the analysis. The estimated average emission trend is 4.01 +/- 1.39% yr(-1), which is slower than the trend of 5.8-10.8% yr(-1) reported for previous years. We find large regional, seasonal, and urban-rural variations in emission trends. The average NOx emission trend of 3.47 +/- 1.07% yr(-1) in warm season (June-September) is less than the trend of 5.03 +/- 1.92% yr(-1) in cool season (October-May). The regional annual emission trends decrease from 4.76 +/- 1.61% yr(-1) in North China Plain to 3.11 +/- 0.98% yr(-1) in Yangtze River Delta and further down to -4.39 +/- 1.81% yr(-1) in Pearl River Delta. The annual emission trends of the four largest megacities, Shanghai, Beijing, Guangzhou, and Shenzhen are -0.76 +/- 0.29%, 0.69 +/- 0.27%, -4.46 +/- 1.22%, and -7.18 +/- 2.88% yr(-1), considerably lower than the regional averages or surrounding rural regions. These results appear to suggest that a number of factors, including emission control measures of thermal power plants, increased hydro-power usage, vehicle emission regulations, and closure or migration of high-emission industries, have significantly reduced or even reversed the increasing trend of NOx emissions in more economically developed megacities and southern coastal regions, but their effects are not as significant in other major cities or less economically developed regions.

Halla JD, Wagner T, Beirle S, Brook JR, Hayden KL, O'Brien JM, et al. 2011. Determination of tropospheric vertical columns of NO2 and aerosol optical properties in a rural setting using MAX-DOAS. Atmospheric Chemistry and Physics 11: 12475-98.

Abstract: Multi-AXis Differential Optical Absorption Spectroscopy (MAX-DOAS) measurements were performed in a rural location of southwestern Ontario during the Border Air Quality and Meteorology Study. Slant column densities (SCDs) of NO2 and O4 were determined using the standard DOAS technique. Using a radiative transfer model and the O4 SCDs, aerosol optical depths were determined for clear sky conditions

and compared to OMI, MODIS, AERONET, and local PM2.5 measurements. This aerosol information was input to a radiative transfer model to calculate NO2 air mass factors, which were fit to the measured NO2 SCDs to determine tropospheric vertical column densities (VCDs) of NO2. The method of determining NO2 VCDs in this way was validated for the first time by comparison to composite VCDs derived from aircraft and ground-based measurements of NO2. The new VCDs were compared to VCDs of NO2 determined via retrievals from the satellite instruments SCIAMACHY and OMI, for overlapping time periods. The satellite-derived VCDs were higher, with a mean bias of $+0.5–0.9\times10^{15}$ molec cm−2. This last finding is different from previous studies whereby MAX-DOAS geometric VCDs were higher than satellite determinations, albeit for urban areas with higher VCDs. An effective boundary layer height, BLHeff, is defined as the ratio of the tropospheric VCD and the ground level concentration of NO2. Variations of BLHeff can be linked to time of day, source region, stability of the atmosphere, and the presence or absence of elevated NOx sources. In particular, a case study is shown where a high VCD and BLHeff were observed when an elevated industrial plume of NOx and SO2 was fumigated to the surface as a lake breeze impacted the measurement site. High BLHeff values (~1.9 km) were observed during a regional smog event when high winds from the SW and high convection promoted mixing throughout the boundary layer. During this event, the regional line flux of NO2 through the region was estimated to be greater than 112 kg NO2 km−1 h−1.

Hart JE, Yanosky JD, Puett RC, Ryan L, Dockery DW, Smith TJ et al. 2009. Spatial modeling of PM10 and NO2 in the continental United States, 1985-2000. Environmental health perspectives 117(11): 1690-6.

Abstract: Background: Epidemiologic studies of air pollution have demonstrated a link between long-term air pollution exposures and mortality. However, many have been limited to city-specific average pollution measures or spatial or land-use regression exposure models in small geographic areas. Objectives: Our objective was to develop nationwide models of annual exposure to particulate matter < 10 μm in diameter (PM10) and nitrogen dioxide during 1985–2000. Methods: We used generalized additive models (GAMs) to predict annual levels of the pollutants using smooth spatial surfaces of available monitoring data and geographic information system–derived covariates. Model performance was determined using a cross-validation (CV) procedure with 10% of the data. We also compared the results of these models with a commonly used spatial interpolation, inverse distance weighting. Results: For PM10, distance to road, elevation, proportion of low-intensity residential, high-intensity residential, and industrial, commercial, or transportation land use within 1 km were all statistically significant predictors of measured PM10 (model R2 = 0.49, CV R2 = 0.55). Distance to road, population density, elevation, land use, and distance to and emissions of the nearest nitrogen oxides–emitting power plant were all statistically significant predictors of measured NO2 (model R2 = 0.88, CV R2 = 0.90). The GAMs performed better overall than the inverse distance models, with higher CV R2 and higher precision. Conclusions: These models provide reasonably accurate and unbiased estimates of annual exposures for PM10 and NO2. This approach provides the spatial and temporal variability necessary to describe exposure in studies assessing the health effects of chronic air pollution.

Huang YK, Luvsan ME, Gombojav E, Ochir C, Bulgan J, Chan CC. 2013. Land use patterns and SO2 and NO2 pollution in Ulaanbaatar, Mongolia. Environmental research 124: 1-6.

Abstract: We proposed to study spatial distribution and source contribution of SO2 and NO2 pollution in Ulaanbaatar, Mongolia. We collected 2-week ambient SO2 and NO2 concentration samples at 38 sites, which were classified by major sources of air pollution such as *ger* areas and/or major roads, in three seasons as warm (September, 2011), cold (November-December, 2011), and moderate (March, 2012) in Ulaanbaatar. The SO2 and NO2 concentrations were collected by Ogawa ambient air passive samplers and analyzed by ion chromatography and spectrophotometry methods, respectively. Stepwise regression models were used to estimate the contribution of emission proxies, such as the distance to major roads, *ger* areas, power plants, and city center, to the ambient concentrations of SO2 and NO2. We found that the SO2 and NO2 concentrations were significantly higher in the cold season than in the warm and moderate seasons at all 38 ambient sampling sites. The SO2 concentrations in 20 *ger* sites (46.60 ppb in the cold season and 17.82 ppb in the moderate season) were significantly higher than in 18 non-*ger* sites (23.35 ppb in the cold season and 12.53 ppb in the

moderate season). The NO2 concentrations at 19 traffic/road sites (12.85 ppb in the warm season and 20.48 ppb in the moderate season) were significantly higher than those at 19 urban sites (7.60 ppb and 14.39 ppb in the moderate season). Multiple regression models show that SO2 concentrations decreased by 23% in the cold and 17% in the moderate seasons at 0.70 km from the *ger* areas, an average of all sampling sites, and by 29% in the moderate season at 4.83 km from the city center, an average of all sampling sites. Multiple regression models show that the NO2 concentrations at 4.83 km from the city center decreased by 38% in the warm and 29% in the moderate seasons. Our models also report that NO2 concentrations at 0.16 km from the main roads decreased by 15% and 9% in the warm and the moderate seasons, respectively, and by 16% in the cold season decreased at the location 0.70 km from the *ger* area. The NO2 concentration at the location 4.83 km from the city center was decreased by 18% and at the location 4.79 km from the power plants by 21%. Our study concludes that SO2 and NO2 concentrations are very high in Ulaanbaatar, especially in the winter, and can be explained by several land use variables, including the distance to the *ger* areas, the city center, the main roads, and the power plants.

Kaldellis JK, Kapsali M, Emmanouilidis M. 2012. Long-term evaluation of nitrogen oxides and sulphur dioxide emissions from the Greek lignite-based electricity generation sector. Fresenius Environmental Bulletin 21: 2676-88.

Abstract: The Greek electricity generation system is mainly based on the operation of Lignite Thermal Power Stations (LTPSs). In this context, although electricity production from natural gas and renewable forms of energy has increased during recent years in Greece, dominant role of LTPSs is not expected to change dramatically in the near future. As a result, owed to the use of local lignite reserves (poor quality lignite), the Greek LTPSs are responsible for the production of significant flue gas emission quantities. Considering the above, this work is focused on investigating the corresponding long-term NOX and SO2 emissions due to lignite combustion (time period 1995-2008). At this point, it should be noted that although the 5.3GW installed capacity of the lignite-fired power plants represent roughly 40% of the national installed capacity, they are responsible for the noteworthy amounts of 60% and 15% of SO2 and NOX national emissions, respectively. To this end, estimation of SO2 and NOX emission factors is currently undertaken for each Greek LTPS, using available long-term official data. Subsequently, the estimated emission factors are used to classify the Greek LTPSs and evaluate their long-term environmental performance in relation with specific flue gas emissions. According to the results obtained, a clear decreasing rate of flue gases' emissions (especially of NOX) is not the case during the time period analyzed, underlining the necessity for the implementation of effective abatement techniques in the next few years, in compliance with the country's commitments -as an EU Member State-under the corresponding environmental legislation.

Kim SW, Heckel A, Frost GJ, Richter A, Gleason J, Burrows JP et al. 2009. NO2 columns in the western U.S. observed from space and simulated by a regional chemistry model and their implications in NOx emissions. Journal of Geophysical Research-Atmospheres D11: D11301.

Abstract: In the western U.S., there are many isolated sources of NOx emissions such as power plants, cities, and highways. Thus, errors in bottom-up NOx emissions from various sectors could be evaluated separately with satellites and atmospheric chemistry models in this part of the U.S. We carried out simulations with the Weather Research and Forecasting-Chemistry model (WRF-Chem) for the western US domain during the summer of 2005. Model NO2 columns are compared with SCIAMACHY and OMI satellite observations. The sensitivities of simulated NO2 columns to chemical mechanism and scalar-advection scheme along with the sensitivities of satellite retrievals to several assumptions are examined. Agreement between the satellite data and the model results will be summarized for each type of source.

Lee CJ, Brook JR, Evans GJ, Martin RV, Mihele C. 2011. Novel application of satellite and in-situ measurements to map surface-level NO2 in the Great Lakes region. Atmospheric Chemistry and Physics 11: 11761–75.

Abstract: Ozone Monitoring Instrument (OMI) tropospheric NO2 vertical column density data were used in conjunction with in-situ NO2 concentrations collected by permanently installed monitoring stations to infer 24 h surface-level NO2 concentrations at 0.1° (~11 km) resolution. The region examined included rural and

suburban areas, and the highly industrialised area of Windsor, Ontario, which is situated directly across the US-Canada border from Detroit, MI. Photolytic NO2 monitors were collocated with standard NO2 monitors to provide qualitative data regarding NOz interference during the campaign. The accuracy of the OMI-inferred concentrations was tested using two-week integrative NO2 measurements collected with passive monitors at 18 locations, approximating a 15 km grid across the region, for 7 consecutive two-week periods. When compared with these passive results, satellite-inferred concentrations showed an 18% positive bias. The correlation of the passive monitor and OMI-inferred concentrations (R=0.69, n=115) was stronger than that for the passive monitor concentrations and OMI column densities (R=0.52), indicating that using a sparse network of monitoring sites to estimate concentrations improves the direct utility of the OMI observations. OMI-inferred concentrations were then calculated for four years to show an overall declining trend in surface NO2 concentrations in the region. Additionally, by separating OMI-inferred surface concentrations by wind direction, clear patterns in emissions and affected down-wind regions, in particular around the US-Canada border, were revealed.

Lee H, Kim YJ, Jung J, Lee C, Heue KP, Platt U et al. 2009a. Spatial and temporal variations in NO2 distributions over Beijing, China measured by imaging differential optical absorption spectroscopy. Journal of Environmental Management 90(5): 1814-23.

Abstract: During the CAREBEIJING campaign in 2006, imaging differential optical absorption spectroscopy (I-DOAS) measurements were made from 08:00 to 16:00 on September 9 and 10 over Beijing, China. Detailed images of the near-surface NO2 differential slant column density (DSCD) distribution over Beijing were obtained. Images with less than a 30-min temporal resolution showed both horizontal and vertical variations in NO2 distributions. For DSCD to mixing ratio conversion, path length along the lines of I-DOAS lines of sight was estimated using the light-extinction coefficient and Ångstrom exponent data obtained by a transmissometer and a sunphotometer, respectively. Mixing ratios measured by an in-situ NO2 analyzer were compared with those estimated by the I-DOAS instrument. The obtained temporal and spatial variations in NO2 distributions measured by I-DOAS for the two days are interpreted with consideration of the locations of the major NOx sources and local wind conditions. I-DOAS measurements have been applied in this study for estimating NO2 distribution over an urban area with multiple and distributed emission sources. Results are obtained for estimated temporal and spatial NO2 distributions over the urban atmosphere; demonstrating the capability of the I-DOAS technique. We discuss in this paper the use of I-DOAS measurements to estimate the NO2 distribution over an urban area with multiple distributed emission sources.

Lee H, Kim YJ, Lee C. 2009b. Estimation of the rate of increase in nitrogen dioxide concentrations from power plant stacks using an imaging-DOAS. Environmental Monitoring and Assessment 152(1-4): 61-70.

Abstract: The emission of nitrogen compounds from power plants accounts for a significant proportion of the total emissions of nitrogen to the atmosphere. This study seeks to understand the nature of chemical reactions in the atmosphere involving nitrogen, which is important in undertaking quantitative assessments of the contribution of such reactions to local and regional air pollution. The slant column density (SCD) of power-plant-generated NO(2) was derived using imaging differential optical absorption spectroscopy (I-DOAS) with scattered sunlight as a light source. The vertical structure of NO(2) SCD from power plant stacks was simultaneously probed using a pushbroom sensor. Measured SCDs were converted to mixing ratios in calculating the rate of NO(2) increase at the center of the plume. This study presents quantitative measurements of the rate of NO(2) increase in a rising plume. An understanding of the rate of NO(2) increase is important because SO(2) and NO(x) compete for the same oxidizing radicals, and the amount of NO(x) is related to the rates of SO(2) oxidation and sulfate formation. This study is the first to directly obtain the rate of NO(2) increase in power plant plumes using the I-DOAS technique. NO(2) increase rates of 60 and 70 ppb s(-1) were observed at distances of about 45 m from the two stacks of the Pyeongtaek Power Plant, northwest South Korea.

Levy I, Makar PA, Sills D, Zhang J, Hayden KL, Mihele C, et al. 2010. Unraveling the complex local-scale flows influencing ozone patterns in the southern Great Lakes of North America. Atmospheric Chemistry and Physics 10: 10895–915.

Abstract: This study examines the complexity of various processes influencing summertime ozone levels in the southern Great Lakes region of North America. Results from the Border Air Quality and Meteorology (BAQS-Met) field campaign in the summer of 2007 are examined with respect to land-lake differences and local meteorology using a large array of ground-based measurements, aircraft data, and simulation results from a high resolution (2.5 km) regional air-quality model, AURAMS. Analyses of average ozone mixing ratio from the entire BAQS-Met intensive campaign period support previous findings that ozone levels are higher over the southern Great Lakes than over the adjacent land. However, there is great heterogeneity in the spatial distribution of surface ozone over the lakes, particularly over Lake Erie during the day, with higher levels located over the southwestern end of the lake. Model results suggest that some of these increased ozone levels are due to local emission sources in large nearby urban centers. While an ozone reservoir layer is predicted by the AURAMS model over Lake Erie at night, the land-lake differences in ozone mixing ratios are most pronounced during the night in a shallow inversion layer of about 200 m above the surface. After sunrise, these differences have a limited effect on the total mass of ozone over the lakes and land during the day, though they do cause elevated ozone levels in the lake-breeze air in some locations. The model also predicts a mean vertical circulation during the day with an updraft over Detroit-Windsor and downdraft over Lake St. Clair, which transports ozone up to 1500 m above ground and results in high ozone over the lake. Oscillations in ground-level ozone mixing ratios were observed on several nights and at several ground monitoring sites, with amplitudes of up to 40 ppbv and time periods of 15–40 min. Several possible mechanisms for these oscillations are discussed, but a complete understanding of their causes is not possible given current data and knowledge.

Li C, Zhang Q, Krotkov NA, Streets DG, He K, Tsay SC et al. 2010. Recent large reduction in sulfur dioxide emissions from Chinese power plants observed by the Ozone Monitoring Instrument. Geophysical Research Letters 37: 8.

Abstract: The Ozone Monitoring Instrument (OMI) aboard NASA's Aura satellite observed substantial increases in total column SO2 and tropospheric column NO2 from 2005 to 2007, over several areas in northern China where large coal-fired power plants were built during this period. The OMI-observed SO2/NO2 ratio is consistent with the SO2/NOx emissions estimated from a bottom-up approach. In 2008 over the same areas, OMI detected little change in NO2, suggesting steady electricity output from the power plants. However, dramatic reductions of SO2 emissions were observed by OMI at the same time. These reductions confirm the effectiveness of the flue-gas desulfurization (FGD) devices in reducing SO2 emissions, which likely became operational between 2007 and 2008. This study further demonstrates that the satellite sensors can monitor and characterize anthropogenic emissions from large point sources.

Lin JT, McElroy MB. 2011. Detection from space of a reduction in anthropogenic emissions of nitrogen oxides during the Chinese economic downturn. Atmospheric Chemistry and Physics 11: 8171-88.

Abstract: Rapid economic and industrial development in China and relatively weak emission controls have resulted in significant increases in emissions of nitrogen oxides (NOx) in recent years, with the exception of late 2008 to mid 2009 when the economic downturn led to emission reductions detectable from space. Here vertical column densities (VCDs) of tropospheric NO2 retrieved from satellite observations by SCIAMACHY, GOME-2 and OMI (both by KNMI and by NASA) are used to evaluate changes in emissions of NOx from October 2004 to February 2010 identifying impacts of the economic downturn. Data over polluted regions of Northern East China suggest an increase of 27–33 % in 12-month mean VCD of NO2 prior to the downturn, consistent with an increase of 49 % in thermal power generation (TPG) reflecting the economic growth. More detailed analysis is used to quantify changes in emissions of NOx in January over the period 2005–2010 when the effect of the downturn was most evident. The GEOS-Chem model is employed to evaluate the effect of changes in chemistry and meteorology on VCD of NO2. This analysis indicates that emissions decreased by 20 % from January 2008 to January 2009, close to the reduction of 18 % in TPG that

occurred over the same interval. A combination of three independent approaches indicates that the economic downturn was responsible for a reduction in emissions by 9–11 % in January 2009 with an additional decrease of 10 % attributed to the slow-down in industrial activity associated with the coincident celebration of the Chinese New Year; errors in the estimate are most likely less than 3.4 %.

Lu Z, Streets DG. 2012. Increase in NOx emissions from Indian thermal power plants during 1996-2010: unit-based inventories and multisatellite observations. Environmental Science and Technology 46(14): 7463-70.

Abstract: Driven by rapid economic development and growing electricity demand, NOx emissions (E) from the power sector in India have increased dramatically since the mid-1990s. In this study, we present the NOx emissions from Indian public thermal power plants for the period 1996-2010 using a unit-based methodology and compare the emission estimates with the satellite observations of NO2 tropospheric vertical column densities (TVCDs) from four spaceborne instruments: GOME, SCIAMACHY, OMI, and GOME-2. Results show that NOx emissions from Indian power plants increased by at least 70% during 1996-2010. Coal-fired power plants, NOx emissions from which are not regulated in India, contribute approximately 96% to the total power sector emissions, followed by gas-fired (approximately 4%) and oil-fired (<1%) ones. A number of isolated NO2 hot spots are observed over the power plant areas, and good agreement between NO2 TVCDs and NOx emissions is found for areas dominated by power plant emissions. Average NO2 TVCDs over power plant areas were continuously increasing during the study period. We find that the ratio of ΔE/E to ΔTVCD/TVCD changed from greater than one to less than one around 2005-2008, implying that a transition of the overall NOx chemistry occurred over the power plant areas, which may cause significant impact on the atmospheric environment.

Lu Z, Streets DG, de Foy B, Krotkov NA. 2013. Ozone monitoring instrument observations of interannual increases in SO2 emissions from Indian coal-fired power plants during 2005-2012. Environmental Science and Technology 47(24): 13993-4000.

Abstract: Due to the rapid growth of electricity demand and the absence of regulations, sulfur dioxide (SO2) emissions from coal-fired power plants in India have increased notably in the past decade. In this study, we present the first interannual comparison of SO2 emissions and the satellite SO2 observations from the Ozone Monitoring Instrument (OMI) for Indian coal-fired power plants during the OMI era of 2005-2012. A detailed unit-based inventory is developed for the Indian coal-fired power sector, and results show that its SO2 emissions increased dramatically by 71% during 2005-2012. Using the oversampling technique, yearly high-resolution OMI maps for the whole domain of India are created, and they reveal a continuous increase in SO2 columns over India. Power plant regions with annual SO2 emissions greater than 50 Gg year(-1) produce statistically significant OMI signals, and a high correlation (R = 0.93) is found between SO2 emissions and OMI-observed SO2 burdens. Contrary to the decreasing trend of national mean SO2 concentrations reported by the Indian Government, both the total OMI-observed SO2 and annual average SO2 concentrations in coal-fired power plant regions increased by >60% during 2005-2012, implying the air quality monitoring network needs to be optimized to reflect the true SO2 situation in India.

Pouliot G, Wisner E, Mobley D, Hunt Jr. W. 2012. Quantification of emission factor uncertainty. Journal of the Air and Waste Management Association 62(3): 287-98.

Abstract: Emissions factors are important for estimating and characterizing emissions from sources of air pollution. There is no quantitative indication of uncertainty for these emission factors, most factors do not have an adequate data set to compute uncertainty, and it is very difficult to locate the data for those that do. The objectives are to compare the current emission factors of Electric Generating Unit NOX sources with currently available continuous emission monitoring data, develop quantitative uncertainty indicators for the Environmental Protection Agency (EPA) data quality rated emission factors, and determine the possible ranges of uncertainty associated with EPA's data quality rating of emission factors. EPA's data letter rating represents a general indication of the robustness of the emission factor and is assigned based on the estimated reliability of the tests used to develop the factor and on the quantity and representativeness of the data. Different sources and pollutants that have the same robustness in the measured emission factor and in the

representativeness of the measured values are assumed to have a similar quantifiable uncertainty. For the purposes of comparison, we assume that the emission factor estimates from source categories with the same letter rating have enough robustness and consistency that we can quantify the uncertainty of these common emission factors based on the qualitative indication of data quality which is known for almost all factors. The results showed that EPA's current emission factor values for NOX emissions from combustion sources were found to be reasonably representative for some sources; however, AP-42 values should be updated for over half of the sources to reflect current data. The quantified uncertainty ranges were found to be 25-62% for A rated emission factors, 45-75% for B rated emission factors, 60-82% for C rated emission factors, and 69-86% for D rated emission factors, and 82-92% for E rated emission factors. Implications: Currently, a letter grade indicates the data quality uncertainty of emission factors in EPA's Compilation of Emission Factors (AP-42). However, a quantitative characterization would be much preferred. If the uncertainty of emission factors is quantified, scientists may be able to more accurately characterize the uncertainty associated with air quality modeling and emission data. A quantitative measure of uncertainty will also give decision makers the ability to determine the confidence that should be placed in the analysis of the data being used for policy decisions.

Prasad AK, Singh RP, Kafatos M. 2012. Influence of coal-based thermal power plants on the spatial-temporal variability of tropospheric NO2 column over India. Environmental Monitoring and Assessment 184(4): 1891-907.

Abstract: The oxides of nitrogen--NO(x) (NO and NO(2))--are an important constituent of the troposphere. The availability of relatively higher spatial (0.25 degrees grid) and temporal (daily) resolution data from ozone monitoring instrument (OMI) onboard Aura helps us to better differentiate between the point sources such as thermal power plants from large cities and rural areas compared to previous sensors. The annual and seasonal (summer and winter) distributions shows very high mean tropospheric NO(2) in specific pockets over India especially over the Indo-Gangetic plains (up to 14.2 x 10(15) molecules/cm(2)). These pockets correspond with the known locations of major thermal power plants. The tropospheric NO(2) over India show a large seasonal variability that is also observed in the ground NO(2) data. The multiple regression analysis show that the influence of a unit of power plant (in gigawatts) over tropospheric NO(2) (x10(15) molecules/cm(2)) is around ten times compared to a unit of population (in millions) over India. The OMI data show that the NO(2) increases by 0.794 +/- 0.12 (x10(15) molecules/cm(2); annual) per GW compared to a previous estimate of 0.014 (x10(15) molecules/cm(2)) over India. The increase of tropospheric NO(2) per gigawatt is found to be 1.088 +/- 0.18, 0.898 +/- 0.14, and 0.395 +/- 0.13 (x10(15) molecules/cm(2)) during winter, summer, and monsoon seasons, respectively. The strong seasonal variation is attributed to the enhancement or suppression of NO(2) due to various controlling factors which is discussed here. The recent increasing trend (2005-2007) over rural thermal power plants pockets like Agori and Korba is due to recent large capacity additions in these regions.

Rivera C, Sosa G, Wöhrnschimmel H, de Foy B, Johansson M, Galle B. 2009. Tula industrial complex (Mexico) emissions of SO2 and NO2 during the MCMA 2006 field campaign using a mobile mini-DOAS system. Atmospheric Chemistry and Physics 9: 6351-61.

Abstract: The Mexico City Metropolitan Area (MCMA) has presented severe pollution problems for many years. There are several point and mobile emission sources inside and outside the MCMA which are known to affect air quality in the area. In particular, speculation has risen as to whether the Tula industrial complex, located 60 km northwest of the MCMA has any influence on high SO2 levels occurring on the northern part of the city, in the winter season mainly. As part of the MILAGRO Field Campaign, from 24 March to 17 April 2006, the differential vertical columns of sulfur dioxide (SO2) and nitrogen dioxide (NO2) were measured during plume transects in the neighborhood of the Tula industrial complex using mobile mini-DOAS instruments. Vertical profiles of wind speed and direction obtained from pilot balloons and radiosondes were used to calculate SO2 and NO2 emissions. According to our measurements, calculated average emissions of SO2 and NO2 during the field campaign were 384±103 and 24±7 tons day−1, respectively. The standard deviation of these estimations is due to actual variations in the observed emissions from the refinery and power plant, as well as to the uncertainty in the wind fields at the exact time of the measurements. Reported values in recent inventories were found to be in good agreement with calculated

emissions during the field campaign. Our measurements were also found to be in good agreement with simulated plumes.

Russell AR, Valin LC, Cohen RC. 2012. Trends in OMI NO2 observations over the US: Effects of emission control technology and the economic recession. Atmospheric Chemistry and Physics 12: 15419-52.

Abstract: Observations of tropospheric NO2 vertical column densities over the United States (US) for 2005–2011 are evaluated using the OMI Berkeley High Resolution (BEHR) retrieval algorithm. We assess changes in NO2 on day-of-week and interannual timescales to assess the impact of changes in emissions from mobile and non-mobile sources on the observed trends. We observe consistent decreases in cities across the US, with an average total reduction of 32 ± 7%. Changes for large power plants have been more variable (−26 ± 12%) due to regionally-specific regulation policies. An increasing trend of 10–20% in background NO2 columns in the Northwestern US is observed. We examine the impact of the economic recession on emissions and find that decreases in NO2 column densities over cities were moderate prior to the recession (−6 ± 5 % yr−1), larger during the recession (−8 ± 5 % yr−1), and then smaller after the recession (−3 ± 4 % yr−1). Differences in the trends observed on weekdays and weekends indicate that prior to the economic recession, NO2 reductions were dominated by technological improvements to the light-duty vehicle fleet but that a decrease in diesel truck activity has dominated emission reductions since the recession. We use the satellite observations to estimate a 34% decrease in NO2 from mobile sources in cities for 2005–2011 and use that value to infer changes in non-mobile sources. We find that reductions in NO2 from non-mobile sources in cities have been more variable than NO2 reductions from mobile sources (−10 ± 13%).

Shie R, Yuan T, Chan C. 2013. Using pollution roses to assess sulfur dioxide impacts in a township downwind of a petrochemical complex. Journal of the Air and Waste Management Association 63(6): 702-11.

Abstract: This study used pollution roses to assess sulfur dioxide (SO2) pollution in a township downwind of a large petrochemical complex based on data collected from a single air quality monitoring station. The pollution roses summarized hourly SO2 concentrations at the Taishi air quality monitoring station, located approximately 7.813.0 km south of the No. 6 Naphtha Cracking Complex in Taiwan, according to 36 sectors of wind direction during the preoperational period (19951999) and two postoperational periods (20002004 and 20052009). The 99th percentile of hourly SO2 concentrations 350 downwind from the complex increased from 28.9 ppb in the preoperational period to 86.2324.2 ppb in the two postoperational periods. Downwind SO2 concentrations were particularly high during 20052009 at wind speeds of 68 m/sec. Hourly SO2 levels exceeded the U.S. Environmental Protection Agency (EPA) health-based standard of 75 ppb only in the postoperational periods, with 65 exceedances from 010 and 330350 downwind directions during 20012009. This study concluded that pollution roses based on a single monitoring station can be used to investigate source contributions to air pollution surrounding industrial complexes, and that it is useful to combine such directional methods with analyses of how pollution varies between different wind speeds, times of day, and periods of industrial development. Implications: The pollution roses summarize SO2 concentrations by wind direction and to investigate source contribution to air quality. Percentile statistics can catch pollution episodes occurring in a very short time at specific wind directions and speeds. The downwind areas have already exceeded regulated 1-hr SO2 standard since the operation of the complex.

Umesi NO, Ideriah TJ, Abah S. 2009. Background concentration of NO2 prior to construction and operation of a gas-fired power plant in the Niger Delta region of Nigeria. Environment and Ecology 27(2): 592-602.

Abstract: Concentrations of NO2 were monitored in the ambient air during a one-year period in an area proposed for a major upgrade of an existing gas-fired power plant and the construction and operation of a new gas-fired power plant in the Niger Delta Region of Nigeria. The new plant will be located immediately adjacent to the existing facility. The exercise was with a view to establish the status of NO2 in this environment prior to commencement of project activities. The project area is predominantly rural and the existing power plant, the only anthropogenic source of NO2 in the area at the moment, was operating at

below optimal capacity. Seven sites were chosen to cover an area within a radius of 5 km of the power station. Another site, 13 km further downwind of the power station was also chosen. It was not possible to choose an area as further upwind as the 13 km downwind site because of the potential influence of both a petrochemical plant and a natural gas processing facility. The survey covered the two seasons prevalent in the Niger Delta region of Nigeria and the existing power station was operating at the same throughput the period of the survey. Nitrogen dioxide concentrations ranged from 8.5 μg/m3 in September to 22.4 μg/m3 in January. The annual mean values ranged from 14.5 to 15.7 μg/m3. These values were considerably below the Nigerian ambient air quality standards recommended by the Federal Ministry of Environment and the World Health Organization air quality guide values. They were however consistently higher during the dry season than during the rainy season. The concentrations were particularly low during July and September; the two months with the highest rainfall. They are on comprehensive data on the ambient concentrations of NO2 for the two seasons in the project area. This survey is, therefore, significant because it will form the basis against which future ambient concentration changes in NO2 will be compared.

Wang S, Streets DG, Zhang Q, He K, Chen D, Kang S et al. 2010. Satellite detection and model verification of NOx emissions from power plants in Northern China. Environmental Research Letters 5(4): 044007.

Abstract: We evaluate the recently increasing tropospheric NO2 columns in Northern China measured by the Ozone Monitoring Instrument (OMI) with an advanced power-plant NOx emission inventory and the NASA INTEX-B emission inventory, using a global chemical transport model (GEOS-Chem). In areas with newly built power plants the modeled and OMI-retrieved summertime average tropospheric NO2 columns increased by 55% and 47%, respectively, between 2005 and 2007. A monthly average increase of 1.79 Gg NOx emissions is calculated to lead to an increase of 1.0 × 1015 molecules cm − 2 in the modeled NO2 columns in the study areas. Good consistency (R2 = 0.61, slope = 1.18, n = 14) between the increased modeled and OMI-retrieved summertime average NO2 columns is found. These results suggest that NOx emissions from large power plants in Northern China can be identified and quantified using OMI retrievals with confidence. The NASA INTEX-B emission inventory appears to underestimate the NOx emissions from the industry and transportation sectors, making it more difficult to quantify power-plant emissions when they are co-located with large cities.

Wang SW, Zhang Q, Streets DG, He KB, Martin RV, Lamsal LN et al. 2012. Growth in NOx emissions from power plants in China: bottom-up estimates and satellite observations. Atmospheric Chemistry and Physics 12: 4429-47.

Abstract: Using OMI (Ozone Monitoring Instrument) tropospheric NO2 columns and a nested-grid 3-D global chemical transport model (GEOS-Chem), we investigated the growth in NOx emissions from coal-fired power plants and their contributions to the growth in NO2 columns in 2005-2007 in China. We first developed a unit-based power plant NOx emission inventory for 2005-2007 to support this investigation. The total capacities of coal-fired power generation have increased by 48.8% in 2005-2007, with 92.2% of the total capacity additions coming from generator units with size >= 300 MW. The annual NOx emissions from coal-fired power plants were estimated to be 8.11 Tg NO2 for 2005 and 9.58 Tg NO2 for 2007, respectively. The modeled summer average tropospheric NO2 columns were highly correlated (R-2 = 0.79-0.82) with OMI measurements over grids dominated by power plant emissions, with only 7-14% low bias, lending support to the high accuracy of the unit-based power plant NOx emission inventory. The ratios of OMI-derived annual and summer average tropospheric NO2 columns between 2007 and 2005 indicated that most of the grids with significant NO2 increases were related to power plant construction activities. OMI had the capability to trace the changes of NOx emissions from individual large power plants in cases where there is less interference from other NOx sources. Scenario runs from GEOS-Chem model suggested that the new power plants contributed 18.5% and 10% to the annual average NO2 columns in 2007 in Inner Mongolia and North China, respectively. The massive new power plant NOx emissions significantly changed the local NO2 profiles, especially in less polluted areas. A sensitivity study found that changes of NO2 shape factors due to including new power plant emissions increased the summer average OMI tropospheric NO2 columns by 3.8-

17.2% for six selected locations, indicating that the updated emission information could help to improve the satellite retrievals.

Yassin MF, Al-Awadhi MM. 2011. Impact of sulfur dioxide emissions of power stations on ambient air quality. Environmental Engineering Science 28(7): 469-75.

Abstract: The ISC-AERMOD dispersion model was used to study the impact of sulfur dioxide (SO2) emitted from 15 power station stacks in Kuwait. One-year meteorological and fuel consumption data were used for simulating the ground level concentrations of SO2 on an hourly, daily, and annual basis. Air quality over the course of a year was monitored at fixed air quality monitoring stations at four different locations. Simulated concentrations were validated by comparing them with the observed values at the four locations. Results demonstrated that there is a great similarity in the simulated concentrations with observed values, which made the model performance satisfactory. Hourly and daily concentrations of the simulated model exceeded Kuwait Environment Public Authority limits. There was a significant influence of SO2 emission from the power stations on the ambient air quality.

Zhou W, Cohan DS, Pinder RW, Neuman JA, Holloway JS, Peischl J, et al. 2012. Observation and modeling of the evolution of Texas power plant plumes. Atmospheric Chemistry and Physics 12: 455-468.

Abstract: During the second Texas Air Quality Study 2006 (TexAQS II), a full range of pollutants was measured by aircraft in eastern Texas during successive transects of power plant plumes (PPPs). A regional photochemical model is applied to simulate the physical and chemical evolution of the plumes. The observations reveal that SO2 and NOy were rapidly removed from PPPs on a cloudy day but not on the cloud-free days, indicating efficient aqueous processing of these compounds in clouds. The model reasonably represents observed NOx oxidation and PAN formation in the plumes, but fails to capture the rapid loss of SO2 (0.37 h−1) and NOy (0.24 h−1) in some plumes on the cloudy day. Adjustments to the cloud liquid water content (QC) and the default metal concentrations in the cloud module could explain some of the SO2 loss. However, NOy in the model was insensitive to QC. These findings highlight cloud processing as a major challenge to atmospheric models. Model-based estimates of ozone production efficiency (OPE) in PPPs are 20–50 % lower than observation-based estimates for the cloudy day.

Grey literature

Al-Awadhi MM, Yassin MF. 2011. Evaluating the impacts of SO2 emissions from power stations in Kuwait. In: WIT Transactions on Ecology and the Environment. 18th International Conference on Modelling, Monitoring and Management of Air Pollution, 59-70.

Abstract: The AER MOD-ISC dispersion model has been used to study the impact SO2 emitted from power stations in Kuwait. SO2 emissions from fifteen stacks were studied to evaluate the pollutant dispersion patterns and the risk of near by populations being negatively affected by such emission. One year's meteorological data was used for simulating the ground level concentrations of SO2. The level was estimated based on a model simulating the concentration on an hourly, daily and annual basis. The air quality was monitored at four different residential areas over the course of a year. The simulated concentrations were validated by comparing them with the observed values at four locations in residential areas. The results demonstrated that there is a great similarity in the simulated concentrations with observed values. The model performance was also found to be satisfactory. The hourly and daily concentrations of the simulated model exceeded the KW-EPA limits. This indicates that there is a significant influence of SO2 emission from the power station in ambient air quality.

Bani P, Oppenheimer C, Tsanev V, Lardy M, Hoibian T, Allenbach M et al. 2008. Correlation between SO2 emissions rate and S contained in fuel used in a power plant, Noumea, New Caledonia. In: Proceedings of SPIE - The International Society for Optical Engineering. Multispectral, Hyperspectral, and Ultraspectral Remote Sensing Technology, Techniques, and Applications II, 9 pp.

Abstract: SO2 emissions from fossil fuel power plants can have significant impacts on human health and ecosystems. Consequently, numerous techniques are in use to monitor these emissions, in order to comply with environmental legislations. Here we highlight the correlation between SO2 emissions rate and the S contained in fuel used in power plant. We obtained a maximum of 1.3 kg.s-1 of SO2 emissions rate and a minimum of 0.4 kg.s-1 corresponding respectively to 2.9 % and 1.2 % of S contained in fuel. Measurements also indicate that high concentration of SO2 released from the Noumea 121 MW power plant is rapidly diluted in the first 10 minutes, corresponding to 3-4 km distance from the source downwind. Thus inhabitants living within the 3-4 km radius are potentially exposed to power plant emissions.

Tita MC. 2012. The impact of large thermal electric power plants on air quality in Craiova area. In: Proceedings of the International Conference on Applied and Theoretical Electricity, 6403477.

Abstract: The activity of obtaining electricity using fossil fuels has produced a wide category of emission. The main pollutant released into the atmosphere from fossil combustion in order to obtain electricity and heat is sulfur dioxide. Taking account of this fact, there is a need of an environmental factors monitoring in nearby the energy complex. This paper contains an evaluation of air quality in vicinity of a large thermal electric power plant and the environmental effects. For this purpose we analyzed sulfur dioxide concentrations in Craiova city using measured values by the automatic stations. According to the obtained graphs, sulfur dioxide daily concentration in the city air is often below the upper specification limits stipulated by the legislation. The amount of sulfur dioxide released in 2011 into the atmosphere trough coal combustion by Isalnita power plant was 26969 tones. In order to demonstrate the influence of Isalnita large power plant on air quality in Craiova it was realized a correlation between the most important monitoring stations. The purpose of this paper is to highlight how chimney concentrations are found in the environment, at ground level. The harmful effect of sulfur dioxide pollution on human health, plants and the environment is represented by acid rain and other combination of pollutants.

Wu W, Chen L, Tao J, Su L, Yan H. 2012. The assessment of air quality using satellite observations in coal-fired power plants. In: Proceedings of the 2nd International Workshop on Earth Observation and Remote Sensing Applications, 176-80.

Abstract: Understanding the spatial and temporal variation of pollutant concentrations over power plant is important for optimizing emission control strategies. Remote sensing technology can help to expand the sparse ground monitoring networks into regions currently not covered. This paper use the monthly mean sulfur dioxide (SO2) and nitrogen dioxide (NO2) from Ozone Monitoring Instrument (OMI) on board NASA's Aura satellite to assess the air quality in several coal-fired power plants over the North China Plain. Our analysis indicates: 1) The inter-annual variation (2007~2009) of SO2 and NO2 showed the implement of flue-gas desulfurization (FGD) devices in power plants was effectiveness; 2) Due to lack of NO2 national standard and the increasing NO2 emissions from automobiles, the NO2 pollutions have a trend of increment in North China Plain in the past decade; 3) By comparing the monthly mean SO2 and NO2 of several big coal-fired power plants over the mountain and plain area, we found that the power output directly affects pollutant concentrations.

3.2.3 SO2 and NOx - modeled emissions (emission inventories)

White literature

Al-Azmi BN, Nassehi V, Khan AR. 2008. Impact of emissions from power stations on the ambient air quality of selected urban areas in Kuwait. American Journal of Environmental Sciences 4(6): 558-68.

Abstract: In Kuwait, two main power stations, one comprising of seven-300 MW steam generators at Doha and other with eight-300 MW steam generators at Subyia cover the major power requirement of Kuwait city. These stations used different types of fuel oil as the prime source of energy that has different sulphur contents (S%). Comprehensive emission inventories for year the 2001 were used to execute Source Complex model for Short-term Dispersion (ISCST4.5) to predict ambient ground level concentrations of sulphur dioxide (SO2) and nitrogen oxide (NOx) at selected receptors. A yearlong meteorological data were used in conjunction with the dispersion model to compute SO2 and NOx levels in and around the power stations. For validation of the model, computed results were compared with the measured daily average values at a fixed Kuwait EPA air quality monitoring station located at the roof of polyclinic in Rabia residential area. Contributions of each power station to the highest predicted values were assessed. Significance of the fifty highest hourly, daily and annual ground level concentration values under existing meteorological conditions was analyzed. The results for year 2001 revealed that daily and annual mean predicted SO2 concentrations had exceedance about 5.7% and 0.16% respectively of the total area under investigation. Based on these results, mitigation strategies would be proposed to abate high pollution levels caused by these power stations.

Bergin MS, Russell AG, Odman MT, Cohan DS, Chameides WL. 2008. Single-source impact analysis using three-dimensional air quality models. Journal of the Air and Waste Management Association 58(10): 1351-9.

Abstract: Isolating the effects of an individual emissions source on secondary air pollutants such as ozone and some components of particulate matter must incorporate complex nonlinear processes, be sensitive to small emissions perturbations, and account for impacts that may occur hundreds of kilometers away. The ability to evaluate these impacts is becoming increasingly important for efficient air quality management. Here, as part of a recent compliance enforcement action for a violation of the Clean Air Act and as an evaluation of ozone response to single-source emissions plumes, two three-dimensional regional photochemical air quality models are used to assess the impact on ozone from approximately 2000 to 3000 excess t/month of nitrogen oxides emitted from a single power plant in Ohio. Periods in May, July, and August are evaluated. Two sensitivity methods are applied: the "brute-force" (B-F) method and the decoupled direct method (DDM). Using DDM, maximum 1-hr averaged ozone concentrations are found to increase by up to 1.8, 1.3, and 2.2 ppbv during May, July, and August episodes, respectively, and concentration increases greater than 0.5 ppbv occur in Ohio, Pennsylvania, Maryland, New York, West Virginia, Virginia, and North and South Carolina. B-F results for the August episode show a maximum 1-hr averaged ozone concentration increase of 2.3 ppbv. Significant localized decreases are also simulated, with a maximum of 3.6 ppbv in Ohio during the August episode and decreases of 0.50 ppbv and greater in Ohio, Pennsylvania, Maryland, West Virginia, and Virginia. Maximum increases are compared with maximum decreases for the August period using second-order DDM and are found, in aggregate, to be greater in magnitude by 42%. When evaluated during hours when ozone concentrations exceed 0.060 ppm, the maximum increases in ozone are higher than decreases by 82%. The spatial extent of ozone increase in both cases is about triple that of reduction.

Chusai C, Manomaiphiboon K, Saiyasitpanich P, Thepanondh S. 2012. NO2 and SO2 dispersion modeling and relative roles of emission sources over Map Ta Phut industrial area, Thailand. Journal of the Air and Waste Management Association 62(8): 932-45.

Abstract: Map Ta Phut industrial area (MA) is the largest industrial complex in Thailand. There has been concern about many air pollutants over this area. Air quality management for the area is known to be difficult, due to lack of understanding of how emissions from different sources or sectors (e.g., industrial, power plant, transportation, and residential) contribute to air quality degradation in the area. In this study, a

dispersion study of NO2 and SO2 was conducted using the AERMOD model. The area-specific emission inventories of NOx and SO2 were prepared, including both stack and nonstack sources, and divided into 11 emission groups. Annual simulations were performed for the year 2006. Modeled concentrations were evaluated with observations. Underestimation of both pollutants was Jbund, and stack emission estimates were scaled to improve the modeled results before quantifying relative roles of individual emission groups to ambient concentration overfour selected impacted areas (two are residential and the others are highly industrialized). Two concentration measures (i.e., annual average area-wide concentration or AC, and area-wide robust highest concentration or AR) were used to aggregately represent mean and high-end concentrations Jbfor each individual area, respectively. For AC-NO2, on-road mobile emissions were found to be the largest contributor in the two residential areas (36-38% of total AC-NO2), while petrochemical-industry emissions play the most important role in the two industrialized areas (34-51%). For AR-NO2, biomass burning has the most influence in all impacted areas (>90%) exceptJor one residential area where on-road mobile is the largest (75%). For AC-SO2, the petrochemical industry contributes most in all impacted areas (38-56%). For AR-SO2, the results vary. Since the petrochemical industry was often identified as the major contributor despite not being the largest emitter, air quality workers should pay special attention to this emission group when managing air quality for the MA.

Gego E, Gilliland A, Godowitch J, Rao ST, Porter PS, Hogrefe C. 2008. Modeling analyses of the effects of changes in nitrogen oxides emissions from the electric power sector on ozone levels in the eastern United States. Journal of the Air and Waste Management Association 58(4): 580-8.

Abstract: In this paper, we examine the changes in ambient ozone concentrations simulated by the Community Multiscale Air Quality (CMAQ) model for summer 2002 under three different nitrogen oxides (NOx) emission scenarios. Two emission scenarios represent best estimates of 2002 and 2004 emissions; they allow assessment of the impact of the NOx emissions reductions imposed on the utility sector by the NOx State Implementation Plan (SIP) Call. The third scenario represents a hypothetical rendering of what NOx emissions would have been in 2002 if no emission controls had been imposed on the utility sector. Examination of the modeled median and 95th percentile daily maximum 8-hr average ozone concentrations reveals that median ozone levels estimated for the 2004 emission scenario were less than those modeled for 2002 in the region most affected by the NOx SIP Call. Comparison of the "no-control" with the "2002" scenario revealed that ozone concentrations would have been much higher in much of the eastern United States if the utility sector had not implemented NOx emission controls; exceptions occurred in the immediate vicinity of major point sources where increased NO titration tends to lower ozone levels.

Hobbs BF, Hu M-, Chen Y, Ellis JH, Paul A, Burtraw D et al. 2010. From regions to stacks: Spatial and temporal downscaling of power pollution scenarios. IEEE Transactions on Power Systems 25(2): 1179-89.

Abstract: National energy models produce aggregate scenarios of generation capacity, energy output, and emissions. However, we need finer scales to study the impact of resource use and air pollution because timing and location determine impacts on sensitive ecosystems and human populations. We present a framework for disaggregating emissions projections to a scale compatible with air quality simulation models. The framework comprises three models that site new power plants consistent with historical patterns while recognizing water, transmission, fuel, and other factors that constrain siting, and then dispatches them consistent with those constraints. The resulting hourly emissions from individual plants are consistent with meteorology, in that peak demands and emissions occur during those hours when temperatures associated with such demands occur. Further, annual emissions vary in a way consistent with year-to-year changes in weather. An application of the framework disaggregates 2030 NOx emissions from a national electricity model in an eight-state region under two climate scenarios: no climate change ("1990s") and accelerated change ("2050s"). Between-year variations in emissions patterns under a particular climate exceed differences between average patterns of the two scenarios. This is in part because NO x emissions are capped; thus, the total cannot change, only its distribution over time and space.

Kahn ME. 2009. Regional growth and exposure to nearby coal fired power plant emissions. Regional Science and Urban Economics 39(1): 15-22.

Abstract: Coal fired power plants emit high levels of air pollution per unit of power generated. A comparison of emissions factors (pounds of emissions per megawatt hour of power generation) based on year 2004 data reveals that the average coal fired power plant emits six times as much nitrogen oxide and more than twelve times as much sulfur dioxide as the average non-coal fired power plant. This paper uses data on the population of all electric utilities in the United States and evidence on population growth across regions to document that; pollution levels are higher in counties with coal fired plants, and that the population is moving away from regions such as the Midwest where the dirtiest coal fired power plants are located. Population growth is taking place in the South and West. Especially in the Western region, the power plants are newer and cleaner and less likely to be coal fired. In the South and West, population growth has a smaller impact on power plant emissions growth than in the Northeast and Midwest.

Kanada M, Dong L, Fujita T, Fujii M, Inoue T, Hirano Y et al. 2013. Regional disparity and cost-effective SO2 pollution control in China: A case study in 5 mega-cities. Energy Policy 61: 1322-31.

Abstract: With rapid development, increasing sulfur dioxide (SO2) emission becomes a key environmental issue in China. To respond to this challenge, the Chinese government established a top-down scheme to reduce its SO2 emissions. However, regional disparity and the associated cost differences brought uncertainties to the policy effectiveness and efficiency. Few studies focus on this field. Therefore, this study tries to fill such a gap by investigating the differences of SO2 emissions, reduction potential, and cost-effectiveness through use of the GAINS-China model in five mega-cities in China, namely, Beijing, Shanghai, Tianjin, Chongqing, and Hong Kong. A scenario analysis approach is employed, focusing on two technologies named flue gas desulfurization (FGD) and limestone injection (LINJ). Results demonstrated that a large SO2 reduction potential exists, as well as a great disparity, among the five mega-cities. Chongqing had the largest reduction potential with lowest unit cost, while Beijng and Hong Kong showed the lowest reduction potential with higher unit cost. In Beijing and Shanghai, FGD and LINJ in the power generation sector had the larger reduction potential with the highest cost-effectiveness. However, in Chongqing, the industry sectors also had large reduction potentials. Finally, appropriate SO2 control strategies and policies are raised by considering the local realities.

Klimont Z, Smith SJ, Cofala J. 2013. The last decade of global anthropogenic sulfur dioxide: 2000-2011 emissions. Environmental Research Letters 8: 014003.

Abstract: The evolution of global and regional anthropogenic SO2 emissions in the last decade has been estimated through a bottom-up calculation. After increasing until about 2006, we estimate a declining trend continuing until 2011. However, there is strong spatial variability, with North America and Europe continuing to reduce emissions, with an increasing role of Asia and international shipping. China remains a key contributor, but the introduction of stricter emission limits followed by an ambitious program of installing flue gas desulfurization on power plants resulted in a significant decline in emissions from the energy sector and stabilization of total Chinese SO2 emissions. Comparable mitigation strategies are not yet present in several other Asian countries and industrial sectors in general, while emissions from international shipping are expected to start declining soon following an international agreement to reduce the sulfur content of fuel oil. The estimated trends in global SO2 emissions are within the range of representative concentration pathway (RCP) projections and the uncertainty previously estimated for the year 2005.

Kurtulus B. 2012. High resolution numerical simulation of sulphur-dioxide emission from a power plant building. Building Simulation 5(2): 135-46.

Abstract: Most sulphur-dioxide (SO2) emission calculations have been performed on an annual basis and do not take into account spatial and temporal variations on fine scale. The main objective of this study is to illustrate spatio-temporal variation of SO2 emission pattern using computational fluid dynamic (CFD) tools of the area surrounding the Yatagan Power Plant (YPP) building in Mugla, Turkey. In order to simulate the atmospheric conditions, wind speed, wind direction and the emission of SO2 from 3 stacks of YPP including

the simplified model of the power plant building, a commercial CFD, FLUENT is used. The results involve 75 km(2) areas surrounding the YPP with a fine mesh resolution of 5 m x 5 m. SO2 emission shows that the CFD tool is able to simulate the emission with fine mesh digital elevation model (DEM). The DEM highly influences the local magnitude and direction of the wind in the domain which effects both spatial and temporal emission distribution of the SO2 gases. It is noted that the hills around the YPP cause the flue gas emissions to move away from the ground for 4 main wind directions when compared with the constant elevation model.

Lu Z, Streets DG, Zhang Q, Wang S, Carmichael GR, Cheng YF et al. 2010. Sulfur dioxide emissions in China and sulfur trends in East Asia since 2000. Atmospheric Chemistry and Physics 10: 6311-31.

Abstract: With the rapid development of the economy, the sulfur dioxide (SO2) emission from China since 2000 is of increasing concern. In this study, we estimate the annual SO2 emission in China after 2000 using a technology-based methodology specifically for China. From 2000 to 2006, total SO2 emission in China increased by 53%, from 21.7 Tg to 33.2 Tg, at an annual growth rate of 7.3%. Emissions from power plants are the main sources of SO2 in China and they increased from 10.6 Tg to 18.6 Tg in the same period. Geographically, emission from north China increased by 85%, whereas that from the south increased by only 28%. The emission growth rate slowed around 2005, and emissions began to decrease after 2006 mainly due to the wide application of flue-gas desulfurization (FGD) devices in power plants in response to a new policy of China's government. This paper shows that the trend of estimated SO2 emission in China is consistent with the trends of SO2 concentration and acid rain pH and frequency in China, as well as with the increasing trends of background SO2 and sulfate concentration in East Asia. A longitudinal gradient in the percentage change of urban SO2 concentration in Japan is found during 2000–2007, indicating that the decrease of urban SO2 is lower in areas close to the Asian continent. This implies that the transport of increasing SO2 from the Asian continent partially counteracts the local reduction of SO2 emission downwind. The aerosol optical depth (AOD) products of Moderate Resolution Imaging Spectroradiometer (MODIS) are found to be highly correlated with the surface solar radiation (SSR) measurements in East Asia. Using MODIS AOD data as a surrogate of SSR, we found that China and East Asia excluding Japan underwent a continuous dimming after 2000, which is in line with the dramatic increase in SO2 emission in East Asia. The trends of AOD from both satellite retrievals and model over East Asia are also consistent with the trend of SO2 emission in China, especially during the second half of the year, when sulfur contributes the largest fraction of AOD. The arrested growth in SO2 emissions since 2006 is also reflected in the decreasing trends of SO2 and SO42− concentrations, acid rain pH values and frequencies, and AOD over East Asia.

Palau JL, Melia J, Segarra D, Perez-Landa G, Santa-Cruz F, Millan MM. 2009. Seasonal differences in SO2 ground-level impacts from a power plant plume on complex terrain. Environmental Monitoring and Assessment 149(1-4): 445-55.

Abstract: The objective of this study is to describe the seasonal differences in SO2 ground-level fumigations from a power plant situated on very complex terrain in the Iberian Peninsula within the Western Mediterranean Basin (WMB). The study area extends more than 80 km around the power plant on very complex semi-arid terrain. Considering different plume-rise schemes, by experimentation and modelling this study attempts to characterise the seasonal differences in both the plume footprint 80 km around the power plant and the turbulent regime (diurnal or nocturnal) driving the main contribution to the accumulated plume footprints at different distances from the power plant within a complex terrain region. Two markedly different SO2 ground-level distributions around the power plant are presented for the typical summer and winter dispersive scenarios in the area. Simulations show that the SO2 footprint of a plume being advected more than 450 m above ground level in complex terrain is highly dependent on the prevailing meteorological conditions and on the mesoscale perturbations of the synoptic flows within the lower layers of the troposphere. The results obtained show how on complex terrain, despite seasonal meteorological differences and under stable dispersive conditions, the simulated mechanical turbulence leeward of the mountain ranges reproduces highly concentrated SO2 fumigations on the ground more than 50 km away from the power plant. Besides, under summer convective activity, plume fumigations have been successfully simulated less than 15 km from the power plant. In conclusion, this study shows how measurements from air quality networks together with information obtained from atmospheric transport and diffusion models are able to

characterise different transport scenarios. This is a clear advantage for the end-users and decision-makers who manage and optimise the regional air quality networks.

Pinder RW, Appel KW, Dennis RL. 2011. Trends in atmospheric reactive nitrogen for the Eastern United States. Environmental Pollution 159(10): 3138-41.

Abstract: Reactive nitrogen can travel far from emission sources and impact sensitive ecosystems. From 2002 to 2006, policy actions have led to decreases in NOx emissions from power plants and motor vehicles. In this study, atmospheric chemical transport modeling demonstrates that these emissions reductions have led to a downward trend in ambient measurements of transported reactive nitrogen, especially atmospheric concentrations and wet deposition of nitrate. The trend in reduced nitrogen, namely ammonium, is ambiguous. As reduced nitrogen becomes a larger fraction of the reactive nitrogen budget, wide-spread NH3 measurements and improved NH3 emissions assessments are a critical need.

Ramadan AA, Al-Sudairawi M, Alhajraf S, Khan AR. 2008. Total SO2 emissions from power stations and evaluation of their impact in Kuwait using a Gaussian plume dispersion model. American Journal of Environmental Sciences 4: 1-12.

Abstract: In Kuwait, most of the power stations use fuel oil as the prime source of energy. The sulfur content (S%) of the fuel used as well as other factors have a direct impact on the ground level concentration of sulfur dioxide (SO2) released by power stations into the atmosphere. The SO2 ground level concentration has to meet the environmental standards set by Kuwait Environment Public Authority (KEPA). In this communication we present results obtained using the Industrial Sources Complex Short Term (ISCST3) model to calculate the SO2 concentration resulting from existing power stations in Kuwait assuming zero background SO2 concentration and entire reliance on Heavy Fuel Oil. 1, 2, 3 and 4S% scenarios were simulated for three emission cycle cases. The computed annual SO2 concentrations were always less than KEPA standards for all scenarios. The daily SO2 concentrations were within KEPA standards for 1S% but violated KEPA standards for higher S%. In general, the concentrations obtained from the combined hourly and seasonal cycle were the lowest and those obtained from the no cycle case were the highest. The comparison between the results of the three cycles revealed that the violation times cannot be solely attributed to the increase in emissions and the meteorological conditions have to be taken into consideration.

Sahu SK, Beig G, Neha S. Parkhi NS. 2012. Emerging pattern of anthropogenic NOX emission over Indian subcontinent during 1990s and 2000s. Atmospheric Pollution Research 3(3): 262-9.

Abstract: The fossil fuel and bio–fuel burning in a developing country like India can have a significant impact on global climate. In the current work, we have set–up a more realistic, accurate and spatially distributed, all India, NOX emissions from different fuel combustion and industrial activities at 1°×1° grid resolution by incorporating the most recently available micro–level activity data as well as country specific emission factor (EFs) at high resolution. The emission scenarios and their trends are studied in a comprehensive way for approximately 593 districts (sub–region) in India. We have developed three scenarios to construct the possible range of past and present NOX emissions using Geographical Information System (GIS) based methodology. The total NOX emissions are estimated to be 2 952 Giga gram (Gg)/yr, 4 487 Gg/yr and 7 583 Gg/yr for three different base years, i.e., 1991, 2001 and 2011. NOX emissions trend in India during 1990s and 2000s due to different major anthropogenic activities are estimated and their growth is discussed. A strong growth of NOX is found during 2000s as compared to 1990s. All major cities remain top emitter of NOX. The present work depicts that the contribution of fossil fuel will gradually increase in coming years and will be around 91% by 2011. The present new gridded emission inventory will be very useful as an input to Chemical Transport Modeling study over Indian geography.

Su S, Li B, Cui S, Tao S. 2011. Sulfur dioxide emissions from combustion in china: from 1990 to 2007. Environmental Science and Technology 45(19): 8403-10.

Abstract: China has become the world's largest emitter of SO(2) since 2005, and aggressive deployment of flue gas desulfurization (FGD) at coal-fired power plants appeared in China when facing the formidable pressure of environment pollution. In this work, we estimate the annual emission from combustion sources at

provincial levels in China from 1990 to 2007, with updated data investigations. We have implemented the method of transportation matrix to gain a better understanding of sulfur content of coal in consuming provinces, which in turn improved the inventory. The total emissions from combustion in 2007 were 28.3 Tg, half of which was contributed by coal-fired power plants. Meanwhile, the industrial boiler coal combustion and residential coal consumed in centralized heating were responsible for another 32% of the total emissions. From 1990 to 2007, annual SO(2) emission was fluctuated with two peaks (1996 and 2006), and total emission doubled from 15.4 Tg to 30.8 Tg, at an annual growth rate of 4.4% (6.3% since 2000). Due to the extensive application of FGD technology and the phase-out of small, high emitting units, the SO(2) emission began to decrease after 2006. Furthermore, the differences among estimates reported in literatures highlight a great need for further research to reduce the uncertainties with more detailed information on key sources and actual operation of devices.

Tian H, Liu K, Hao J, Wang Y, Gao J, Qiu P et al. 2013. Nitrogen oxides emissions from thermal power plants in china: current status and future predictions. Environmental Science and Technology 47(19): 11350-7.

Abstract: Increasing emissions of nitrogen oxides (NOx) over the Chinese mainland have been of great concern due to their adverse impacts on regional air quality and public health. To explore and obtain the temporal and spatial characteristics of NOx emissions from thermal power plants in China, a unit-based method is developed. The method assesses NOx emissions based on detailed information on unit capacity, boiler and burner patterns, feed fuel types, emission control technologies, and geographical locations. The national total NOx emissions in 2010 are estimated at 7801.6 kt, of which 5495.8 kt is released from coal-fired power plant units of considerable size between 300 and 1000 MW. The top provincial emitter is Shandong where plants are densely concentrated. The average NOx-intensity is estimated at 2.28 g/kWh, markedly higher than that of developed countries, mainly owing to the inadequate application of high-efficiency denitrification devices such as selective catalytic reduction (SCR). Future NOx emissions are predicted by applying scenario analysis, indicating that a reduction of about 40% by the year 2020 can be achieved compared with emissions in 2010. These results suggest that NOx emissions from Chinese thermal power plants could be substantially mitigated within 10 years if reasonable control measures were implemented effectively.

Vijayaraghavan K, Zhang Y, Seigneur C, Karamchandani P, Snell HE. 2009. Export of reactive nitrogen from coal-fired power plants in the U. S.: Estimates from a plume-in-grid modeling study. Journal of Geophysical Research-Atmospheres 114, D4.

Abstract: The export of reactive nitrogen (nitrogen oxides and their oxidation products, collectively referred to as NOy) from coal-fired power plants in the U. S. to the rest of the world could have a significant global contribution to ozone. Traditional Eulerian gridded air quality models cannot characterize accurately the chemistry and transport of plumes from elevated point sources such as power plant stacks. A state-of-the-science plume-in-grid (PinG) air quality model, a reactive plume model embedded in an Eulerian gridded model, is used to estimate the export of NOy from 25 large coal-fired power plants in the U. S. (in terms of NOx and SO2 emissions) in July 2001 to the global atmosphere. The PinG model used is the Community Multiscale Air Quality Model with Advanced Plume Treatment (CMAQ-APT). A benchmark simulation with only the gridded model, CMAQ, is also conducted for comparison purposes. The simulations with and without advanced plume treatment show differences in the calculated export of NOy from the 25 plants considered reflecting the effect of using a detailed and explicit treatment of plume transport and chemistry. The advanced plume treatment results in 31% greater simulated export of NOy compared to the purely grid-based modeling approach. The export efficiency of NOy (the fraction of NOy emitted that is exported) is predicted to be 21% without APT and 27% with APT. When considering only export through the eastern boundary across the Atlantic, CMAQ-APT predicts that the export efficiency is 24% and that 2% of NOy is exported as NOx, 49% as inorganic nitrate, and 25% as PAN. These results are in reasonably good agreement with an analysis reported in the literature of aircraft measurements over the North Atlantic.

Yang D, Wang Z, Zhang R. 2008. Estimating air quality impacts of elevated point source emissions in Chongqing, China. Aerosol and Air Quality Research 8(3): 279-94.

Abstract: In this study, the CALPUFF/MM5 modeling system was applied to estimate the air quality impacts of elevated point sources in 2004 in Chongqing. An intercomparison of the performance of CALPUFF against the observed data is discussed and an examination of scatter plots and QQ plots is provided. Results show that in 2004 the high emission contribution induced a relatively high contribution to average ambient concentration and significant impact on the urban area (higher than 10 μg/m3 of 24-hour averaged SO2 concentration, maximum of 650 μg /m3). The highest 24-hour averaged SO2 concentration exceeds the Grade NAAQS by 10.6%, 153.3%, 60% and 333.0% for January, April, July and October, respectively. The concentration distributions demonstrate the heterogeneity patterns in spatial and temporal scales due to significant topographic diversity and weather variations over short distances. The source of the SO2 in the Chongqing area is local air pollution, which results from the lower effective stack height, low wind velocity in the area, basin topography, and the use of coal with high sulfur content. Parametric sensitivity analyses are still needed to determine the magnitude of uncertainty associated with CALPUFF.

Zhao B, Wang SX, Xu JY, Fu K, Klimont Z, Hao JM et al. 2013. NOx emissions in China: historical trends and future perspectives. Atmospheric Chemistry and Physics 13: 9869-97.

Abstract: Nitrogen oxides (NOx) are key pollutants for the improvement of ambient air quality. Within this study we estimated the historical NOx emissions in China for the period 1995–2010, and calculated future NOx emissions every five years until 2030 under six emission scenarios. Driven by the fast growth of energy consumption, we estimate the NOx emissions in China increased rapidly from 11.0 Mt in 1995 to 26.1 Mt in 2010. Power plants, industry and transportation were major sources of NOx emissions, accounting for 28.4%, 34.0%, and 25.4% of the total NOx emissions in 2010, respectively. Two energy scenarios, a business as usual scenario (BAU) and an alternative policy scenario (PC), were developed to project future energy consumption. In 2030, total energy consumption is projected to increase by 64% and 27% from 2010 level respectively. Three sets of end-of-pipe pollution control measures, including baseline, progressive, and stringent control case, were developed for each energy scenario, thereby constituting six emission scenarios. By 2030, the total NOx emissions are projected to increase (compared to 2010) by 36% in the baseline while policy cases result in reduction up to 61% in the most ambitious case with stringent control measures. More than a third of the reduction achieved by 2030 between least and most ambitious scenario comes from power sector, and more than half is distributed equally between industry and transportation sectors. Selective catalytic reduction dominates the NOx emission reductions in power plants, while life style changes, control measures for industrial boilers and cement production are major contributors to reductions in industry. Timely enforcement of legislation on heavy-duty vehicles would contribute significantly to NOx emission reductions. About 30% of the NOx emission reduction in 2020 and 40% of the NOx emission reduction in 2030 could be treated as the ancillary benefit of energy conservation. Sensitivity analysis was conducted to explore the impact of key factors on future emissions.

Grey literature

Balaceanu CM, Cepisca C. 2011. Impact assessment of the thermoelectric power plants on the air quality in Bucharest. In: 7th International Symposium on Advanced Topics in Electrical Engineering, 1-4.

Abstract: Impact assessment of the thermoelectric power plants (Progresu and Grozavesti) in Bucharest on the environmental air quality is the aim of this paper. The thermoelectric power stations produce as much gaseous (CO, CO2, NOx, and SO2) as solid (ash and heavy metals) pollutants. The study has been performed for a year, For NOx and SO2 pollutant for all seasons and the main objective are the comparison of two power plants to see which the impact has in Bucharest and in neighbourhoods. All the input information's are provided by the air quality dispersion Gaussian model OML (Operational Local Model): meteorological data, emissions data, point sources (inner and height of stack, speed of gases). The paper also approaches the influence of coal on the environment by transborder SO2 pollution.

Bravo AH, Sosa ER, Cureño GIV, Marin HA, Sanchez AP, Rosas AS et al. 2011. The importance of the pollutant emissions variation for the use in the emission inventories and application on dispersion models in Mexico. In: Proceedings of the Air and Waste Management Association's Annual Conference and Exhibition, 220-30.

Abstract: The precise, exact, and temporary variation of atmospheric emissions of an industry in particular, is of great importance for the elaboration of emission inventories and application on dispersion models. Estimation of the atmospheric emissions in the case of the thermo power plant in Mexico was carried out. This estimation was carried on considering the characteristic of the fuel, its consumption in a given time, and the right emission factors. The calculated emissions for SO2 considered the percentage of sulfur in the fuel oil, in addition to its consumption. For the case of the SO2, the daily emission average for all the power plant is 252.5 ton/day, a maximum of 755.3 ton/day, and a minimum of 68.9 ton/day. The correct estimated emission obtained in this study case when introduce to the dispersion model CALPUFF, contributed to daily air quality concentrations, with very low uncertainty as a product from the operation of the Thermo Power Plant.

European Environment Agency. 2008. Air pollution from electricity-generating large combustion plants: An assessment of the theoretical emission reduction of SO2 and NOx through implementation of BAT as set in the BREFs. EEA Technical report No 4/2008, Denmark. Available at http://bookshop.europa.eu/en/air-pollution-from-electricity-generating-large-combustion-plants-pbTHAK08004/.

Abstract: *No abstract available.*
Excerpt from Executive Summary:
[This report presents the results of a study that assesses the theoretical potential to reduce air emissions of SO2 and NOX that might have occurred had the best available techniques (BAT) and associated emission levels (AELs), as described in the large combustion plant best available techniques reference document (LCP BREF), been fully introduced in a set of electricity-generating large combustion plants (LCP) within the European Union (EU-25) in 2004. A similar analysis is also provided, illustrating the potential effect of implementing the LCP Directive emission limit values (ELVs) at the facilities included within the scope of the work. The study covers more than 70 % of the emissions of SO2 and NOX included in EPER for the LCP sector.]
[The results of the study clearly indicate that EU-25 emissions of the air pollutants NOX and SO2 from large combustion plants facilities included in the scope of the study could be significantly reduced if the emission levels associated with the best available techniques described in the large combustion plants BREF were to be achieved.]
[The NOX and SO2 emissions from the 450 facilities included in this study might have been considerably lower (20 % and 61 % respectively) if all units within these facilities had met the LCP Directive emission limit values.]

European Environment Agency. 2013. Reducing air pollution from electricity-generating large combustion plants in the European Union: An assessment of potential emission reductions of NOX, SO2 and dust. EEA Technical report No 9/2013, Denmark. Available at http://bookshop.europa.eu/en/reducing-air-pollution-from-electricity-generating-large-combustion-plants-in-the-european-union-pbTHAK13009/.

Abstract: *No abstract available.*

Excerpt from Executive Summary:

[This report presents results from an updated assessment of the hypothetical emission reduction potential of NOX, SO2 and dust from European large combustion plants for the year 2009. This new assessment is based upon improved statistics increasing the accuracy of the analysis compared to the earlier report, notably the

latest available emission and fuel-use data from 2009 reported by Member States under the Large Combustion Plant Directive (2001/80/EC) (LCPD; EU, 2001).]
[A small number of large-scale coal plants and plants co-combusting coal with other fuels dominate the reported emissions for all three pollutants. Just 50 plants (i.e. 3 % of the 1 595 plants addressed in this report) contribute 50 % of NOX emissions, with 454 (28 %) responsible for 90 % of emissions. The situation is more striking for SO2 with only 20 plants (1 %) responsible for 50 % of total emissions and 165 (10 %) contributing 90 %. For dust, just 21 plants (1 %) contribute 50 % and 175 (11 %) contribute 90 % of the total reported emissions. In general, a good correlation is noted at the Member State level between the 2009 emissions reported under the LCPD for the electricity generation sector and those reported under the European Pollutant Release and Transfer Register (E-PRTR), although some potential errors in official reporting were identified and are described. Unfortunately, a detailed plant-by-plant comparison is not possible because there is no direct link established between the two datasets.
The results of the present study clearly indicate that EU-27 emissions of the air pollutants NOX, SO2 and dust from the selected LCPs could potentially be significantly lower if all plants operating in 2009 were to meet the ELVs set out in the Industrial Emission Directive.]

Randall L. 2011. Dirty Energy's Assault on our Health: Ozone Pollution. Environment America Research and Policy Center. Available at http://www.environmentamerica.org/sites/environment/files/reports/EnvAmerica-OzonePollutionReport-Mar2011.pdf.

Abstract: *No abstract available.*

Excerpt from Executive Summary:
[Dirty energy pollutes the air we breathe, threatening our health and our environment. When power plants burn coal, oil or gas, they create the ingredients for ground-level ozone pollution, one of the main components of "smog" pollution. Especially on hot summer days, across wide areas of the United States, ozone pollution reaches levels that are unhealthy to breathe, putting our lives at risk. In 2009, U.S. power plants emitted more than 1.9 million tons of ozone-forming nitrogen oxide pollution into the air. In order to better protect public health, the United States Environmental Protection Agency (EPA) should issue a new air quality standard to reduce ground-level ozone pollution. To achieve these reductions in pollution, the United States should increase pollution control technologies for power plants and accelerate the transition to clean electricity sources, including wind and solar power. In addition, the United States should reduce ozone-forming pollution from mobile sources.
Emissions from power plants contribute to widespread ozone pollution in the United States.
-More than half of the people in the United States -56 percent- live in areas with unhealthy levels of ozone.
-Power plants emitted 1,927,569.3 tons of nitrogen oxide pollution, a key precursor to ozone pollution, into the environment in 2009.
-Emissions from power plants in just eleven states account for 50 percent of the total nitrogen oxide pollution emitted by power plants into our environment.]

3.3 Particulate Matter

3.3.1 PM - health effects

Diaz EA, Lemos M, Coull B, Long MS, Rohr AC, Ruiz P, et al. 2011. Toxicological evaluation of realistic emission source aerosols (TERESA)–power plant studies: assessment of breathing pattern. Inhalation Toxicology 23(S2): 42-59.

Funding Agency: Electric Power Research Institute, NIEHS (Center for Environmental Health), US Department of Energy, US Environmental Protection Agency (Center for Particle Health Effects at the Harvard School of Public Health), State of Wisconsin	
Study Location: Midwest, Upper Midwest, and Southeast USA	**Study Design:** Animal toxicology study
Fuel Type: Coal	**Chemicals:** NOx, O3, PM (+ species), SO2

Abstract: Our approach to study multi-pollutant aerosols isolates a single emissions source, evaluates the toxicity of primary and secondary particles derived from this source, and simulates chemical reactions that occur in the atmosphere after emission. Three U.S. coal-fired power plants utilizing different coals and with different emission controls were evaluated. Secondary organic aerosol (SOA) derived from α-pinene and/or ammonia was added in some experiments. Male Sprague-Dawley rats were exposed for 6 h to filtered air or different atmospheric mixtures. Scenarios studied at each plant included the following: primary particles (P); secondary (oxidized) particles (PO); oxidized particles + SOA (POS); and oxidized and neutralized particles + SOA (PONS); additional control scenarios were also studied. Continuous respiratory data were obtained during exposures using whole body plethysmography chambers. Of the 12 respiratory outcomes assessed, each had statistically significant changes at some plant and with some of the 4 scenarios. The most robust outcomes were found with exposure to the PO scenario (increased respiratory frequency with decreases in inspiratory and expiratory time); and the PONS scenario (decreased peak expiratory flow and expiratory flow at 50%). PONS findings were most strongly associated with ammonium, neutralized sulfate, and elemental carbon (EC) in univariate analyses, but only with EC in multivariate analyses. Control scenario O (oxidized without primary particles) had similar changes to PO. Adjusted R^2 analyses showed that scenario was a better predictor of respiratory responses than individual components, suggesting that the complex atmospheric mixture was responsible for respiratory effects.

Strengths and Limitations:

Strengths: Detailed and thorough study. Large sample size. Continuous monitoring of respiratory outcomes. Utilized a mobile laboratory (in a trailer) for exposures to PM emissions from 3 different coal-fired power plants. Continuous measurement of pollutants. Considered 4 different atmospheric mixtures of primary and secondary particles. Examined impact of individual PM components.
Limitations: Number of days that each atmospheric mixture scenario was run differed between power plants; this may have impacted the scenario-specific analyses. Some inconsistencies observed between individual component models and multivariate models (overall, the investigators found mixture scenario to be a stronger predictor of outcome than individual components).

Study Score and Ranking:

0.92; High

Godleski JJ, Diaz EA, Lemos M, Long M, Ruiz P, Gupta T, et al. 2011. Toxicological evaluation of realistic emission source aerosols (TERESA)-power plant studies: assessment of cellular responses. Inhalation Toxicology 23(S2): 60-74.

Funding Agency: Electric Power Research Institute, NIEHS (Center for Environmental Health), US Department of Energy, US Environmental Protection Agency (Center for Particle Health Effects at the Harvard School of Public Health), State of Wisconsin	
Study Location: Midwest, Upper Midwest, and Southeast USA	**Study Design:** Animal toxicology study
Fuel Type: Coal	**Chemicals:** NOx, O3, PM (+ species), SO2

Abstract: The Toxicological Evaluation of Realistic Emission Source Aerosols (TERESA) project assessed primary and secondary particulate by simulating the chemical reactions that a plume from a source might undergo during atmospheric transport and added other atmospheric constituents that might interact with it. Three coal-fired power plants with different coal and different emission controls were used. Male Sprague-Dawley rats were exposed for 6 h to either filtered air or aged aerosol from the power plant. Four exposure scenarios were studied: primary particles (P); primary + secondary (oxidized) particles (PO); primary + secondary (oxidized) particles + SOA (POS); and primary + secondary (oxidized) particles neutralized + SOA (PONS). Exposure concentrations varied by scenario to a maximum concentration of 257.1 ± 10.0 μg/m3. Twenty-four hours after exposure, pulmonary cellular responses were assessed by bronchoalveolar lavage (BAL), complete blood count (CBC), and histopathology. Exposure to the PONS and POS scenarios produced significant increases in BAL total cells and macrophage numbers at two plants. The PONS and P scenarios were associated with significant increases in BAL neutrophils and the presence of occasional neutrophils and increased macrophages in the airways and alveoli of exposed animals. Univariate analyses and random forest analyses showed that increases in total cell count and macrophage cell count were significantly associated with neutralized sulfate and several correlated measurements. Increases in neutrophils in BAL were associated with zinc. There were no significant differences in CBC parameters or blood vessel wall thickness by histopathology. The association between neutrophils increases and zinc raises the possibility that metals play a role in this response.

Strengths and Limitations:

Strengths: Detailed and thorough study. Large sample size. Utilized a mobile laboratory (in a trailer) for exposures to PM emissions from 3 different coal-fired power plants. Continuous measurement of pollutants. Considered 4 different atmospheric mixtures of primary and secondary particles. Examined impact of individual PM components.
Limitations: Some inconsistencies observed between individual component models and multivariate models. Not known if investigators blinded to exposure status (for analysis of biological samples).

Study Score and Ranking:

0.88; High

Harkema JR, Wagner JG, Kaminski NE, Morishita M, Keeler GJ, McDonald JD, Barrett EG. 2009. Effects of concentrated ambient particles and diesel engine exhaust on allergic airway disease in Brown Norway rats. Research Report Health Effects Institute 145: 5-55.

Funding Agency: Health Effects Institute	
Study Location: Detroit	**Study Design:** Animal toxicology study
Fuel Type: Coal	**Chemicals:** CO, NOx, O3, PAH, PM (+ species), SO2

Abstract: Increased concentrations of airborne fine particulate matter (PM2.5; particulate matter with an aerodynamic diameter ≤ 2.5 μm) are associated with increases in emergency room visits and hospitalizations of asthmatic patients. Emissions from local stationary combustion sources (e.g., coal-burning power plants) or mobile motor vehicles (e.g., diesel-powered trucks) have been identified as potential contributors to the development or exacerbation of allergic airway disease. In the present study, a rodent model of allergic airway disease was used to study the effects of concentrated ambient particles (CAPs) or diesel engine exhaust (DEE) on the development of allergic airway disease in rats sensitized to the allergen ovalbumin (OVA). The overall objective of our project was to understand the effects of PM2.5 on the development of OVA-induced allergic airway disease. Our specific aims were to test the following hypotheses: (1) exposure to CAPs during OVA challenge enhances epithelial remodeling of the airway and inflammation in rats previously sensitized to the allergen; and (2) exposure to DEE during OVA sensitization, or during OVA challenge, exacerbates epithelial remodeling of the airway and inflammation in rats. In the DEE studies, Brown Norway (BN) rats were sensitized with three daily intranasal (IN) instillations of 0.5% OVA, and then two weeks later were challenged with IN OVA or saline for 3 consecutive days. Rats were exposed to DEE diluted to mass concentrations of 30 or 300 μg/m3 diesel exhaust particles (DEPs) or to filtered air during either the sensitization or challenge periods. For the CAPs studies, the same OVA sensitization and challenge rat model was used but exposures to Detroit, Michigan, CAPs were limited to the OVA challenge period. Two separate 3-day CAPs exposures were conducted (week 1, high mean mass concentration = 595 μg/m3; week 2, low mean mass concentration = 356 μg/m3) during OVA challenge. In both the DEE and CAPs studies, rats were killed 24 hours after the last OVA challenge, bronchoalveolar lavage fluid (BALF) was collected and analyzed for cellularity and secreted mediators, and lungs and nose were processed for histopathologic examination and morphometric analysis of intraepithelial mucosubstances (IM). The results of our animal inhalation studies in the southwest (SW) Detroit community, an area with elevated ambient PM2.5 concentrations, suggested that, during allergen challenge, exposure to CAPs that were predominantly associated with emissions from combustion sources markedly enhanced the OVA-induced allergic airway disease, which was characterized by an increased infiltration in the lungs of eosinophilic and lymphocytic inflammation, increased IM in conducting airways, and increased concentrations in BALF of mucin-specific proteins and inflammatory cytokines. These findings suggest that urban airborne PM2.5 derived from stationary combustion sources (e.g., refineries, coal-burning power plants, waste-treatment plants) may enhance the development of human allergic airway diseases like childhood asthma. Previous animal inhalation studies in this community have also suggested that these fine, ambient combustion-derived particles may also exacerbate preexisting allergic airway disease. In contrast to our CAPs studies in Detroit, the controlled DEE exposures of allergen-sensitized BN rats, during either allergen sensitization or challenge periods, caused only a few mild modifications in the character of the allergen-induced disease. This finding contrasts with other reported studies that indicate that DEPs at relatively higher exposure doses do enhance allergic airway disease in some rodent models. The reasons for these disparities between studies likely reflect differences in exposure dose, animal models, the timing of exposures to the allergens and DEP exposures, the methods of allergen sensitization and challenge, or physicochemical differences among DEEs.

Strengths and Limitations:

Strengths: Detailed and thorough study. Sufficient sample size. Utilized a mobile air research laboratory (in a semi-trailer) for assessment of "real-world" exposures to airborne particles. Continuous measurement of pollutants. Detailed analysis of pulmonary effects (biochemical and histopathological examinations).
Limitations: Allocation of animals to exposure group not discussed. No discussion of blinding (particularly for analysis of biological samples). Multiple PM sources in the area (eg. chemical plants, refineries, traffic, coal-fired utilities); contribution of power plants to pollution not assessed.

Study Score and Ranking:

0.81; High

Kamal AS, Rohr AC, Mukherjee B, Morishita M, Keeler GJ, Harkema J.R, Wagner JG. 2011. PM2.5-induced changes in cardiac function of hypertensive rats depend on wind direction and specific sources in Steubenville, Ohio. Inhalation Toxicology 23(7): 417-430.

Funding Agency: Electric Power Research Institute, US Department of Energy (National Energy Technology Laboratory)

Study Location: Steubenville, Ohio	**Study Design:** Animal toxicology study
Fuel Type: Coal	**Chemicals:** NOx, PM2.5 (+ species), SO2

Abstract: Background: Increases in particulate matter less than 2.5 μm (PM2.5) in ambient air is linked to acute cardiovascular morbidity and mortality. Specific components and potential emission sources of PM2.5 responsible for adverse health effects of cardiovascular function are unclear. Methods: Spontaneously hypertensive rats were implemented with radiotelemeters to record ECG responses during inhalation exposure to concentrated ambient particles (CAPs) for 13 consecutive days in Steubenville, OH. Changes in heart rate (HR) and its variability (HRV) were compared to PM2.5 trace elements in 30-min time frames to capture acute physiological responses with real-time fluctuations in PM2.5 composition. Using positive matrix factorization, six major source factors were identified: (i) coal/secondary, (ii) mobile sources, (iii) metal coating/processing, (iv) iron/steel manufacturing, (v) lead and (vi) incineration. Results: Exposure-related changes in HR and HRV were dependant on winds predominately from either the northeast (NE) or southwest (SW). During SW winds, the metal processing factor was associated with increased HR, whereas factors of incineration, lead and iron/steel with NE winds were associated with decreased HR. Decreased SDNN was dominated during NE winds by the incinerator factor, and with SW winds by the metal factor. Metals and mobile source factors also had minor impacts on decreased SDNN with NE winds. Individual elemental components loaded onto these factors generally showed significant associations, although there were some discrepancies. Conclusions: Acute cardiovascular changes in response to ambient PM2.5 exposure can be attributed to specific PM constituents and sources linked with incineration, metal processing, and iron/steel production.

Strengths and Limitations:

Strengths: Sufficient sample size. Utilized a mobile air research laboratory (in a semi-trailer) for assessment of "real-world" exposures to airborne particles. Continuous measurement of pollutants. Objective outcome measure. Aimed to determine source-specific effects of PM.
Limitations: Allocation of animals to exposure group not discussed. Some inconsistencies observed between individual component models and source factor models.

Study Score and Ranking:

0.81; High

Lemos M, Diaz EA, Gupta T, Kang CM, Ruiz P, Coull BA, et al. Cardiac and pulmonary oxidative stress in rats exposed to realistic emissions of source aerosols. Inhalation Toxicology 23(S2): 75-83.

Funding Agency: Electric Power Research Institute, NIEHS (Center for Environmental Health), US Department of Energy, US Environmental Protection Agency (Center for Particle Health Effects at the Harvard School of Public Health), Harvard Clean Air Research Center, State of Wisconsin

Study Location: Midwest, Upper Midwest, and Southeast USA	**Study Design:** Animal toxicology study
Fuel Type: Coal	**Chemicals:** NOx, O3, PM (+ species), SO2

Abstract: In vivo chemiluminescence (CL) is a measure of reactive oxygen species in tissues. CL was used to assess pulmonary and cardiac responses to inhaled aerosols derived from aged emissions of three coal-fired power plants in the USA. Sprague-Dawley rats were exposed to either filtered air or: (1) primary emissions (P); (2) ozone oxidized emissions (PO); (3) oxidized emissions + secondary organic aerosol (SOA) (POS); (4) neutralized oxidized emissions + SOA (PONS); and (5) control scenarios: oxidized emissions + SOA in the absence of primary particles (OS), oxidized emissions alone (O), and SOA alone (S). Immediately after 6 hours of exposure, CL in the lung and heart was measured. Tissues were also assayed for thiobarbituric acid reactive substances (TBARS). Exposure to P or PO aerosols led to no changes compared to filtered air in lung or heart CL at any individual plant or when all data were combined. POS caused significant increases in lung CL and TBARS at only one plant, and not in combined data from all plants; PONS resulted in increased lung CL only when data from all plants were combined. Heart CL was also significantly increased with exposure to POS only when data from all plants were combined. PONS increased heart CL significantly in one plant with TBARS accumulation, but not in combined data. Exposure to O, OS, and S had no CL effects. Univariate analyses of individual measured components of the exposure atmospheres did not identify any component associated with increased CL. These data suggest that coal-fired power plant emissions combined with other atmospheric constituents produce limited pulmonary and cardiac oxidative stress.

Strengths and Limitations:

Strengths: Detailed and thorough study. Sufficient sample size (however, only 2 animals per group per day were exposed). Utilized a mobile laboratory (in a trailer) for exposures to PM emissions from 3 different coal-fired power plants. Continuous measurement of pollutants. Considered 4 different atmospheric mixtures of primary and secondary particles. Examined impact of individual PM components.
Limitations: Not known if investigators blinded to exposure status (for analysis of biological samples). Results showed a lack of positive univariate associations for PM components; this finding was inconsistent with other TERESA studies.

Study Score and Ranking:

0.88; High

Morishita M, Keeler GJ, McDonald JD, Wagner JG, Young LH, Utsunomiya S, Ewing RC, Harkema JR. 2009. Source-to-receptor pathways of anthropogenic PM2.5 in Detroit, Michigan: Comparison of two inhalation exposure studies. Atmospheric Environment 43(10): 1805-1813.

Funding Agency: Health Effects Institute, Michigan Life Sciences Corridor	
Study Location: Detroit	**Study Design:** Animal toxicology study
Fuel Type: Coal	**Chemicals:** CO, NOx, O3, PAH, PM (+ species), SO2

Abstract: Recent studies have attributed toxic effects of ambient fine particulate matter (aerodynamic diameter ≤ 2.5 μm; PM2.5) to physical and/or chemical properties rather than total mass. However, identifying specific components or sources of a complex mixture of ambient PM2.5 that are responsible for adverse health effects is still challenging. In order to improve our understanding of source-to-receptor pathways for ambient PM2.5 (links between sources of ambient PM2.5 and measures of biologically relevant dose), integrated inhalation toxicology studies using animal models and concentrated air particles (CAPs) were completed in southwest Detroit, a community where the pediatric asthma rate is more than twice the national average. Ambient PM2.5 was concentrated with a Harvard fine particle concentrator housed in AirCARE1, a mobile air research laboratory which facilitates inhalation exposure studies in real-world settings. Detailed characterizations of ambient PM2.5 and CAPs, identification of major emission sources of PM2.5, and quantification of trace elements in the lung tissues of laboratory rats that were exposed to CAPs for two distinct 3-day exposure periods were completed. This paper describes the physical/chemical properties and sources of PM2.5, pulmonary metal concentrations and meteorology from two different 3-day exposure periods – both conducted at the southwest Detroit location in July 2003 – which resulted in disparate biological effects. More specifically, during one of the exposure periods, ambient PM2.5-derived trace metals were recovered from lung tissues of CAPs-exposed animals, and these metals were linked to local combustion point sources in southwest Detroit via receptor modeling and meteorology; whereas in the other exposure period, no such trace metals were observed. By comparing these two disparate results, this investigation was able to define possible links between PM2.5 emitted from refineries and incinerators and biologically relevant dose, which in turn may be associated with observed health effects.

Strengths and Limitations:

Strengths: Detailed and thorough study. Sufficient sample size. Utilized a mobile air research laboratory (in a semi-trailer) for assessment of "real-world" exposures to airborne particles. Continuous measurement of pollutants. Detailed analysis of pulmonary effects (biochemical and histopathological examinations). Aimed to determine source-specific effects of PM.
Limitations: Allocation of animals to exposure group not discussed. No discussion of blinding (particularly for analysis of biological samples).

Study Score and Ranking:

0.81; High

Ostro B, Tobias A, Querol X, Alastuey A, Amato F, Pey J, Perez N, Sunyer J. 2011. The effects of particulate matter sources on daily mortality: a case-crossover study of Barcelona, Spain. Environmental Health Perspectives 119(12): 1781-1787.

Funding Agency: Spanish Council for Scientific Research, Spanish Ministry of Science and Innovation	
Study Location: Spain	**Study Design:** Time-series
Fuel Type: N/A	**Chemicals:** PM2.5, PM10 (+ species)

Abstract: Background: Dozens of studies link acute exposure to particulate matter (PM) air pollution with premature mortality and morbidity, but questions remain about which species and sources in the vast PM mixture are responsible for the observed health effects. Although a few studies exist on the effects of species and sources in U.S. cities, European cities-which have a higher proportion of diesel engines and denser urban populations-have not been well characterized. Information on the effects of specific sources could aid in targeting pollution control and in articulating the biological mechanisms of PM. Objectives: Our study examined the effects of various PM sources on daily mortality for 2003 through 2007 in Barcelona, a densely populated city in the northeast corner of Spain. Methods: Source apportionment for PM ≤ 2.5 μm and ≤ 10 μm in aerodynamic diameter (PM2.5 and PM10) using positive matrix factorization identified eight different factors. Case-crossover regression analysis was used to estimate the effects of each factor. Results: Several sources of PM2.5, including vehicle exhaust, fuel oil combustion, secondary nitrate/organics, minerals, secondary sulfate/organics, and road dust, had statistically significant associations ($p < 0.05$) with all-cause and cardiovascular mortality. Also, in some cases relative risks for a respective interquartile range increase in concentration were higher for specific sources than for total PM2.5 mass. Conclusions: These results along with those from our multisource models suggest that traffic, sulfate from shipping and long-range transport, and construction dust are important contributors to the adverse health effects linked to PM.

Strengths and Limitations:

Strengths: Examined mortality and PM2.5 speciation data over a 5-year period. Large sample size. Considered several different PM sources. Assessed multiple lags.
Limitations: Weak exposure assessment (PM measured every 6 days at single site). Contribution of power plant emissions to total 'secondary sulfate' source not known (ship emissions and long-range transport also contributors to this category). No individual data.

Study Score and Ranking:

0.83; High

Rohr AC, Kamal A, Morishita M, Mukherjee B, Keeler GJ, Harkema JR, Wagner JG. 2011. Altered heart rate variability in spontaneously hypertensive rats is associated with specific particulate matter components in Detroit, Michigan. Environmental Health Perspectives 119(4): 474-480.

Funding Agency: Electric Power Research Institute, US Department of Energy (National Energy Technology Laboratory)

Study Location: Detroit	**Study Design:** Animal toxicology study
Fuel Type: Coal	**Chemicals:** CO, NOx, O3, PM (+ species), SO2

Abstract: Background: Exposure to fine particulate matter [aerodynamic diameter ≤ 2.5 μm (PM2.5)] is linked to adverse cardiopulmonary health effects; however, the responsible constituents are not well defined. Objective: We used a rat model to investigate linkages between cardiac effects of concentrated ambient particle (CAP) constituents and source factors using a unique, highly time-resolved data set. Methods: Spontaneously hypertensive rats inhaled Detroit Michigan, CAPs during summer or winter (2005-2006) for 13 consecutive days. Electrocardiogram data were recorded continuously, and heart rate (HR) and heart rate variability (HRV) metrics were derived. Extensive CAP characterization, including use of a Semicontinuous Elements in Aerosol Sampler (SEAS), was performed, and positive matrix factorization was applied to investigate source factors. Results: Mean CAP exposure concentrations were 518 μg/m3 and 357 μg/m3 in the summer and winter, respectively. Significant reductions in the standard deviation of the normal-to-normal intervals (SDNN) in the summer were strongly associated with cement/lime, iron/steel, and gasoline/diesel factors, whereas associations with the sludge factor and components were less consistent. In winter, increases in HR were associated with a refinery factor and its components. CAP-associated HR decreases in winter were linked to sludge incineration, cement/lime, and coal/secondary sulfate factors and most of their associated components. Specific relationships for increased root mean square of the standard deviation of successive normal-to-normal intervals (RMSSD) in winter were difficult to determine because of lack of consistency between factors and associated constituents. Conclusions: Our results indicate that specific modulation of cardiac function in Detroit was most strongly linked to local industrial sources. Findings also highlight the need to consider both factor analytical results and component-specific results when interpreting findings.

Strengths and Limitations:

Strengths: Sufficient sample size. Utilized a mobile air research laboratory (in a semi-trailer) for assessment of "real-world" exposures to airborne particles. Continuous measurement of pollutants. Aimed to determine source-specific effects of PM. Conducted experiments in 2 seasons.
Limitations: Allocation of animals to exposure group not discussed. Some inconsistencies observed between individual component models and source factor models.

Study Score and Ranking:

0.81; High

Sarnat JA, Marmur A, Klein M, Kim E, Russell AG, Sarnat SE, Mulholland JA, Hopke PK, Tolbert PE. 2008. Fine particle sources and cardiorespiratory morbidity: An application of chemical mass balance and factor analytical source-apportionment methods. Environmental Health Perspectives 116(4): 459-466.

Funding Agency: US Environmental Protection Agency, National Institute of Environmental Health Sciences	
Study Location: Atlanta	**Study Design:** Time-series
Fuel Type: Coal	**Chemicals:** PM2.5 (+ species)

Abstract: Background: Interest in the health effects of particulate matter (PM) has focused on identifying sources of PM, including biomass burning, power plants, and gasoline and diesel emissions that may be associated with adverse health risks. Few epidemiologic studies, however, have included source-apportionment estimates in their examinations of PM health effects. We analyzed a time-series of chemically speciated PM measurements in Atlanta, Georgia, and conducted an epidemiologic analysis using data from three distinct source-apportionment methods. Objective: The key objective of this analysis was to compare epidemiologic findings generated using both factor analysis and mass balance source-apportionment methods. Methods: We analyzed data collected between November 1998 and December 2002 using positive-matrix factorization (PMF), modified chemical mass balance (CMB-LGO), and a tracer approach. Emergency department (ED) visits for a combined cardiovascular (CVD) and respiratory disease (RD) group were assessed as end points. We estimated the risk ratio (RR) associated with same day PM concentrations using Poisson generalized linear models. Results: There were significant, positive associations between same-day PM2.5 (PM with aerodynamic diameter ≤ 2.5 μm) concentrations attributed to mobile sources (RR range, 1.018-1.025) and biomass combustion, primarily prescribed forest burning and residential wood combustion, (RR range, 1.024-1.033) source categories and CVD-related ED visits. Associations between the source categories and RD visits were not significant for all models except sulfate-rich secondary PM2.5 (RR range, 1.012-1.020). Generally, the epidemiologic results were robust to the selection of source-apportionment method, with strong agreement between the RR estimates from the PMF and CMB-LGO models, as well as with results from models using single-species tracers as surrogates of the source-apportioned PM2.5 values. Conclusions: Despite differences among the source-apportionment methods, these findings suggest that modeled source-apportioned data can produce robust estimates of acute health risk. In Atlanta, there were consistent associations across methods between PM2.5 from mobile sources and biomass burning with both cardiovascular and respiratory ED visits, and between sulfate-rich secondary PM2.5 with respiratory visits.

Strengths and Limitations:

Strengths: Study well-designed and thorough. Examined morbidity and pollution data over ~4 years. Large sample size. Considered several different PM sources. Compared results from three different source apportionment approaches.

Limitations: No individual data. Some missing pollutant data; analyses were restricted to days when estimates for all source categories were available (however, a sensitivity analysis comparing restricted and complete data sets showed little difference in the RR estimates). The tracer for power plants (selenium) was weak due to a low signal-to-noise ratio.

Study Score and Ranking:

0.83; High

Wagner JG, Morishita M, Keeler GJ, Harkema JR. 2012. Divergent effects of urban particulate air pollution on allergic airway responses in experimental asthma: a comparison of field exposure studies. Environmental Health 11: 45.

Funding Agency: Health Effects Institute, Michigan Life Sciences Corridor	
Study Location: Detroit and Grand Rapids	**Study Design:** Animal toxicology study
Fuel Type: Coal	**Chemicals:** CO, NOx, O3, PM (+ species), SO2

Abstract: Background: Increases in ambient particulate matter of aerodynamic diameter of 2.5 μm (PM2.5) are associated with asthma morbidity and mortality. The overall objective of this study was to test the hypothesis that PM2.5 derived from two distinct urban U.S. communities would induce variable responses to aggravate airway symptoms during experimental asthma. Methods: We used a mobile laboratory to conduct community-based inhalation exposures to laboratory rats with ovalbumin-induced allergic airways disease. In Grand Rapids exposures were conducted within 60 m of a major roadway, whereas the Detroit was located in an industrial area more than 400 m from roadways. Immediately after nasal allergen challenge, Brown Norway rats were exposed by whole body inhalation to either concentrated air particles (CAPs) or filtered air for 8 h (7:00 AM - 3:00 PM). Both ambient and concentrated PM2.5 was assessed for mass, size fractionation, and major component analyses, and trace element content. Sixteen hours after exposures, bronchoalveolar lavage fluid (BALF) and lung lobes were collected and evaluated for airway inflammatory and mucus responses. Results: Similar CAPs mass concentrations were generated in Detroit (542 μg/m3) and Grand Rapids (519 μg/m3). Exposure to CAPs at either site had no effects in lungs of non-allergic rats. In contrast, asthmatic rats had 200% increases in airway mucus and had more BALF neutrophils (250% increase), eosinophils (90%), and total protein (300%) compared to controls. Exposure to Detroit CAPs enhanced all allergic inflammatory endpoints by 30-100%, whereas inhalation of Grand Rapids CAPs suppressed all allergic responses by 50%. Detroit CAPs were characterized by high sulfate, smaller sized particles and were derived from local combustion sources. Conversely Grand Rapids CAPs were derived primarily from motor vehicle sources. Conclusions: Despite inhalation exposure to the same mass concentration of urban PM2.5, disparate health effects can be elicited in the airways of sensitive populations such as asthmatics. Modulation of airway inflammatory and immune responses is therefore dependent on specific chemical components and size distributions of urban PM2.5. Our results suggest that air quality standards based on particle speciation and sources may be more relevant than particle mass to protect human health from PM exposure.

Strengths and Limitations:

Strengths: Sufficient sample size. Utilized a mobile air research laboratory (in a semi-trailer) for assessment of "real-world" exposures to airborne particles. Continuous measurement of pollutants. Aimed to determine source-specific effects of PM.
Limitations: Allocation of animals to exposure group not discussed. No discussion of blinding (particularly for analysis of biological samples). Did not analyze samples for endotoxin; endotoxin may have contributed to observed effects.

Study Score and Ranking:

0.81; High

Wellenius GA, Diaz EA, Gupta T, Ruiz PA, Long M, Kang CM, et al. 2011. Electrocardiographic and respiratory responses to coal-fired power plant emissions in a rat model of acute myocardial infarction: Results from the Toxicological Evaluation of Realistic Emissions of Source Aerosols Study. Inhalation Toxicology 23(S2) 84-94.

Funding Agency: Electric Power Research Institute, NIEHS (Center for Environmental Health), US Department of Energy, US Environmental Protection Agency (Center for Particle Health Effects at the Harvard School of Public Health), State of Wisconsin

Study Location: Midwest, Upper Midwest, and Southeast USA	**Study Design:** Animal toxicology study
Fuel Type: Coal	**Chemicals:** NOx, O3, PM (+ species), SO2

Abstract: Background: Ambient particulate matter (PM) derived from coal-fired power plants may have important cardiovascular effects, but existing toxicological studies are inadequate for understanding these effects. The Toxicological Evaluation of Realistic Emissions of Source Aerosols (TERESA) study aims to evaluate the toxicity of primary and secondary PM derived from coal-fired power plants. As a part of this effort, we evaluated in susceptible animals the effect of stack emissions on cardiac electrophysiology and respiratory function under exposure conditions intended to simulate an aged plume with unneutralized acidity and secondary organic aerosols (POS exposure scenario). Methods: Rats with acute myocardial infarction were exposed to either stack emissions (n = 15) or filtered air (n = 14) for 5 h at a single power plant. Respiration and electrocardiograms were continuously monitored via telemetry and heart rate, heart rate variability (HRV), premature ventricular beat (PVB) frequency, electrocardiographic intervals, and respiratory intervals and volumes were evaluated. Similar experiments at another power plant were attempted but were unsuccessful. Results: POS exposure (fine particle mass = 219.1 μg/m3; total sulfate = 172.5 μg/m3; acidic sulfate = 132.5 μg/m3; organic carbon = 50.9 μg/m3) was associated with increased PVB frequency and decreased respiratory expiratory time and end-inspiratory pause, but not with changes in heart rate, HRV, or electrocardiographic intervals. Results from a second power plant were uninterpretable. Conclusions: Short-term exposure to primary and unneutralized secondary PM formed from aged emissions from a coal-fired power plant, as simulated by the POS scenario, may be associated with increased risk of ventricular arrhythmias in susceptible animals.

Strengths and Limitations:

Strengths: Detailed and thorough study. Sufficient sample size. Continuous monitoring of cardiovascular and respiratory outcomes. Utilized a mobile laboratory (in a trailer) for exposures to PM emissions from coal-fired power plants (under an exposure scenario that included primary + secondary (oxidized) particles + secondary organic aerosol). Continuous measurement of pollutants.
Limitations: Insufficient variability in PM mass/component concentrations to assess dose-response relationships. Results reported for 1 power plant only (data from 1 plant excluded due to unexpected shutdown and technical complications with ECG).

Study Score and Ranking:

0.92; High

Zhou J, Ito K, Lall R, Lippmann M, Thurston G. 2011. Time-series analysis of mortality effects of fine particulate matter components in Detroit and Seattle. Environmental Health Perspectives 119(4): 461-466.

Funding Agency: National Particle Component Toxicity Initiative (Health Effects Institute), National Institutes of Environmental Health Sciences Center

Study Location: Detroit and Seattle	**Study Design:** Time-series
Fuel Type: Coal	**Chemicals:** PM2.5 (+ species)

Abstract: Background: Recent toxicological and epidemiological studies have shown associations between particulate matter (PM) and adverse health effects, but which PM components are most influential is less well known. Objectives: In this study, we used time-series analyses to determine the associations between daily fine PM [PM ≤ 2.5 μm in aerodynamic diameter (PM2.5)] concentrations and daily mortality in two U.S. cities-Seattle, Washington, and Detroit, Michigan. Methods: We obtained daily PM2.5 filters for the years of 2002-2004 and analyzed trace elements using X-ray fluorescence and black carbon using light reflectance as a surrogate measure of elemental carbon. We used Poisson regression and distributed lag models to estimate excess deaths for all causes and for cardiovascular and respiratory diseases adjusting for time-varying covariates. We computed the excess risks for interquartile range increases of each pollutant at lags of 0 through 3 days for both warm and cold seasons. Results: The cardiovascular and respiratory mortality series exhibited different source and seasonal patterns in each city. The PM2.5 components and gaseous pollutants associated with mortality in Detroit were most associated with warm season secondary aerosols and traffic markers. In Seattle, the component species most closely associated with mortality included those for cold season traffic and other combustion sources, such as residual oil and wood burning. Conclusions: The effects of PM2.5 on daily mortality vary with source, season, and locale, consistent with the hypothesis that PM composition has an appreciable influence on the health effects attributable to PM.

Strengths and Limitations:

Strengths: Examined mortality and daily PM2.5 speciation data over a 3-year period. Large sample size. Considered several different PM sources. Assessed multiple lags.
Limitations: Weak exposure assessment (PM measured at single site in each city). Contribution of power plant emissions to total 'coal combustion' source not known. No individual data.

Study Score and Ranking:

0.83; High

Jayasekher T. 2009. Aerosols near by a coal fired thermal power plant: chemical composition and toxic evaluation. Chemosphere 75(11): 1525-1530.

Funding Agency: Not stated	
Study Location: India	**Study Design:** *in vitro* study
Fuel Type: Coal	**Chemicals:** PM10 (+ species)

Abstract: Industrial processes discharge fine particulates containing organic as well as inorganic compounds into the atmosphere which are known to induce damage to cell and DNA, both in vitro and in vivo. Source and area specific studies with respect to the chemical composition, size and shape of the particles, and toxicity evaluations are very much limited. This study aims to investigate the trace elements associated with the aerosol particles distributed near to a coal burning thermal power plant and to evaluate their toxicity through Comet assay. PM10 (particles determined by mass passing an inlet with a 50% cut-off efficiency having a 10-μm aerodynamic diameter) samples were collected using respirable dust samplers. Twelve elements (Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd, Pb, Se, Hg, and As) were analyzed using ICP-AES. Comet assay was done with the extracts of aerosols in phosphate buffered saline (PBS). Results show that Fe and Zn were found to be the predominant elements along with traces of other analyzed elements. Spherical shaped ultrafine particles of <1 μm aerodynamic diameter were detected through scanning electron microscope. PM10 particles near to the coal burning power plant produced comets indicating their potential to induce DNA damage. DNA damage property is found to be depending upon the chemical characteristics of the components associated with the particles besides the physical properties such as size and shape.

Strengths and Limitations:

Strengths: The only recent *in vitro* study found that evaluated cellular toxicity of power plant emissions. Compared toxicity of PM collected near power plant with PM collected in control area.
Limitations: Small sample size. Blood lymphocytes collected from 1 person only. Not known if investigators blinded to exposure status (for analysis of DNA damage). Only used single dose level for cellular exposure.

Study Score and Ranking:

0.71; Moderate

Nikolov MC, Coull BA, Catalano PJ, Diaz E, Godleski JJ. 2008. Statistical methods to evaluate health effects associated with major sources of air pollution: a case-study of breathing patterns during exposure to concentrated Boston air particles. Journal of the Royal Statistical Society: Series C Applied Statistics 57(3): 357-378.

Funding Agency: American Chemistry Council, National Institute of Environmental Health Sciences, National Institutes of Health

Study Location: Boston	**Study Design:** Animal toxicology study
Fuel Type: N/A	**Chemicals:** PM (+ species)

Abstract: We conduct a case-study evaluating the source-specific effects of particulate matter on respiratory function. Using a structural equation approach, we assess the effect of different receptor models on the estimated source-specific effects for univariate respiratory response. Furthermore, we extend the structural equation model by placing a factor analysis model on the response to represent the measured respiratory responses in terms of underlying respiratory patterns. We estimate the particulate matter source-specific effects on respiratory rate, accentuated normal breathing and airway irritation and find a strong increase in airway irritation that is associated with exposure to motor vehicle particulate matter.

Strengths and Limitations:

Strengths: Objective outcome measure. 116 usable dog-exposure days (respiratory/exposure data points). Continuous measurement of PM and species. Assessed several different approaches for source apportionment.
Limitations: Small sample size. CAPs exposure via tracheostomy tube (not whole body exposure). No discussion of blinding. Allocation of animals to exposure group not discussed. The effects of motor vehicle and power plant sources could not be disentangled.

Study Score and Ranking:

0.69; Moderate

Rohr AC, Wagner JG, Morishita M, Kamal A, Keeler GJ, Harkema JR. 2010. Cardiopulmonary responses in spontaneously hypertensive and Wistar-Kyoto rats exposed to concentrated ambient particles from Detroit, Michigan. Inhalation Toxicology 22(6): 522-533.

Funding Agency: Electric Power Research Institute, Michigan Life Sciences Corridor	
Study Location: Detroit	**Study Design:** Animal toxicology study
Fuel Type: Coal	**Chemicals:** CO, NOx, O3, PM (+ species), SO2

Abstract: Toxicological effects have been observed in rats exposed to concentrated ambient particles (CAPs) from different regions of the United States. The objective of this study was to evaluate the cardiopulmonary and systemic effects of CAPs in Detroit. The authors stationed a mobile concentrator at a location near major traffic and industrial sources. Spontaneously hypertensive (SH) and Wistar-Kyoto (WKY) rats were exposed to fine CAPs (diameter < 0.1-2.5 μm) 8 h/day for 13 consecutive days. Animals were implanted with telemeters, and electrocardiogram data were recorded continuously. Bronchoalveolar lavage (BAL) fluid and plasma were analyzed. Comprehensive exposure monitoring was conducted, including CAPs components. CAPs exposure concentrations were 103-918 μg/m3 (mean = 502 μg/m3). The authors found no statistically significant differences in heart rate or SDNN (standard deviation of the normal-to-normal intervals), a measure of heart rate variability, between CAPs-exposed and control rats. The authors found significantly higher levels of C-reactive protein in the serum of CAPs-exposed SH rats compared with air-exposed animals. Protein in BAL fluid was elevated in WKY rats exposed to CAPs. Measurement of trace metals in lung tissue showed elevated concentrations of V, Sb, La, and Ce in CAPs-exposed SH animals versus controls. These elements are generally associated with oil combustion, oil refining, waste incineration, and traffic. Examination of wind rose data from the exposure period confirmed that the predominant wind direction was SSW, the direction of many of the aforementioned sources. These results indicate that ambient particles in Detroit can cause mild pulmonary and systemic changes in rats, and suggest the importance of local PM2.5 sources in these effects.

Strengths and Limitations:

Strengths: Utilized a mobile air research laboratory (in a semi-trailer) for assessment of "real-world" exposures to airborne particles. Continuous measurement of pollutants. Used two different rat models.
Limitations: Small sample size (4 animals per group); statistical power was limited. Observed only mild effects. Allocation of animals to exposure group not discussed. No discussion of blinding (particularly for analysis of biological samples). Multiple PM sources in the area (eg. chemical plants, refineries, traffic, coal-fired utilities); contribution of power plants to pollution not assessed.

Study Score and Ranking:

0.73; Moderate

Ukehaxhaj A, Gjorgjev D, Ramadani M, Krasniqi S, Gjergji T, Zogaj D. 2013. Air pollution in Pristina, influence on cardiovascular hospital morbidity. Medical Archives 67: 438-441.

Funding Agency: Not stated	
Study Location: Kosovo	**Study Design:** Time-series
Fuel Type: Coal	**Chemicals:** PM2.5, PM10

Abstract: Introduction: Numerous studies observed health effects of particulate air pollution. Ambient air quality is particularly bad in Pristina. The principal sources of contaminants are sulfur dioxide (SO2), nitrogen oxides NO and NO2 (NOx), ozone (O3), lead (Pb), carbon dioxide (CO2), particulate matter (PM or dust). Objective: to investigate effects of concentrations of pollutants in ambient air on hospital admissions for cardiovascular disease in UCCK- Pristina. Methods: Retrospective ecological study. During the three year analytical research predict the potential benefit of decreasing for concentration of PM2.5, PM10 were measured in two station in Pristina. The study population consisted of all hospitalization patient in intern clinic for 2010, 2011 and 2012 year. Air pollution measurements will be used by KHMI data for the year of 2010, 2011 and 2012 for the municipality of Pristina in the measurements point in: KHMI-MESP which is equipped with automatic analyzer- Air Compact Monitoring System (Version 2.2) recordum MESSTECHNIK GmbH. Statistical data processing will be done with SPSS 17.0 statistical package. Results: Based on the results obtained during the study period concentrated PM are higher level than standards value. The results showed that the number of hospital admissions for cardiovascular disease are positively correlated with concentration pollutants. Results show clear seasonal variation in the effects of PM on hospital admissions in Kosovo. The study period was short but the mean daily admissions for cardiovascular illnesses were quite large. Conclusion: The main source for air pollution was coal-burned power plant and traffic (old vehicles) in Kosovo.

Strengths and Limitations:

Strengths: Examined data over 3 year period. Objective outcome measure.
Limitations: Weak exposure assessment. Limited individual data. Only examined monthly associations (did not examine daily associations). Contribution of power plant emissions to pollution not known (traffic also a major contributor). Not clear how mortality data were obtained.

Study Score and Ranking:

0.63; Moderate

3.3.2 PM - measured emissions (flue gas or ambient air)

White literature

Alolayan MA, Brown KW, Evans JS, Bouhamra WS, Koutrakis P. 2013. Source apportionment of fine particles in Kuwait City. Science of the Total Environment 448: 14-25.

Abstract: This study investigated major sources of PM2.5 in the atmosphere of Kuwait based on a sampling program conducted between February 2004 and October 2005. Three source identification techniques were used in this study: (1) a positive matrix factorization model; (2) backward trajectory profiles; and (3) concentration rose plots. Five major sources of PM2.5 were estimated. These were sand dust (sand storms), oil combustion (power plants), petrochemical industry (fertilizer, nylon or catalyst regeneration facilities), traffic (vehicle emissions and road dust) and transported emissions (emissions from outside Kuwait, such as those from automobiles, road dust or smelters). The estimated contributions to PM2.5 of these sources were: 54% from sand dust, 18% from oil combustion, 12% from petrochemical industry, 11% from traffic and 5% from anthropogenic sources transported from outside the country. Oil combustion, petrochemical industry and traffic were found to emanate from local sources, whereas sand dust and some emissions from traffic, and possibly smelters, appeared to originate from sources outside of Kuwait (transported). The PM2.5 levels in Kuwait during our previous sampling study averaged 53 μg/m3. More than half of the measured PM2.5 appears to have been due to crustal material, much originating outside of the country. However, the relatively high levels of PM2.5 contributed by anthropogenic local sources, such as oil combustion, petrochemical industry emissions, and traffic indicated that there may be great opportunities for Kuwait to improve public health. The application of cost-effective emission controls and development of forward looking environmental health policies have the potential to significantly reduce emissions, population exposures to PM2.5 and the burden of mortality and morbidity from air pollution.

Argyropoulos G, Grigoratos T, Voutsinas M, Samara C. 2013. Concentrations and source apportionment of PM10 and associated elemental and ionic species in a lignite-burning power generation area of southern Greece. Environmental Science and Pollution Research International 20(10): 7214-30.

Abstract: Ambient concentrations of PM10 and associated elemental and ionic species were measured over the cold and the warm months of 2010 at an urban and two rural sites located in the lignite-fired power generation area of Megalopolis in Peloponnese, southern Greece. The PM10 concentrations at the urban site (44.2 +/- 33.6 μg m-3) were significantly higher than those at the rural sites (23.7 +/- 20.4 and 22.7 +/- 26.9 μg m-3). Source apportionment of PM10 and associated components was accomplished by an advanced computational procedure, the robotic chemical mass balance model (RCMB), using chemical profiles for a variety of local fugitive dust sources (power plant fly ash, flue gas desulfurization wet ash, feeding lignite, infertile material from the opencast mines, paved and unpaved road dusts, soil), which were resuspended and sampled through a PM10 inlet onto filters and then chemically analyzed, as well as of other common sources such as vehicular traffic, residential oil combustion, biomass burning, uncontrolled waste burning, marine aerosol, and secondary aerosol formation. Geological dusts (road/soil dust) were found to be major PM10 contributors in both the cold and warm periods of the year, with average annual contribution of 32.6 % at the urban site vs. 22.0 and 29.0 % at the rural sites. Secondary aerosol also appeared to be a significant source, contributing 22.1 % at the urban site in comparison to 30.6 and 28.7 % at the rural sites. At all sites, the contribution of biomass burning was most significant in winter (28.2 % at the urban site vs. 14.6 and 24.6 % at the rural sites), whereas vehicular exhaust contribution appeared to be important mostly in the summer (21.9 % at the urban site vs. 11.5 and 10.5 % at the rural sites). The highest contribution of fly ash (33.2 %) was found at the rural site located to the north of the power plants during wintertime, when winds are favorable. In the warm period, the highest contribution of fly ash was found at the rural site located to the south of the power plants, although it was less important (7.2 %). Moderate contributions of fly ash were found at the urban site (5.4 and 2.7 % in the cold and the warm period, respectively). Finally, the mine field was identified as a minor PM10 source, occasionally contributing with lignite dust and/or deposited wet ash dust under dry summer conditions, with the summertime contributions ranging between 3.1 and 11.0 %

among the three sites. The non-parametric bootstrapped potential source contribution function analysis was further applied to localize the regions of sources apportioned by the RCMB. For the majority of sources, source regions appeared as being located within short distances from the sampling sites (within the Peloponnesse Peninsula). More distant Greek areas of the NNE sector also appeared to be source regions for traffic emissions and secondary calcium sulfate dust.

Argyropoulos G, Manoli E, Kouras A, Samara C. 2012. Concentrations and source apportionment of PM10 and associated major and trace elements in the Rhodes Island, Greece. Science of the Total Environment 432: 12-22.

Abstract: Ambient concentrations of PM10 and associated major and trace elements were measured over the cold and the warm season of 2007 at two sites located in the Rhodes Island (Greece), in Eastern Mediterranean, aimed at source apportionment by Chemical Mass Balance (CMB) receptor modeling. Source chemical profiles, necessary in CMB modeling, were obtained for a variety of emission sources that could possibly affect the study area, including sea spray, geological material, soot emissions from the nearby oil-fuelled thermal power plant, and other anthropogenic activities, such as vehicular traffic, residential oil combustion, wood burning, and uncontrolled open-air burning of agricultural biomass and municipal waste. Source apportionment of PM10 and elemental components was carried out by employing an advanced CMB version, the Robotic Chemical Mass Balance model (RCMB). Vehicular emissions were found to be major PM10 contributor accounting, on average, for 36.8% and 31.7% during the cold period, and for 40.9% and 39.2% in the warm period at the two sites, respectively. The second largest source of ambient PM10, with minor seasonal variation, was secondary sulfates (mainly ammonium and calcium sulfates), with total average contribution around 16.5% and 18% at the two sites. Soil dust was also a remarkable source contributing around 22% in the warm period, whereas only around 10% in the cold season. Soot emitted from the thermal power plant was found to be negligible contributor to ambient PM10 (<1%), however it appeared to appreciably contribute to the ambient V and Ni (11.3% and 5.1%, respectively) at one of the sites during the warm period, when electricity production is intensified. Trajectory analysis did not indicate any transport of Sahara dust; on the contrary, long range transport of soil dust from arid continental regions of Minor Asia and of biomass burning aerosol from the countries surrounding the Black Sea was considered possible.

Behera SN, Sharma M, Dikshit O, Shukla SP. 2011. GIS-based emission inventory, dispersion modeling, and assessment for source contributions of particulate matter in an urban environment. Water Air and Soil Pollution 218: 423-36.

Abstract: The Industrial Source Complex Short Term (ISCST3) model was used to discern the sources responsible for high PM10 levels in Kanpur City, a typical urban area in the Ganga basin, India. A systematic geographic information system-based emission inventory was developed for PM10 in each of 85 grids of 2 x 2 km. The total emission of PM10 was estimated at 11 t day(-1) with an overall breakup as follows: (a) industrial point sources, 2.9 t day(-1) (26%); (b) vehicles, 2.3 t day(-1) (21%); (c) domestic fuel burning, 2.1 t day(-1) (19%); (d) paved and unpaved road dust, 1.6 t day(-1) (15%); and the rest as other sources. To validate the ISCST3 model and to assess air-quality status, sampling was done in summer and winter at seven sampling sites for over 85 days; PM10 levels were very high (89-632 μg m-3). The results show that the model-predicted concentrations are in good agreement with observed values, and the model performance was found satisfactory. The validated model was run for each source on each day of sampling. The overall source contribution to ambient air pollution was as follows: vehicular traffic (16%), domestic fuel uses (16%), paved and unpaved road dust (14%), and industries (7%). Interestingly, the largest point source (coal-based power plant) did not contribute significantly to ambient air pollution. The reason might be due to release of pollutant at high stack height. The ISCST3 model was shown to produce source apportionment results like receptor modeling that could generate source apportionment results at any desired time and space resolution.

Buonanno G, Anastasi P, Di Iorio F, Viola A. 2010a. Ultrafine particle apportionment and exposure assessment in respect of linear and point sources. Atmospheric Pollution Research 1: 36-43.

Abstract: The effects of particulate matter on the environment and public health were widely studied in recent years but agreement amongst these studies on the relative importance of the particle size and its origin

with respect to health effects is still lacking. Nevertheless, air quality standards are moving towards greater focus on the smaller particles. In industrialized areas, anthropogenic activities are a major contributor to the particle concentrations. Then, it is important to characterize the emission sources as well as the evolution of particle size distribution in the proximity of these emission points. In this study, the authors evaluated the particle concentration and size distribution at a downwind receptor site of a linear (a major highway) and point (waste incinerator plant) source in an area characterized by high anthropic environmental impact. The particle emissions of the incinerator under examination were characterized by using a Scanning Mobility Particle Sizer® (SMPS), an Aerodynamic Particle Sizer® (APS) Spectrometer, a Rotating Disk Thermodiluter and a Thermal Conditioner (Matter Engineering AG). As regards the linear source, concentrations were determined at increasing distances from the most important Italian road, the A1 highway. Particle number, surface and mass exponentially decreases away from the freeway, whereas particle number concentration measured at 400 m downwind from the freeway is indistinguishable from upwind background concentration. Annual mean values of $8.6x10^3 \pm 3.7x10^2$ particle cm-3 and 31.1 ± 9.0 μg m-3 were found for particle number and PM10 concentration, typical of a rural site. The particle apportionment and exposure assessment in respect of linear and point sources for ultrafine particles represent the major novelty of the present paper. The study here presented could be very important in developing appropriate management and control strategies for air quality in areas characterized by high anthropic pressure and to perform exposure assessment for populations involved.

Buonanno G, Ficco G, Stabile L. 2009. Size distribution and number concentration of particles at the stack of a municipal waste incinerator. Waste Management 29(2): 749-55.

Abstract: A large number of particles and gaseous products are generated by waste combustion processes. Of particular importance are the ultrafine particles (less than 0.1 μm in aerodynamic diameter) that are emitted in large quantities from all the combustion sources. Recent findings of toxicological and epidemiological studies indicate that fine and ultrafine particles could represent health and environmental risks. Quantifying particulate emissions from combustion sources is important: (i) to examine the source status in compliance with regulations; (ii) to create inventories of such emissions at local, regional and national levels, for developing appropriate management and control strategies in relation to air quality; (iii) to predict ambient air quality in the areas involved at the source and (iv) to perform source apportionment and exposure assessment for the human populations and/or ecological systems involved. In order to control and mitigate the particles in the view of health and environmental risk reduction, a good understanding of the relative and absolute contribution from the emission sources to the airborne concentrations is necessary. For these purposes, the concentration and size distribution of particles in terms of mass and number in a waste gas of a municipal waste incineration plant were measured in the stack gas. The mass concentrations obtained are well below the imposed daily threshold value for both incineration lines and the mass size distribution is on average very stable. The total number concentrations are between 1×10^5 and 2×10^5 particles/cm3 and are on average relatively stable from one test to another. The measured values and the comparison with other point sources show a very low total number concentration of particles at the stack gas, revealing the importance of the flue gas treatment also for ultrafine particles. Also in respect to linear sources (high and light duty vehicles), the comparison shows a negligible emission in terms of the total number of particles.

Buonanno G, Scungio M, Stabile L, Tirler W. 2012. Ultrafine particle emission from incinerators: The role of the fabric filter. Journal of the Air and Waste Management Association 62(1): 103-11.

Abstract: Incinerators are claimed to be responsible of particle and gaseous emissions: to this purpose Best Available Techniques (BAT) are used in the flue-gas treatment sections leading to pollutant emission lower than established threshold limit values. As regard particle emission, only a mass-based threshold limit is required by the regulatory authorities. However; in the last years the attention of medical experts moved from coarse and fine particles towards ultrafine particles (UFPs; diameter less than 0.1 μm), mainly emitted by combustion processes. According to toxicological and epidemiological studies, ultrafine particles could represent a risk for health and environment. Therefore, it is necessary to quantify particle emissions from incinerators also to perform an exposure assessment for the human populations living in their surrounding areas. A further topic to be stressed in the UFP emission from incinerators is the particle filtration efficiency

as function of different flue-gas treatment sections. In fact, it could be somehow important to know which particle filtration method is able to assure high abatement efficiency also in terms of UFPs. To this purpose, in the present work experimental results in terms of ultrafine particle emissions from several incineration plants are reported. Experimental campaigns were carried out in the period 2007-2010 by measuring UFP number distributions and total concentrations at the stack of five plants through condensation particle counters and mobility particle sizer spectrometers. Average total particle number concentrations ranging from 0.4×10^3 to 6.0×10^3 particles cm-3 were measured at the stack of the analyzed plants. Further experimental campaigns were performed to characterize particle levels before the fabric filters in two of the analyzed plants in order to deepen their particle reduction effect; particle concentrations higher than 1×10^7 particles cm-3 were measured, leading to filtration efficiency greater than 99.99%.

Buonanno G, Stabile L, Avino P, Belluso E. 2011. Chemical, dimensional and morphological ultrafine particle characterization from a waste-to-energy plant. Waste Management 31(11): 2253-62.

Abstract: Waste combustion processes are responsible of particles and gaseous emissions. Referring to the particle emission, in the last years specific attention was paid to ultrafine particles (UFPs, diameter less than 0.1 μm), mainly emitted by combustion processes. In fact, recent findings of toxicological and epidemiological studies indicate that fine and ultrafine particles could represent a risk for health and environment. Therefore, it is necessary to quantify particle emissions from incinerators also to perform an exposure assessment for the human populations living in their surrounding areas. To these purposes, in the present work an experimental campaign aimed to monitor UFPs was carried out at the incineration plant in San Vittore del Lazio (Italy). Particle size distributions and total concentrations were measured both at the stack and before the fabric filter inlet in order to evaluate the removal efficiency of the filter in terms of UFPs. A chemical characterization of UFPs in terms of heavy metal concentration was performed through a nuclear method, i.e. Instrumental Neutron Activation Analysis (INAA), as well as a mineralogical investigation was carried out through a Transmission Electron Microscope (TEM) equipped with an Energy Dispersive Spectrometer (EDS) in order to evaluate shape, crystalline state and mineral compound of sampled particles. Maximum values of 2.7×10^7 part. cm-3 and 2.0×10^3 part. cm-3 were found, respectively, for number concentration before and after the fabric filter showing a very high efficiency in particle removing by the fabric filter. With regard to heavy metal concentrations, the elements with higher boiling temperature present higher concentrations at lower diameters showing a not complete evaporation in the combustion section and the consequent condensation of semi-volatile compounds on solid nuclei. In terms of mineralogical and morphological analysis, the most abundant compounds found in samples collected before the fabric filter are Na–K–Pb oxides followed by phyllosilicates, otherwise, different oxides of comparable abundance were detected in the samples collected at the stack.

Buonanno G, Stabile L, Avino P, Vanoli R. 2010b. Dimensional and chemical characterization of particles at a downwind receptor site of a waste-to-energy plant. Waste Management 30(7): 1325-33.

Abstract: In the last years numerous epidemiological studies were carried out to evaluate the effects of particulate matter on human health. In industrialized areas, anthropogenic activities highly contribute to the fine and ultrafine particle concentrations. Then, it is important to characterize the evolution of particle size distribution and chemical composition near these emission points. Waste incineration represents a favorable technique for reducing the waste volume. However, in the past, municipal waste incinerators (MWIs) had a bad reputation due to the emission of toxic combustion byproducts. Consequently, the risk perception of the people living near MWIs is very high even if in Western countries waste incineration has nowadays to be considered a relatively clean process from a technical point of view. The study here presented has an exemplary meaning for developing appropriate management and control strategies for air quality in the surrounding of MWIs and to perform exposure assessment for populations involved. Environment particles were continuously measured through a SMPS/APS system over 12 months. The monitoring site represents a downwind receptor of a typical MWI. Furthermore, elements and organic fractions were measured by means of the Instrumental Neutron Activation Analysis and using dichotomous and high volume samplers. Annual mean values of $8.6 \times 10^3 \pm 3.7 \times 10^2$ part. cm−3 and 31.1 ± 9.0 μg m−3 were found for number and mass concentration, typical of a rural site. Most of the elements can be attributed to long-range transport from

other natural and/or anthropogenic sources. Finally, the Polycyclic Aromatic Hydrocarbons present low concentrations with a mean value of 24.6 ng m−3.

Burr MJ, Zhang Y. 2011a. Source apportionment of fine particulate matter over the Eastern U.S. Part I: Source sensitivity simulations using CMAQ with the Brute Force method. Atmospheric Pollution Research 2(3): 300-17.

Abstract: Exposure to elevated levels of fine particulate matter (PM2.5) is found to be associated with adverse effects on human health, climate change, and visibility. Identification of major sources contributing to PM2.5 is an important step in the formulation of effective reduction strategies. This study uses the U.S. EPA's Community Multiscale Air Quality (CMAQ) modeling system with the brute-force method (BFM) to conduct source apportionment of PM2.5 for 10 source categories over the eastern U.S. at a 12 km horizontal grid resolution for both January and July of 2002. Biomass burning is found to be the greatest contributor to domainwide PM2.5 with a monthly-mean domainwide contribution of ~14% (1.1 μg m-3). The next two largest contributors in January are miscellaneous area sources and coal combustion with contributions of ~12% (0.9 μg m-3) and ~11% (0.9 μg m-3), respectively. In July, coal combustion, miscellaneous area sources, and industrial processes are the top three contributors (by ~31% (2.3 μg m-3), ~9% (0.7 μg m-3), and ~7% (0.5 μg m-3), respectively). Site-specific source contributions indicate that industrial processes and biomass burning are the most important sources of PM2.5 at urban and rural sites, respectively, in January, while coal combustion dominates at both sites in July. While the BFM is theoretically simple and can capture indirect effects resulting from the interactions among precursor and secondary pollutants in the real atmosphere, it is computationally expensive and assumes that the source contributions to each emission category are additive. This assumption does not hold for secondary PM components because of the highly non-linear relationships between precursor emissions and all secondary PM components and, therefore, source apportionment provides no useful information whatsoever on the possible effect of emission reductions on secondary PM.

Burr MJ, Zhang Y. 2011b. Source apportionment of fine particulate matter over the Eastern U.S. Part II: source apportionment simulations using CAMx/PSAT and comparisons with CMAQ source sensitivity simulations. Atmospheric Pollution Research 2(3): 318-36.

Abstract: This Part II paper describes source apportionment (SA) for 10 source categories at a 12 km horizontal grid resolution over the eastern U.S. for January and July of 2002 using the Comprehensive Air Quality Model with extensions/Particulate Source Apportionment Technology (CAMx/PSAT). SA results from CAMx/PSAT are contrasted with those from CMAQ/BFM in Part I. The top three sources domainwide in January are identified to be coal combustion (with a monthly–mean contribution of 14.0%, or 1.1 μg m–3), biomass burning (11.3%, 0.9 μg m–3) and other mobile sources (6.8%, 0.6 μg m–3) by CAMx/PSAT but biomass burning (13.7%, 1.1 μg m–3), miscellaneous area sources (11.8%, 0.9 μg m–3), and coal combustion (10.8%, 0.9 μg m–3) by CMAQ/BFM. Both agree that coal combustion, industrial processes, and miscellaneous area sources are the top three sources in July, though they differ in the magnitude of contributions. Both give similar contributions for primary PM, but they differ substantially in SA results for secondary PM, due primarily to their treatments for oxidant–limiting and indirect effects. While CMAQ/BFM inherently accounts for these effects and can provide useful information for primary and secondary PM species, CAMx/PSAT neglects them by linking each PM species only with its direct primary emission precursor. These effects are enhanced in January due to the increased importance of NO3– and lower concentrations of oxidants relative to July. CAMx/PSAT is thus accurate for SA of the primary PM species but incorrect in its SA for secondary PM species. For a highly non–linear system studied here, the true SA cannot be obtained with current SA methods. Policy–makers must be mindful of relative strengths and weaknesses of each method, as well as the limitation of current SA methods in the SA of secondary PM species, when using such information in support of state implementation plan and epidemiological studies.

Callen MS, Lopez JM, Mastral AM. 2012. Apportionment of the airborne PM10 in Spain. Episodes of potential negative impact for human health. Journal of Environmental Monitoring 14(4): 1211-20.

Abstract: The particulate matter with an aerodynamic diameter less than or equal to 10 and 2.5 microns respectively (PM10 and PM2.5) constitutes one of the main air pollutants, which is currently regulated in Europe through Directive 2008/50/EC due to its proven harmful effects on human health. In this paper, the airborne PM10 samples collected in Zaragoza city during 2001-2009 were apportioned by statistical tools based on principal component analysis with absolute principal component scores (PCA-APCS). PM10 samples were characterized regarding their concentrations of polycyclic aromatic hydrocarbons (PAH) and water-soluble ions. PAH were analyzed by gas chromatography-mass spectrometry-mass spectrometry detection (GC-MS-MS) and ions were analyzed by ion chromatography. A total of five factors were identified by PCA-APCS corresponding to different anthropogenic and natural sources. This work was focused on analyzing in more detail those samples involving higher negative impact on human health, in particular, PM10 samples exceeding the daily PM10 limit value of 50 μg m-3 according to Directive 2008/50/EC and samples with concentrations of benzo[a]pyrene (BaP) higher than the upper assessment threshold (BaP > 0.6 ng m-3) established by the Directive 2004/107/EC. Most of the exceedances of the daily PM10 limit value were associated with direct and indirect North-African long-range transport. During these exceedances, it was observed that anthropogenic pollution sources slightly decreased with regard to the natural sources. This indicated that episodes of high PM10 could have a natural origin associated with long-range transport from the African continent. On the contrary, those exceedances with regional contribution and samples with BaP concentrations higher than 0.6 ng m-3 showed an important contribution of anthropogenic pollution sources increasing their negative impact on human health.

Cao J, Shen Z, Chow JC, Qi G, Watson JG. 2009. Seasonal variations and sources of mass and chemical composition for PM10 aerosol in Hangzhou, China. Particuology 7(3): 161-8.

Abstract: Aerosol observation was conducted for four seasons from September 2001 to August 2002 at five sampling sites in Hangzhou, South China, on PM10 mass, 22 elements (Na, Mg, Al, Si, P, S, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Se, Br, Cd, Ba, and Pb), 5 major ions (F-. Cl-, NO3-, SO42-, and NH4+), and organic and elemental carbon (OC and EC), showing that PM10 mass ranged from 46.7 to 270.8 μg/m3, with an annual average of 119.2 μg/m3. Na, Al, Si, S, K, Ca, and Fe were the most abundant elements in PM10, most of S being in the form of SO42-, SO42-, NO3-, and NH4+ were the major ions, which contributed to about 20% of the PM10 mass. The mean seasonal concentrations for SO42-, averaged over all sites. were found to be 18.0, 18.5, 24.7, and 21.4 μg/m3, for spring, summer, autumn, and winter, respectively, while the corresponding loadings for NO3- were 7.2, 4.7, 7.1, and 11.2 μg/m3, and for NH4+ were 6.0, 5.9. 8.2, and 9.3 μg/m3, in the form mostly of NH4NO3 in spring, autumn, and winter, and mostly of (NH4)(2)SO4 in Summer. The low NO3-/SO42- ratio found indicates coal combustion as the major source throughout the year. The mean annual concentrations of OC and EC in PM10 were found to be 21.4, and 4.1 μg/m3, respectively. Material balance calculation indicated that fugitive dust, the secondary aerosol, and carbonaceous matter were the most abundant species in PM10 for the four seasons, as is characteristic for cities in South China.

Capatina C, Simonescu CM. 2013. The current state of PM10 air pollution in the area of influence of the Rovinari thermal power plant. Revista de Chimie 64(12): 1471-6.

Abstract: This paper presents the current state of PM10 air pollution in the area of influence of Rovinari thermal power plant in Gorj county. In the Rovinari area the air quality monitoring network includes an automatic station on the Southeast part of Rovinari town. PM10 concentration was monitored by this automatic station (code GJ-2). The reference method for the sampling and measurement of PM10 fraction is described by EN12341/1998 European Norm. Exceeding of particulate emissions is admitted until 2013 under the condition of complying with the emission limits allocated to the ROVINARI thermal power plant. The highest concentrations of PM10 were recorded during the cold season (December – February) when the number of exceeded permitted limits by 42% of overtaking in 2012. During the year 2012 the lowest number of exceeding was recorded in period April – August. The Rovinari thermal power plant promoted and

executed upgrading works of electro filters related to power units in order to reduce dust concentrations to fit the emission permitted limits of 50mg/m3.

Cernuschi S, Giugliano M, Ozgen S, Consonni S. 2012. Number concentration and chemical composition of ultrafine and nanoparticles from WTE (waste to energy) plants. Science of the Total Environment 420: 319-26.

Abstract: Stack field testing at four municipal waste-to-energy (WTE) plants was conducted to investigate total number concentrations and size distributions in a size range extended towards the evaluation of ultrafine (UFP) and nanoparticle (NP) fractions with diameters smaller than 100nm and 50nm, respectively. Measurements were performed with a specifically designed sampling line, equipped with a dilution system and a particle counting device for measuring both primary particles in raw flue gases at stack conditions and the contributions of condensable origin, arising from their cooling and dilution immediately following stack release into the atmosphere. Average concentration levels detected ranged between $5x10^3$-$6x10^5$ cm(-3): for all sampling conditions, ultrafine fractions largely prevailed in number size distributions, with average diameters constantly located in the nanoparticle size range. Stack concentrations appeared to be influenced by the design and process configuration of flue gas cleaning systems, with most significant effects related to the presence of wet scrubbing units and the baghouse operating temperature of dry removal processes. Chemical speciation (i.e., trace metals, anions and cations, carbonaceous compounds) of size-resolved particulate fractions was performed on one of the plants. NP and UFP composition was essentially in accordance with the most important fuel and combustion process characteristics: in particular, the presence of chlorides and metal species was consistent with the respective waste feed content and their expected behavior during combustion and flue gas cleaning processes.

Cherian R, Venkataraman C, Kumar A, Sarin MM, Sudheer AK, Ramachandran S. 2010. Source identification of aerosols influencing atmospheric extinction: Integrating PMF and PSCF with emission inventories and satellite observations. Journal of Geophysical Research-Atmospheres 115, D22212.

Abstract: The relative influence of source categories of aerosols that affect atmospheric extinction is analyzed by evaluating the potential source contribution function (PSCF) based source regions of the positive matrix factorization (PMF) estimated factors against satellite retrievals of aerosol index and active fires and combining with emission inventory information. This approach has been applied to aerosol chemical data obtained from the integrated campaign undertaken during March-May 2006: Integrated Campaign for Aerosols, Gases and Radiation Budget (ICARB). Four source categories were identified: dust, nitrate-and-dust, biomass-and-fossil combustion, and secondary species. The relative influence of dust and nitrate-and-dust was higher during north-south transport from west Asia over the Arabian Sea during the period of campaign, coincident with highs in the spatial distribution of Ultraviolet Aerosol Index (UVAI) from the Ozone Monitoring Instrument (OMI), implying dust-nitrate association in the outflow from west Asia. The relative influence of anthropogenic sources (biomass-and-fossil combustion and secondary species) was higher over Bay of Bengal during March-April 2006. High fire frequency from the Moderate Resolution Imaging Spectroradiometer (MODIS), coincident with the probable source regions identified in the central Indo-Gangetic plain and central India (south of 27 degrees N), indicates influence of biomass burning source. The biomass-and-fossil combustion factor arising from biofuel, crop residue, and forest fires is evident by their large emission flux rather than from industrial sources in the probable source regions associated with this factor. In contrast, thermal power plant and industries largely influenced the secondary species factor. This approach provides verification of source categories identified through PMF against active sources from satellite remote sensing and provides an estimate of their relative strength based on emission inventory information.

Cohen DD, Crawford J, Stelcer E, Bac VT. 2010. Long range transport of fine particle windblown soils and coal fired power station emissions into Hanoi between 2001 to 2008. Atmospheric Environment 44(31): 3761-9.

Abstract: Fine particulate matter (PM2.5), source fingerprints and their contributions have been measured and reported previously at Hanoi, Vietnam, from 25 April 2001 to 31 December 2008. In this study back trajectories are used to identify long range transport into Hanoi for two of these sources, namely, windblown dust (Soil) from 12 major deserts in China and emissions from 33 coal fired power plants (Coal) in Vietnam and China. There were 28 days of extreme Soil events with concentrations greater than 6 μg m−3 and 25 days of extreme Coal with concentrations greater than 30 μg m−3 from a total of 748 sampling days during the study period. Through the use of back trajectories it was found that long range transport of soil from the Taklamakan and Gobi desert regions (more than 3000 km to the north west) accounted for 76% of the extreme events for Soil. The three local Vietnamese power stations contributed to 15% of the extreme Coal events, while four Chinese power stations between 300 km and 1700 km to the north-east of Hanoi contributed 50% of the total extreme Coal events measured at the Hanoi sampling site.

Cohen DD, Crawford J, Stelcer E, Atanacio AJ. 2012. Application of positive matrix factorization, multi-linear engine and back trajectory techniques to the quantification of coal-fired power station pollution in metropolitan Sydney. Atmospheric Environment 61: 204-11.

Abstract: Over 900 fine particle Teflon filters were collected within the Sydney Basin between 1 January 2001 and 31 December 2011 and analyzed using simultaneous PIXE, PIGE, RBS and PESA techniques to determine 21 different elements between hydrogen and lead. These elements were used in positive matrix factorization (PMF) and multi-linear engine (ME) techniques together with HYSPLIT wind back trajectory techniques to quantitatively determine source fingerprints and their contributions from coal-fired power stations. The power stations were many kilometers outside the greater Sydney metropolitan area but still had a significant impact on the fine particle mass loadings measured at the sampling site within this metropolitan area. The PM2.5 eleven year average mass at the sampling site was 6.48 μg m-3. The corresponding ammonium sulfate estimate was 1.65 μg m-3 or 26% of the PM2.5 mass. By applying back trajectory data and (ME) analysis methods, two power related fingerprints, secondary sulfate (2ndryS-Power) and aged industrial sulfur (IndSagedPower) were determined. These two power related fingerprints were responsible for between 14 and 18% of the total PM2.5 mass and 34-47% of the total sulfate measured at the sampling site. That is on average somewhere between a third and a half of all the sulfate measured in the greater Sydney region could be attributed to coal-fired power station emissions.

Cohen DD, Crawford J, Stelcer E, Bac VT. 2010. Characterisation and source apportionment of fine particulate sources at Hanoi from 2001 to 2008. Atmospheric Environment 44(3): 320-8.

Abstract: PM2.5 particulate matter has been collected on Teflon filters every Sunday and Wednesday at Hanoi, Vietnam for nearly eight years from April 2001 to December 2008. These filters have been analysed for over 21 different chemical species from hydrogen to lead by ion beam analysis techniques. This is the first long term PM2.5 dataset for this region. The average PM2.5 mass for the study period was (54 ± 33) μg m−3, well above the current US EPA health goal of 15 μg m−3. The average PM2.5 composition was found to be (29 ± 8)% ammonium sulfate, (8.9 ± 3.3)% soil, (28 ± 11)% organic matter, (0.6 ± 1.4)% salt and (9.2 ± 2.8)% black carbon. The remaining missing mass (25%) was mainly nitrates and absorbed water. Positive matrix factorisation techniques identified the major source contributions to the fine mass as automobiles and transport (40 ± 10)%, windblown soil (3.4 ± 2)%, secondary sulfates (7.8 ± 10)%, smoke from biomass burning (13 ± 6)%, ferrous and cement industries (19 ± 8)%, and coal combustion (17 ± 7)% during the 8 year study period.

Contini D, Belosi F, Gambaro A, Cesari D, Stortini AM, Bove MC. 2012. Comparison of PM10 concentrations and metal content in three different sites of the Venice Lagoon: an analysis of possible aerosol sources. Journal of Environmental Sciences 24(11): 1954-65.

Abstract: The Venice Lagoon is exposed to atmospheric pollutants from industrial activities, thermoelectric power plants, petrochemical plants, incinerator, domestic heating, ship traffic, glass factories and vehicular

emissions on the mainland. In 2005, construction began on the mobile dams (MOSE), one dam for each channel connecting the lagoon to the Adriatic Sea as a barrier against high tide. These construction works could represent an additional source of pollutants. PM10 samples were taken on random days between 2007 and 2010 at three different sites: Punta Sabbioni, Chioggia and Malamocco, located near the respective dam construction worksites. Chemical analyses of V, Cr, Fe, Co, Ni, Cu, Zn, As, Mo, Cd, Sb, Tl and Pb in PM10 samples were performed by Inductively coupled plasma-quadrupole mass spectrometry (ICP-QMS) and results were used to identify the main aerosol sources. The correlation of measured data with meteorology, and source apportionment, failed to highlight a contribution specifically associated to the emissions of the MOSE construction works. The comparison of the measurements at the three sites showed a substantial homogeneity of metal concentrations in the area. Source apportionment with principal component analysis (PCA) and positive matrix factorization (PMF) showed that a four principal factors model could describe the sources of metals in PM10. Three of them were assigned to specific sources in the area and one was characterised as a source of mixed origin (anthropogenic and crustal). A specific anthropogenic source of PM10 rich in Ni and Cr, active at the Chioggia site, was also identified.

Cvetkovic Z, Logar M, Rosic A, Ciric A. 2012. Mineral composition of the airborne particles in the coal dust and fly ash of the Kolubara basin (Serbia). Periodico Di Mineralogia 81(2): 205-23.

Abstract: The airborne particles were collected near the power plant and the opencast coal mine of the Kolubara basin. This paper represents the part of the one-year project aiming to collect, characterize and then determine the mineralogical composition of the airborne particles. Samples of deposited particulate matter from the air were collected between March 2007 and March 2008. Mean concentrations content of soluble, insoluble and total deposited matter measured annually exceed 200 mg/m2 per day (U-1 and U-3). The particle distribution at all sites was classified in three classes: the particles larger than 10 μm, the particles from 10 to 2.5 μm and the particles below 2.5 μm. Such a division gave the ratio of inhaled and respiratory particle concentrations by the measuring points. Scanning electron microscopy showed that dust from coal mines and power plant largely consists of the group of mineral grains and coal particles. SEM-EDS analysis also showed that the mineral composition of the deposited particulate matter was heterogeneous but uniform throughout the investigated area. These findings were also supported by X-ray powder diffraction analytical studies, which gave a similar mineral composition for all samples (quartz, feldspar, clays, gypsum, dolomite, calcite, micas, chlorite and hematite). This paper shows that both concentration and mineralogical characterization of airborne particles from mine and power plant are essential for quantification of the fractions that are inhaled and for the identification of potentially dangerous (hazardous) components in the deposited matter.

Davy PK, Gunchin G, Markwitz A, Trompetter WJ, Barry BJ, Shagjjamba D et al. 2011. Air particulate matter pollution in Ulaanbaatar, Mongolia: Determination of composition, source contributions and source locations. Atmospheric Pollution Research 2(2): 126-37.

Abstract: Ulaanbaatar, the capital city of Mongolia is subject to high air particulate matter pollution episodes during winter and during dust storm events in spring and autumn that have severe implications for the health of the exposed population. This paper presents the results of fine (PM2.5) and coarse (PM10-2.5) particulate matter monitoring in Ulaanbaatar from 2004 to 2008 and receptor modelling to determine the sources contributing to particulate matter pollution. Ion Beam Analysis was used to determine elemental concentrations in the two size fractions and black carbon was measured with a light reflectance device. Mass contributions to ambient particle concentrations from emission sources were estimated by positive matrix factorisation and air mass back-trajectory analysis was used to assess probable source locations. The results show that crustal matter sources are the primary contributors to the coarse particle fraction. Combustion sources (coal combustion, biomass burning, and motor vehicles) dominate the fine fraction of particulate matter in the Ulaanbaatar airshed, primarily from local emission sources but forest fires to the north can be a significant contributor to biomass burning concentrations at times. Analysis of seasonal differences showed that coal combustion processes were largely responsible for fine particle air pollution episodes during winter. Temporal trends show an increase in the coal combustion contributions over the monitoring period. We

suggest that this is linked to the increase in the Ulaanbaatar population and a consequent increase in the use of coal for power generation and domestic heating purposes.

Fang GC, Chang CC. 2009. Atmospheric particulates and ionic pollutants study at Wu-Chi, central Taiwan. Environmental Forensics 10(2): 93-100.

Abstract: This study characterizes ambient air particulate mass and ionic species near industrial zones and the Taiwan Strait in central Taiwan. Analysis results indicated that average particulate mass concentration at the sampling site for fine particulate matter (PM2.5) and coarse (PM2.5-10) particles were 40.1 ± 21.1 (μg/m3) and 26.7 ± 14.3 (μg/m3), respectively. Analysis of the average component percentage of various kinds of ionic species showed that the major components of PM2.5 were SO42-, NO3- and NH4+. Their possible origin is from the combustion of fossil fuels for power and transportation, as well as from manufacturing processes. Furthermore, the major components of PM2.5-10 were NO3-, Na+, Ca2+ and Cl-. Their possible origin is from vehicle emissions, crustal materials, secondary aerosols, biomass burning, industrial emissions, and marine spray. Nevertheless, the emission source for the SO42-, NO3- and NH4+ was situated close to a roadway (approximately 10 m away). And the emission source for the Cl-, Na+ and Ca2+ was situated close to seaboard (approximately 2 km away). Moreover, the emission source for SO42- had originated from the Taichung power plant, which was approximately 2 km away from the sampling site. As presented in a previous study, the Taichung power plant was responsible for the high concentration of SO42- in this region (Fang et al., 1999; Fang et al., 2006).

Fang GC, Huang CS. 2012. Apply Woods model in the predictions of ambient air particles and metallic elements (Mn, Fe, Zn, Cr, and Cu) at industrial, suburban/coastal, and residential sampling sites. The Scientific World Journal 2012: 207620.

Abstract: The main purpose for this study was to monitor ambient air particles and metallic elements (Mn, Fe, Zn, Cr, and Cu) in total suspended particulates (TSPs) concentration, dry deposition at three characteristic sampling sites of central Taiwan. Additionally, the calculated/measured dry deposition flux ratios of ambient air particles and metallic elements were calculated with Woods models at these three characteristic sampling sites during years of 2009-2010. As for ambient air particles, the results indicated that the Woods model generated the most accurate dry deposition prediction results when particle size was 18 μm in this study. The results also indicated that the Woods model exhibited better dry deposition prediction performance when the particle size was greater than 10 μm for the ambient air metallic elements in this study. Finally, as for Quan-xing sampling site, the main sources were many industrial factories under process around these regions and were severely polluted areas. In addition, the highest average dry deposition for Mn, Fe, Zn, and Cu species occurred at Bei-shi sampling site, and the main sources were the nearby science park, fossil fuel combustion, and Taichung thermal power plant (TTPP). Additionally, as for He-mei sampling site, the main sources were subjected to traffic mobile emissions.

Frey AK, Saarnio K, Lamberg H, Myllari F, Karjalainen P, Teinila K et al. 2014. Optical and chemical characterization of aerosols emitted from coal, heavy and light fuel oil, and small-scale wood combustion. Environmental Science and Technology 48(1): 827-36.

Abstract: Particle emissions affect radiative forcing in the atmosphere. Therefore, it is essential to know the physical and chemical characteristics of them. This work studied the chemical, physical, and optical characteristics of particle emissions from small-scale wood combustion, coal combustion of a heating and power plant, as well as heavy and light fuel oil combustion at a district heating station. Fine particle (PM1) emissions were the highest in wood combustion with a high fraction of absorbing material. The emissions were lowest from coal combustion mostly because of efficient cleaning techniques used at the power plant. The chemical composition of aerosols from coal and oil combustion included mostly ions and trace elements with a rather low fraction of absorbing material. The single scattering albedo and aerosol forcing efficiency showed that primary particles emitted from wood combustion and some cases of oil combustion would have a clear climate warming effect even over dark earth surfaces. Instead, coal combustion particle emissions had a cooling effect. Secondary processes in the atmosphere will further change the radiative properties of these emissions but are not considered in this study.

Goodarzi F, Sanei H. 2009. Plerosphere and its role in reduction of emitted fine fly ash particles from pulverized coal-fired power plants. Fuel 88(2): 382-6.

Abstract: Fine particles (PM2.5) emitted from the stacks of the coal-fired power plants are of environmental concern since they can easily enter the human respiratory track. The detailed study of the fly ash particles using scanning electron microscope/electron dispersive spectrometry (SEM/EDX) show that fine solid spherical particles (microspheres) are contained by the large cenosphere particles (>50 μm) during the combustion process. The resulting macro particles are known as "plerosphere", which are typically impregnated by the fine microspheres. The coal-fired power plants' particle control devices such as the electrostatic precipitators (ESP) and baghouse filters tend to capture the large plerospheres, more efficiently. Therefore, the result of this study suggests that the containment of the microspheres by plerospheres during the coal combustion process can effectively reduce the amount of fine particles and associated elements released into atmosphere.

Hammond DM, Dvonch JT, Keeler GJ, Parker EA, Kamal AS, Barres JA et al. 2008. Sources of ambient fine particulate matter at two community sites in Detroit, Michigan. Atmospheric Environment 42(4): 720-32.

Abstract: Detroit, Michigan is a non-attainment area of the annual PM2.5 (particles ⩽2.5 μm in diameter) National Ambient Air Quality Standard (NAAQS), and contains a host of local pollution contributors including high diesel traffic from a nearby international border crossing. A source apportionment analysis was conducted using PM2.5 data collected from 1999 to 2002 by the Community Action Against Asthma (CAAA) project in Detroit, Michigan. CAAA used a community-based participatory research approach to identify and address the environmental triggers for asthma among children residing in southwest and east Detroit. The data used for the study included 24-h measurements of PM2.5 mass, elemental and organic carbon, and a suite of trace element species, along with hourly measurements of PM2.5 mass and black carbon. Positive matrix factorization (PMF2) was used to quantitatively apportion the sources of ambient PM2.5 at each of two Detroit community sites. Results showed that southwest Detroit PM2.5 levels can be apportioned to seven source categories: secondary sulfate/coal combustion, gasoline vehicles, diesel vehicles, refinery/oil combustion, iron–steel manufacturing/waste incineration, automotive electroplating, and sewage sludge incineration that includes crustal material from runoff. The PMF2 model apportioned the east Detroit PM2.5 data into five source categories: secondary sulfate/coal combustion, motor vehicles/combustion, refinery/oil combustion, iron–steel manufacturing/waste incineration, and automotive electroplating. For both locations, approximately over 60% of the PM2.5 mass was attributed to secondary sulfate/coal combustion sources, approximately 30% to vehicular sources, and 1–5% to local industrial sources. The unexplained mass accounted for <2% of the measured PM2.5 mass. This study illustrates that regional secondary sulfate/coal combustion and local motor vehicle emissions alone are enough for this mid-western US city to be in non-attainment for the annual PM2.5 NAAQS.

Happonen M, Myllari F, Karjalainen P, Frey A, Saarikoski S, Carbone S et al. 2013. Size distribution, chemical composition, and hygroscopicity of fine particles emitted from an oil-fired heating plant. Environmental Science and Technology 47(24): 14468-75.

Abstract: Heavy fuel oil (HFO) is a commonly used fuel in industrial heating and power generation and for large marine vessels. In this study, the fine particle emissions of a 47 MW oil-fired boiler were studied at 30 MW power and with three different fuels. The studied fuels were HFO, water emulsion of HFO, and water emulsion of HFO mixed with light fuel oil (LFO). With all the fuels, the boiler emitted considerable amounts of particles smaller than 200 nm in diameter. Further, these small particles were quite hygroscopic even as fresh and, in the case of HFO+LFO emulsion, the hygroscopic growth of the particles was dependent on particle size. The use of emulsions and the addition of LFO to the fuel had a reducing effect on the hygroscopic growth of particles. The use of emulsions lowered the sulfate content of the smallest particles but did not affect significantly the sulfate content of particles larger than 42 nm and, further, the addition of LFO considerably increased the black carbon content of particulate matter. The results indicate that even the

fine particles emitted from HFO based combustion can have a significant effect on cloud formation, visibility, and air quality.

Hendriks C, Kranenburg R, Kuenen J, van Gijlswijk R, Wichink Kruit R, Segers A et al. 2013. The origin of ambient particulate matter concentrations in the Netherlands. Atmospheric Environment 69: 289-303.

Abstract: Particulate matter poses a significant threat to human health. To be able to develop effective mitigation strategies, the origin of particulate matter needs to be established. The regional air quality model LOTOS-EUROS, equipped with a newly developed labeling routine, was used to establish the origin of PM10 and PM2.5 in the Netherlands for 2007-2009 at the source sector level, distinguishing between national and foreign sources. The results suggest that 70-80% of modeled PM10 and 80-95% of PM2.5 in the Netherlands is of anthropogenic origin. About 1/3 of anthropogenic PM10 is of Dutch origin and 2/3 originates in foreign countries. Agriculture and transport are the Dutch sectors with the largest contribution to PM10 mass in the Netherlands, whereas the foreign contribution is more equally apportioned to road transport, other transport, industry, power generation and agriculture. For the PM2.5 fraction, a larger share is apportioned to foreign and anthropogenic origin than for PM10, but the same source sectors are dominant. The national contribution to PM levels is significantly higher in the densely populated Randstad area than for the country on average and areas close to the borders. In general, the Dutch contribution to the concentration of primary aerosol is larger than for secondary species. The sectoral origin varies per component and is location and time dependent. During peak episodes, natural sources are less important than under normal conditions, whereas especially road transport and agriculture become more important.

Hinkley JT, Bridgman HA, Buhre BJ, Gupta RP, Nelson PF, Wall TF. 2008. Semi-quantitative characterisation of ambient ultrafine aerosols resulting from emissions of coal fired power stations. Science of the Total Environment 391(1): 104-13.

Abstract: Emissions from coal fired power stations are known to be a significant anthropogenic source of fine atmospheric particles, both through direct primary emissions and secondary formation of sulfate and nitrate from emissions of gaseous precursors. However, there is relatively little information available in the literature regarding the contribution emissions make to the ambient aerosol, particularly in the ultrafine size range. In this study, the contribution of emissions to particles smaller than 0.3 μm in the ambient aerosol was examined at a sampling site 7 km from two large Australian coal fired power stations equipped with fabric filters. A novel approach was employed using conditional sampling based on sulfur dioxide (SO2) as an indicator species, and a relatively new sampler, the TSI Nanometer Aerosol Sampler. Samples were collected on transmission electron microscope (TEM) grids and examined using a combination of TEM imaging and energy dispersive X-ray (EDX) analysis for qualitative chemical analysis. The ultrafine aerosol in low SO2 conditions was dominated by diesel soot from vehicle emissions, while significant quantities of particles, which were unstable under the electron beam, were observed in the high SO2 samples. The behaviour of these particles was consistent with literature accounts of sulfate and nitrate species, believed to have been derived from precursor emissions from the power stations. A significant carbon peak was noted in the residues from the evaporated particles, suggesting that some secondary organic aerosol formation may also have been catalysed by these acid seed particles. No primary particulate material was observed in the minus 0.3 μm fraction. The results of this study indicate the contribution of species more commonly associated with gas to particle conversion may be more significant than expected, even close to source.

Hoinaski L, Franco D, Stuetz RM, Sivret EC, De Melo Lisboa H. 2013. Investigation of PM10 sources in Santa Catarina, Brazil through graphical interpretation analysis combined with receptor modelling. Environmental Technology 34(17): 2453-63.

Abstract: Epidemiological studies have documented that elevated airborne particulate matter (PM) concentrations, especially those with an aerodynamic diameter less than 10 μm (PM10), are associated with adverse health effects. Two receptor models, UNMIX and positive matrix factorization (PMF), were used to identify and quantify the sources of PM10 concentrations in Tubarão and Capivari de Baixo, Santa Catarina,

Brazil. This region is known for its high pollution levels due to intense industrial activity and exploitation of natural resources. PM10 samples were collected using high volume samplers at two sites in the region and statistical exploratory analysis techniques were applied to identify and assess PM10 sources. The two primary PM10 sources were identified as soil re-suspension/road dust emissions and coal burning emissions, contributing 65–75% and 15–25% of the PM10, respectively. The study confirmed the significance of the influence of local PM10 emissions (power plants, soil re-suspension and road dust emissions) on regional air quality, although no violations of the Brazilian PM10 standards (limit of 150 μg/m3) were observed, with a mean concentration of 27.6 μg/m3 measured in this study. This study demonstrated the usefulness of statistical exploratory analysis techniques in assessing the validity of modelling results and contributing to the interpretation of ambient air quality data.

Huang J, Chen X, Liu CK, Huang CS, Fang GC. 2013. Ambient trace metals sources in Taichung, Taiwan: Principal component analysis. Aerosol and Air Quality Research 13(2): 672-9.

Abstract: There were eight trace metals, including As, Hg, Mn, Fe, Zn, Cr, Cu, and Pb, measured in the total suspended particles collected in central Taiwan using PS-1 samplers at five different sites. Overall, these trace metal concentrations were lower in summer than other seasons, and higher in industrial areas than in wetland. Principal Component Analysis (PCA) was utilized to identify the pollutant sources for each site. Three distinct sources were found in this study, and the results suggest that mobile sources were the main factor contributing to Mn, Fe, Zn, and Cr emissions, which were mainly from urban areas and in the vicinity of highways intersections. Within addition, municipal solid waste incinerators are significantly associated with emissions of As, Hg, Cu, and Pb. Finally, smelters were associated with high Hg, As, Fe, and Zn emissions from local industrial areas. However, contributions from two known point sources, a coal-fired power plant and a steeling plant could not be distinguished from the PCA results. This may be due to the prevailing wind directions and limitations of the measurements used in this work. These two sources are located to the west of these sampling sites, while the prevailing wind direction in this area was southwest.

Iordanidis A, Buckman J, Triantafyllou AG, Asvesta A. 2008a. ESEM-EDX characterisation of airborne particles from an industrialised area of northern Greece. Environmental Geochemistry and Health 30(5): 391-405.

Abstract: The aim of this study was to characterise individual airborne particles collected from the Ptolemais-Kozani region (Western Macedonia), northern Greece. Throughout a 1-year period (March 2003 to February 2004), we collected several filters that captured airborne particles at seven sampling sites distributed throughout the area. The airborne particles captured on the filters were then characterised by environmental scanning electron microscopy (ESEM) coupled with energy-dispersive X-ray analysis (EDX). The particles were categorised as geogenic, biogenic and anthropogenic. The main anthropogenic airborne particles were fly ash (released from lignite-fired power plants) and carbonaceous (soot and char) and metalliferous (mainly iron- and copper-enriched) particulates. We present here characteristic ESEM and EDX spectra for the airborne particles and underline the presence of characteristic primary and secondary sulphates.

Iordanidis A, Buckman J, Triantafyllou AG, Asvesta A. 2008b. Fly ash-airborne particles from Ptolemais-Kozani area, northern Greece, as determined by ESEM-EDX. International Journal of Coal Geology 73(1): 63-73.

Abstract: The aim of this study is to investigate the contribution of fly ash from lignite-fired power stations to the air pollution of the Western Macedonia region of northern Greece. Several filters that capture airborne particles were collected over a year's period (March 2003 to February 2004), from seven sampling sites spread throughout the area. In addition, fly ash was collected from two power plants in this area along with stack ash (fly ash that escaped the electrostatic precipitators and trapped at the stack's exit). Both fly ash and filters were analysed with the help of Environmental Scanning Electron Microscopy (ESEM), coupled with energy dispersive X-ray analysis (EDX) in order to determine the morphological, mineralogical and chemical characteristics of fly ash particles. Cenospheres, vesicular spheres, spheroids, dense spheres and chars were the main recognized fly ash particles. Similar airborne particles were also present in almost every filter collected in the area. Sampling sites situated nearby power plants had apparently more fly ash particles. Fine

fly ash particles (= 10 μm) were mostly recorded in the vicinity of power stations. The analysis also revealed the presence of potential toxic elements in the fly ash, a fact with important environmental implications.

Iordanidis A, Zoras S, Triantafyllou AG, Buckman J, Asvesta A, Evagelopoulos V. 2008c. Characterisation of airborne particles collected proximal to lignite mines and power plants of Ptolemais-Kozani area, northern Greece. Fresenius Environmental Bulletin 17: 378-98.

Abstract: Several filters of total suspended particles (TSP) were collected from two sampling sites, situated near opencast lignite mines and lignite-fired power plants, within the Ptolemais-Kozani region, northern Greece. Environmental Scanning Electron Microscopy (ESEM), coupled with Energy Dispersive X-Ray analysis (EDX) was employed for the characterisation of individual airborne particles trapped into TSP filters. Mining activities along with lignite burning contributed to the heavy air pollution load of one site, while fugitive dust from power plants were the main air pollutants in the other sampling site. High TSP concentrations have been favored due to stagnation and light surface winds. Characteristic ESEM images of airborne particles are presented in this study. Particles were categorized as geogenic, biogenic and anthropogenic (mainly fly ash released from the power plants) and found to agree with the explanation given by means of meteorology and local terrain characteristics.

Jeong CH, Evans GJ, McGuire ML, Chang RYW, Abbatt JPD, Zeromskiene K. 2010. Particle formation and growth at five rural and urban sites. Atmospheric Chemistry and Physics 10: 7979-95.

Abstract: Ultrafine particle (UFP) number and size distributions were simultaneously measured at five urban and rural sites during the summer of 2007 in Ontario, Canada as part of the Border Air Quality and Meteorology Study (BAQS-Met 2007). Particle formation and growth events at these five sites were classified based on their strength and persistence as well as the variation in geometric mean diameter. Regional nucleation and growth events and local short-lived strong nucleation events were frequently observed at the near-border rural sites, upwind of industrial sources. Surprisingly, the particle number concentrations at one of these sites were higher than the concentrations at a downtown site in a major city, despite its high traffic density. Regional nucleation and growth events were favored during intense solar irradiance and in less polluted cooler drier air. The most distinctive regional particle nucleation and growth event during the campaign was observed simultaneously at all five sites, which were up to 350 km apart. Although the ultrafine particle concentrations and size distributions generally were spatially heterogeneous across the region, a more uniform spatial distribution of UFP across the five areas was observed during this regional nucleation event. Thus, nucleation events can cover large regions, contributing to the burden of UFP in cities and potentially to the associated health impacts on urban populations. Local short-lived nucleation events at the three near-border sites during this summer three-week campaign were associated with high SO2, which likely originated from US and Canadian industrial sources. Hence, particle formation in southwestern Ontario appears to often be related to anthropogenic gaseous emissions but biogenic emissions at times also contribute. Longer-term studies are needed to help resolve the relative contributions of anthropogenic and biogenic emissions to nucleation and growth in this region.

Jorquera H, Barraza F. 2012. Source apportionment of ambient PM2.5 in Santiago, Chile: 1999 and 2004 results. Science of the Total Environment 435-436: 418-29.

Abstract: A receptor model analysis has been applied to ambient PM2.5 measurements taken at Santiago, Chile (33.5 degrees S, 70.7 degrees W) in 2004 (117 samples) and in 1999 (95 samples) on a receptor site on the eastern side of the city. For both campaigns, six sources have been identified at Santiago and their contributions in 1999/2004 are: motor vehicles: 28 +/- 2.5/31.2 +/- 3.4%, wood burning: 24.8 +/- 2.3/28.9 +/- 3.3%, sulfates: 18.8 +/- 1.7/16.2 +/- 2.5%, marine aerosol: 13 +/- 2.1/9.9 +/- 1.5%, copper smelters: 11.5 +/- 1.4/9.7 +/- 3.3% and soil dust: 3.9 +/- 1.5/4.0 +/- 2.4%. Hence relative contributions are statistically the same but the absolute contributions have been reduced because ambient PM2.5 has decreased from 34.2 to 25.1 μg/m3 between 1999 and 2004 at Santiago. Similarity of results for both data sets - analyzed with different techniques at different laboratory facilities - shows that the analysis performed here is robust. Source identification was carried out by inspection of key species in source profiles, seasonality of source contributions, comparison with published source profiles and by looking at wind trajectories

computed using the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) from USA's National Oceanic and Atmospheric Administration (NOAA); for the wood burning sources the MODIS burned area daily product was used to confirm wildfire events along the year. Using this combined methodology we have shown conclusively that: a) marine air masses do reach Santiago's basin in significant amounts but combined with anthropogenic sources; b) all copper smelters surrounding Santiago - and perhaps coal-fired power plants as well - contribute to ambient PM2.5; c) wood burning is the second largest source, coming from residential wood burning in fall and winter and from regional wildfires in spring and summer. The results of the present analysis can be used to improve emission inventories, air quality forecasting systems and cost-benefit analyses at local and regional scales.

Junkermann W, Hagemann R, Vogel B. 2011a. Nucleation in the Karlsruhe plume during the COPS/TRACKS-Lagrange experiment. Quarterly Journal of the Royal Meteorological Society 137: 267-74.

Abstract: A plume of ultrafine particles was observed downwind of the Karlsruhe city and industrial area during the COPS/TRACKS Lagrangian airborne experiment in summer 2007. These ultrafine particles were identified as nucleation-generated aerosols from emissions of a coal-fired power plant and an adjacent refinery, the two main emitters of sulphur dioxide in the area. Modelling the production and growth of aerosols with the COSMO-ART model required, in agreement with the known emission sources, a strong elevated source of sulphur dioxide to explain the temporal evolution of the particle plume. The power plant at Karlsruhe Rheinhafen emits from a 233 m high chimney. The ultrafine particles produced from these fossil-fuel-related sources were the dominant fraction of all ultrafine particles in the rural area of the Kraichgau downwind of Karlsruhe, exceeding all other anthropogenic sources and are suspected of being the major contribution to the number of cloud condensation nuclei (CCN) on a regional scale. Compared to previous investigations on the sulphur chemistry in power-plant plumes, emissions from this power plant, which is equipped with modern stack-gas cleaning technology, had a higher yield of nucleation-mode aerosols as CCN precursors per emitted sulphur dioxide mass.

Junkermann W, Vogel B, Sutton MA. 2011b. The climate penalty for clean fossil fuel combustion. Atmospheric Chemistry and Physics 11: 12917-24.

Abstract: To cope with the world's growing demand for energy, a large number of coal-fired power plants are currently in operation or under construction. To prevent environmental damage from acidic sulphur and particulate emissions, many such installations are equipped with flue gas cleaning technology that reduces the emitted amounts of sulphur dioxide (SO2) and nitrogen dioxide (NO2). However, the consequences of this technology for aerosol emissions, and in particular the regional scale impact on cloud microphysics, have not been studied until now. We performed airborne investigations to measure aerosol size distributions in the air masses downwind of coal-fired power installations. We show how the current generation of clean technology reduces the emission of sulphur and fine particulate matter, but leads to an unanticipated increase in the direct emission of ultrafine particles (1-10 nm median diameter) which are highly effective precursors of cloud condensation nuclei (CCN). Our analysis shows how these additional ultrafine particles probably modify cloud microphysics, as well as precipitation intensity and distribution on a regional scale downwind of emission sources. Effectively, the number of small water droplets might be increased, thus reducing the water available for large droplets and rain formation. The possible corresponding changes in the precipitation budget with a shift from more frequent steady rain to occasionally more vigorous rain events, or even a significant regional reduction of annual precipitation, introduce an unanticipated risk for regional climate and agricultural production, especially in semi-arid climate zones.

Junninen H, Mønster J, Rey M, Cancelinha J, Douglas K, Duane M et al. 2009. Quantifying the impact of residential heating on the urban air quality in a typical European coal combustion region. Environmental Science and Technology 43(20): 7964-70.

Abstract: The present investigation, carried out as a case study in a typical major city situated in a European coal combustion region (Krakow, Poland), aims at quantifying the impact on the urban air quality of residential heating by coal combustion in comparison with other potential pollution sources such as power

plants, industry, and traffic. Emissions were measured for 20 major sources, including small stoves and boilers, and the particulate matter (PM) was analyzed for 52 individual compounds together with outdoor and indoor PM10 collected during typical winter pollution episodes. The data were analyzed using chemical mass balance modeling (CMB) and constrained positive matrix factorization (CMF) yielding source apportionments for PM10, B(a)P, and other regulated air pollutants namely Cd, Ni, As, and Pb. The results are potentially very useful for planning abatement strategies in all areas of the world, where coal combustion in small appliances is significant. During the studied pollution episodes in Krakow, European air quality limits were exceeded with up to a factor 8 for PM10 and up to a factor 200 for B(a)P. The levels of these air pollutants were accompanied by high concentrations of azaarenes, known markers for inefficient coal combustion. The major culprit for the extreme pollution levels was demonstrated to be residential heating by coal combustion in small stoves and boilers (>50% for PM10 and >90% B(a)P), whereas road transport (<10% for PM10 and <3% for B(a)P), and industry (4-15% for PM10 and <6% for B(a)P) played a lesser role. The indoor PM10 and B(a)P concentrations were at high levels similar to those of outdoor concentrations and were found to have the same sources as outdoors. The inorganic secondary aerosol component of PM10 amounted to around 30%, which for a large part may be attributed to the industrial emission of the precursors SO2 and NOx.

Khodeir M, Shamy M, Alghamdi M, Zhong M, Sun H, Costa M et al. 2012. Source apportionment and elemental composition of PM2.5 and PM10 in Jeddah City, Saudi Arabia. Atmospheric Pollution Research 3(3): 331-40.

Abstract: This paper presents the first comprehensive investigation of PM2.5 and PM10 composition and sources in Saudi Arabia. We conducted a multi-week multiple sites sampling campaign in Jeddah between June and September, 2011, and analyzed samples by XRF. The overall mean mass concentration was 28.4 +/- 25.4 μg/m3 for PM2.5 and 87.3 +/- 47.3 μg/m3 for PM10, with significant temporal and spatial variability. The average ratio of PM2.5/PM10 was 0.33. Chemical composition data were modeled using factor analysis with varimax orthogonal rotation to determine five and four particle source categories contributing significant amount of for PM2.5 and PM10 mass, respectively. In both PM2.5 and PM10 sources were (1) heavy oil combustion characterized by high Ni and V; (2) resuspended soil characterized by high concentrations of Ca, Fe, Al, and Si; and (3) marine aerosol. The two other sources in PM2.5 were (4) Cu/Zn source; (5) traffic source identified by presence of Pb, Br, and Se; while in PM10 it was a mixed industrial source. To estimate the mass contributions of each individual source category, the CAPs mass concentration was regressed against the factor scores. Cumulatively, resuspended soil and oil combustion contributed 77 and 82% mass of PM2.5 and PM10, respectively.

Kolker A, Engle MA, Orem WH, Bunnell JE, Lerch HE, Krabbenhoft DP et al. 2008. Mercury, trace elements and organic constituents in atmospheric fine particulate matter, Shenandoah National Park, Virginia, USA: A combined approach to sampling and analysis. Geostandards and Geoanalytical Research 32(3): 279-93.

Abstract: Compliance with U.S. air quality regulatory standards for atmospheric fine particulate matter (PM2.5) is based on meeting average 24 hour (35 μm-3) and yearly (15 μg m-3) mass-per-unit-volume limits, regardless of PM2.5 composition. Whereas this presents a workable regulatory framework, information on particle composition is needed to assess the fate and transport of PM2.5 and determine potential environmental/human health impacts. To address these important non-regulatory issues an integrated approach is generally used that includes (1) field sampling of atmospheric particulate matter on filter media, using a size-limiting cyclone, or with no particle-size limitation; and (2) chemical extraction of exposed filters and analysis of separate particulate-bound fractions for total mercury, trace elements and organic constituents, utilising different USGS laboratories optimised for quantitative analysis of these substances. This combination of sampling and analysis allowed for a more detailed interpretation of PM2.5 sources and potential effects, compared to measurements of PM2.5 abundance alone. Results obtained using this combined approach are presented for a 2006 air sampling campaign in Shenandoah National Park (Virginia, USA) to assess sources of atmospheric contaminants and their potential impact on air quality in the Park. PM2.5 was collected at two sampling sites (Big Meadows and Pinnacles) separated by 13.6 km. At both sites, element concentrations in PM2.5 were low, consistent with remote or rural locations. However, element/Zr

crustal abundance enrichment factors greater than 10, indicating anthropogenic input, were found for Hg, Se, S, Sb, Cd, Pb, Mo, Zn and Cu, listed in decreasing order of enrichment. Principal component analysis showed that four element associations accounted for 84% of the PM2.5 trace element variation; these associations are interpreted to represent: (1) crustal sources (Al, REE); (2) coal combustion (Se, Sb), (3) metal production and/or mobile sources (Mo, Cd, Pb, Cu, Zn) and (4) a transient marine source (Sr, Mg). Concentrations of Hg in PM2.5 at background levels in the single pg m-3 were shown by collection and analysis of PM2.5 on filters and by an automated speciation analyser set up at the Big Meadows air quality site. The speciation unit revealed periodic elevation of reactive gaseous mercury (RGM) that co-occurred with peaks in SO2, indicating an anthropogenic source. GC/MS total ion current chromatograms for the two sites were quite similar indicating that organic signatures were regional in extent and/or that the same compounds were present locally at each site. Calculated carbon preference index values for n-alkanes indicated that plant waxes rather than anthropogenic sources, were the dominant alkane source. Polycyclic aromatic hydrocarbons (PAHs) were detected, with a predominance of non-alkylated, and higher molecular weight PAHs in this fraction, suggestive of a combustion source (fossil fuel or forest fires).

Kolker A, Engle MA, Peucker-Ehrenbrink B, Geboy NJ, Krabbenhoft DP, Bothner MH et al. 2013. Atmospheric mercury and fine particulate matter in coastal New England: Implications for mercury and trace element sources in the northeastern United States. Atmospheric Environment 79: 760-8.

Abstract: Intensive sampling of ambient atmospheric fine particulate matter was conducted at Woods Hole, Massachusetts over a four-month period from 3 April to 29 July, 2008, in conjunction with year-long deployment of the USGS Mobile Mercury Lab. Results were obtained for trace elements in fine particulate matter concurrently with determination of ambient atmospheric mercury speciation and concentrations of ancillary gasses (SO2, NOx, and O3). For particulate matter, trace element enrichment factors greater than 10 relative to crustal background values were found for As, Bi, Cd, Cu, Hg, Pb, Sb, V. and Zn, indicating contribution of these elements by anthropogenic sources. For other elements, enrichments are consistent with natural marine (Na, Ca, Mg, Sr) or crustal (Ba, Ce, Co, Cs, Fe, Ga, La, Rb, Sc, Th, Ti, U, Y) sources, respectively. Positive matrix factorization was used together with concentration weighted air-mass back trajectories to better define element sources and their locations. Our analysis, based on events exhibiting the 10% highest PM2.5 contributions for each source category, identifies coal-fired power stations concentrated in the U.S. Ohio Valley, metal smelting in eastern Canada, and marine and crustal sources showing surprisingly similar back trajectories, at times each sampling Atlantic coastal airsheds. This pattern is consistent with contribution of Saharan dust by a summer maximum at the latitude of Florida and northward transport up the Atlantic Coast by clockwise circulation of the summer Bermuda High. Results for mercury speciation show diurnal production of RGM by photochemical oxidation of Hg degrees in a marine environment, and periodic traverse of the study area by correlated RGM-SO2(NOx) plumes, indicative of coal combustion sources.

Kong S, Ji Y, Lu B, Bai Z, Chen L, Han B et al. 2012. Chemical compositions and sources of atmospheric PM10 in heating, non-heating and sand periods at a coal-based city in northeastern China. Journal of Environmental Monitoring 14(3): 852-65.

Abstract: Mass concentrations and chemical components (18 elements, 9 ions, organic carbon [OC] and elemental carbon [EC]) in atmospheric PM10 were measured at five sites in Fushun during heating, non-heating and sand periods in 2006-2007. PM10 mass concentrations varied from 62.0 to 226.3 μg m-3, with 21% of the total samples' mass concentrations exceeding the Chinese national secondary standard value of 150 μg m(-3), mainly concentrated in heating and sand periods. Crustal elements, trace elements, water-soluble ions, OC and EC represented 20-47%, 2-9%, 13-34%, 15-34% and 13-25% of the particulate matter mass concentrations, respectively. OC and crustal elements exhibited the highest mass percentages, at 27-34% and 30-47% during heating and sand period. Local agricultural residuals burning may contribute to EC and ion concentrations, as shown by ion temporal variation and OC and EC correlation analysis. Heavy metals (Cr, Ni, Zn, Cu and Mn) from coal combustion and industrial processes should be paid attention to in heating and sand periods. The anion/cation ratios exhibited their highest values for the background site with the influence of stationary sources on its upper wind direction during the sand period. Secondary organic carbon were 1.6-21.7, 1.5-23.0, 0.4-17.0, 0.2-33.0 and 0.2-21.1 μg m-3, accounting for 20-77%, 44-88%, 4-

77%, 8-69% and 4-73% of OC for the five sampling sites ZQ, DZ, XH, WH and SK, respectively. From the temporal and spatial variation analysis of major species, coal combustion, agricultural residual burning and industrial emission including dust re-suspended from raw material storage piles were important sources for atmospheric PM10 in Fushun at heating, non-heating and sand periods, respectively. It was confirmed by principal component analysis that coal combustion, vehicle emission, industrial activities, soil dust, cement and construction dust and biomass burning were the main sources for PM10 in this coal-based city.

Kumar R, Srivastava SK, Prasad RS. 2008. Characterization of particulate matters (SPM and RPM) and its environmental impact on Korba coalfield. Indian Journal of Environmental Protection 28: 145-50.

Abstract: The industrial activities related with winning, transport, processing of coal, bauxite and subsequent burning of fossil fuel in power plant generating 3650 Mw of thermal powers deteriorate the air quality of Korba coalfield. This paper focuses on some of the key issues of air pollutions. Coal mining activities, coal used in thermal power plant and transportations of bauxite ore through roads near the residential zone, generates high volume of flyash, SPM and RPM. The average concentration of SPM is high in summer season in all the monitoring locations. FTIR analysis confirms the presence of minerals, for example kaolinite Al2O3.2SiO2 2H2O, oxides, sulphates phosphates and aliphatic hydrocarbons in air dust of Korba coalfield and AAS spectroscopy study revealed higher concentration levels of Al and Si along with the other trace elements determined in suspended particulate matter (SPM) and respirable particulate matter (RPM). These trace elements are iron (Fe), copper (Cu), lead (Pb), zinc (Zn), cadmium (Cd), nickel (Ni), manganese (Mn), chromium (Cr), arsenic (As) and mercury (Hg). The occurrence of higher concentration of Al and Si in the air dust samples are mainly due to coal mining, coal combustion, and aluminium smelter.

Li TC, Chen WH, Yuan CS, Wu SP, Wang XH. 2013a. Physicochemical characteristics and source apportionment of atmospheric aerosol particles in Kinmen-Xiamen airshed. Aerosol and Air Quality Research 13: 308-23.

Abstract: The objective of this study was to characterize the chemical properties of atmospheric particles sampled in the Kinmen-Xiamen Airshed located on the west bank of the Taiwan Strait. Seven particulate matter (PM) sampling sites in the Kinmen-Xiamen Airshed, including three sites at Kinmen Island and four in urban Xiamen, were selected for this particular study. Regular sampling was conducted to collect PM10 with high-volume samplers twice a month from March 2008, while intensive sampling was conducted to collect PM2.5 and PM2.5–10 with dichotomous samplers and PM10 with high-volume samplers in the spring and winter of 2008–2009. After sampling, the metallic contents of PM10 were analyzed with an inductively coupled plasma-atomic emission spectrometer (ICP-AES). Ionic species and carbonaceous contents of PM10 were analyzed with an ion chromatograph (IC) and elemental analyzer (EA), respectively. Finally, the source identification and apportionment of PM were analyzed by principal component analysis (PCA) and receptor modeling (CMB), respectively. The results from PM10 sampling indicated that atmospheric aerosol particles had a tendency to accumulate in Xiamen Bay all year round, particularly in spring and winter. The five sampling sites at the center of Xiamen Bay had relatively higher PM10 concentrations than the two sampling sites outside Xiamen Bay, suggesting that local emissions from Xiamen Bay were more significant than emissions transported over a long distance by the Northeastern Monsoon. The phenomenon of superimposition was regularly observed during air pollution episodes at Xiamen Bay. Moreover, the results of chemical analysis showed that the main chemical components of the PM were SO42–, NO3–, NH4+, OC, and EC and crustal elements (Ca, Mg, Fe, and Al) in the aerosol particles in the Kinmen-Xiamen Airshed. The neutralization ratios (NR) of PM were generally smaller than unity, indicating that the atmospheric particulates were mostly acidic. The averaged sulfur oxidation ratio (SOR) ranged from 0.20 to 0.51, and the nitrogen oxidation ratio (NOR) ranged from 0.10 to 0.41 for all seasons. The ratios of sulfur and nitrogen oxidation were generally higher than 0.25 and 0.10, respectively, suggesting that secondary sulfate and nitrate aerosols came mainly from across-boundary transportation and could be further accumulated in the Kinmen-Xiamen Airshed. The results from CMB receptor modeling showed that the major sources of atmospheric PM10 in the Kinmen-Xiamen Airshed were soil dusts, secondary aerosols, the petroleum industry, motor

vehicle exhausts, the iron and steel industry, the cement industry, diesel vehicle exhausts, marine aerosols, and biomass burning.

Li TC, Wu CY, Chen WH, Yuan CS, Wu SP, Wang XH et al. 2013b. Diurnal variation and chemical characteristics of atmospheric aerosol particles and their source fingerprints at Xiamen Bay. Aerosol and Air Quality Research 13: 596-607.

Abstract: This study investigated the diurnal variation of mass concentration and chemical composition of atmospheric aerosol particles sampled at Xiamen Bay, located on the west bank of the Taiwan Strait. Atmospheric PM10 samples were collected at ten particulate matter (PM) sampling sites at Xiamen Bay, including five sites at the Kinmen Islands and five sites in urban Xiamen, at both daytime and nighttime during the regular and intensive sampling periods. Regular sampling was conducted to collect PM10 with high-volume samplers three times a month from April 2009 to April 2010, while intensive sampling was conducted to collect PM2.5 and PM2.5–10 with dichotomous samplers in the spring and winter of 2009 and 2010. This study further selected ten major emission sources (e.g., stone processing, power plants, soil dusts, and biomass burning) at Xiamen Bay to collect fugitive particulate samples which were then resuspended in a self-designed resuspension chamber to collect PM2.5 and PM2.5–10 with two separate dichotomous samplers for further chemical analysis. The results from PM10 sampling indicated that atmospheric aerosol particles tended to be accumulated in Xiamen Bay all year round, but especially in spring and winter. A significant diurnal variation of PM10 was observed, with higher PM10 concentrations in the daytime during the regular sampling periods. The chemical analysis results showed that the major chemical components of PM10 were SO42–, NO3–, NH4+, OC, EC, and crustal elements (Ca, Mg, Fe, and Al), which were usually higher in the daytime than at night at Xiamen Bay. The differences were most pronounced at night, where the concentrations of most anthropogenic elements (Ni, Cu, As, and V) were higher than those in the daytime. The elemental composition of PM emitted from stone processing and the cement industry were dominated by crustal elements, particularly Ca, whereas the profile of top-soil mainly contained Al and Ca. The profiles of industrial sources were dominated by secondary inorganic aerosols and EC. Moreover, construction and road dusts contained large amounts of Fe and Al, while biomass burning released large amounts of K, OC, and SO42–.

Liu X, Wang W, Liu H, Geng C, Zhang W, Wang H et al. 2010. Number size distribution of particles emitted from two kinds of typical boilers in a coal-fired power plant in China. Energy and Fuels 24(3): 1677-81.

Abstract: Ultrafine particles (Dp<100 nm) are suspected to have considerably stronger impacts on human health in recent studies, and the coal-fired power plants are one of the major anthropogenic sources of the ultrafine particles. In order to characterize the ultrafine particles emitted from power plants, comprehensive field research on the number size distribution for boilers with and without low NOx burners (LNBs) was conducted online in a pulverized coal-fired power plant in China. With the use of an engine exhaust particle sizer (EEPS) and an aerodynamic particle sizer (APS), the lower limit of particles measured is extended to 5.6 nm. The particle number concentrations decrease with increasing size, and the nucleation mode particles are dominant in the number concentration. Additionally, the size distributions for boilers with or without LNBs are compared. Results show that the concentrations of ultrafine particles are notably higher for the boiler with LNBs than those for the boiler without LNBs. In addition, the shapes of particle size distributions (PSDs) for the two boilers are quite different in the PSDs measured with the EEPS but uniform in the PSDs measured by the APS. This suggests that LNBs favor the formation of fine particles, which should be considered in the emission control measures of coal-fired power plants.

Martello DV, Pekney NJ, Anderson RR, Davidson CI, Hopke PK, Kim E et al. 2008. Apportionment of ambient primary and secondary fine particulate matter at the Pittsburgh National Energy

Laboratory particulate matter characterization site using positive matrix factorization and a potential source contributions function analysis. Journal of the Air and Waste Management Association 58(3): 357-68.

Abstract: Fine particulate matter (PM2.5) concentrations associated with 202 24-hr samples collected at the National Energy Technology Laboratory (NETL) particulate matter (PM) characterization site in south Pittsburgh from October 1999 through September 2001 were used to apportion PM2.5 into primary and secondary contributions using Positive Matrix Factorization (PMF2). Input included the concentrations of PM2.5 mass determined with a Federal Reference Method (FRM) sampler, semi-volatile PM2.5 organic material, elemental carbon (EC), and trace element components of PM2.5. A total of 11 factors were identified. The results of potential source contributions function (PSCF) analysis using PMF2 factors and HYSPLIT-calculated back-trajectories were used to identify those factors associated with specific meteorological transport conditions. The 11 factors were identified as being associated with emissions from various specific regions and facilities including crustal material, gasoline combustion, diesel combustion, and three nearby sources high in trace metals. Three sources associated with transport from coal-fired power plants to the southeast, a combination of point sources to the northwest, and a steel mill and associated sources to the west were identified. In addition, two secondary-material-dominated sources were identified, one was associated with secondary products of local emissions and one was dominated by secondary ammonium sulfate transported to the NETL site from the west and southwest. Of these 11 factors, the four largest contributors to PM2.5 were the secondary transported material (dominated by ammonium sulfate) (47%), local secondary material (19%), diesel combustion emissions (10%), and gasoline combustion emissions (8%). The other seven factors accounted for the remaining 16% of the PM2.5 mass. The findings are consistent with the major source of PM2.5 in the Pittsburgh area being dominated by ammonium sulfate from distant transport and so decoupled from local activity emitting organic pollutants in the metropolitan area. In contrast, the major local secondary sources are dominated by organic material.

McGuire ML, Jeong CH, Slowik JG, Chang RYW, Corbin JC, Lu G, et al. 2011. Elucidating determinants of aerosol composition through particle-type-based receptor modeling. Atmospheric Chemistry and Physics 11: 8133-8155.

Abstract: An aerosol time-of-flight mass spectrometer (ATOFMS) was deployed at a semi-rural site in southern Ontario to characterize the size and chemical composition of individual particles. Particle-type-based receptor modelling of these data was used to investigate the determinants of aerosol chemical composition in this region. Individual particles were classified into particle-types and positive matrix factorization (PMF) was applied to their temporal trends to separate and cross-apportion particle-types to factors. The extent of chemical processing for each factor was assessed by evaluating the internal and external mixing state of the characteristic particle-types. The nine factors identified helped to elucidate the coupled interactions of these determinants. Nitrate-laden dust was found to be the dominant type of locally emitted particles measured by ATOFMS. Several factors associated with aerosol transported to the site from intermediate local-to-regional distances were identified: the Organic factor was associated with a combustion source to the north-west; the ECOC Day factor was characterized by nearby local-to-regional carbonaceous emissions transported from the south-west during the daytime; and the Fireworks factor consisted of pyrotechnic particles from the Detroit region following holiday fireworks displays. Regional aerosol from farther emissions sources was reflected through three factors: two Biomass Burning factors and a highly chemically processed Long Range Transport factor. The Biomass Burning factors were separated by PMF due to differences in chemical processing which were in part elucidated by the passage of two thunderstorm gust fronts with different air mass histories. The remaining two factors, ECOC Night and Nitrate Background, represented the night-time partitioning of nitrate to pre-existing particles of different origins. The distinct meteorological conditions observed during this month-long study in the summer of 2007 provided a unique range of temporal variability, enabling the elucidation of the determinants of aerosol chemical composition, including source emissions, chemical processing, and transport, at the Canada-US border. This paper presents the first study to elucidate the coupled influences of these determinants on temporal variability in aerosol chemical composition using single particle-type-based receptor modelling.

Mohan M, Bhati S, Sreenivas A, Marrapu P. 2011. Performance evaluation of AERMOD and ADMS-

Urban for total suspended particulate matter concentrations in megacity Delhi. Aerosol and Air Quality Research 11(7): 883-94.

Abstract: Regulatory models are useful tools for air quality management. However, application of models without proper evaluation may lead to erroneous conclusions and thus systematic model evaluation studies are essential prior to model application. Often, models are evaluated for a specific source and climatic condition and then find application to another source and climatic condition without this realization. In this context, two well known regulatory models namely; AERMOD (07026) and ADMS-Urban (2.2) are applied throughout the world in various countries without rigorous evaluation procedures. An attempt is made here to undertake performance evaluation of these models for a tropical city such as Delhi in India which is a well known megacity of the world. The models have been applied to estimate ambient particulate matter concentrations for the years 2000 and 2004 over seven sites in Delhi and model evaluation and inter-comparison is performed. Concentrations have been estimated for winter season in both years as the low temperature and low speed wind conditions in this season make it most significant from air pollution point of view. It has been found that though both the models have a tendency towards under-prediction, estimated values by both models agree with the observed concentrations within factor of two. However ADMS-Urban results show better trend correlation with observed values while bias between observed and estimated values is lower for AERMOD Results. The models include all the urban sources (ie. elevated point sources, vehicular traffic, domestic and other sources) in the city. The model validation is discussed in the light of emission inventory, requisite meteorological inputs and statistical performance measures. Performance evaluation of the above models is examined based on boundary layer parameterisations used in these models. Intercomparison of the model performances is envisaged to be useful for application to air quality management and further development of these models.

Morishita M, Keeler GJ, Kamal AS, Wagner JG, Harkema JR, Rohr AC. 2011a. Identification of ambient PM2.5 sources and analysis of pollution episodes in Detroit, Michigan using highly time-resolved measurements. Atmospheric Environment 45(8): 1627-37.

Abstract: Recent studies have indicated that the chemical composition of ambient PM2.5, or fine particulate matter (aerodynamic diameter <2.5 μm), may be closely associated with the health effects induced by PM. Thus, identification of the sources of these components of PM2.5 is critical to understanding source-specific health risks posed by PM2.5. However, ambient PM measurements are typically 24-h average concentrations, masking the temporal variability of individual sources. These daily samples can limit our understanding of the associations between sources and observed heath effect parameters. In the present study, highly time-resolved sampling methods were utilized to characterize trace element concentrations and to obtain information on potential emission sources impacting a site in urban Detroit where a complex mixture of local point and mobile sources, as well as regional sources, is observed. Positive matrix factorization (PMF) was applied to 117 8-h PM2.5 filter samples from which six major factors were extracted including secondary aerosol, gasoline-powered vehicles, iron and steel manufacturing, diesel-powered vehicles, refining, and sludge incineration. In addition, PMF was applied to 268 30-min PM2.5 samples where six major source factors were identified including secondary aerosol, gasoline- and diesel-powered vehicles, iron and steel manufacturing, refining, sludge incineration, and cement/lime production. Contributions of various emission source factors and peak concentrations for each factor were characterized using detailed meteorology and, factor directionality analysis. Although some variations were observed between the 8-h integrated filter samples and the 30-min SEAS samples, the results from the two datasets are generally consistent, suggesting that 46% and 43% of ambient PM, respectively, is derived from local sources. These findings have advanced our understanding of temporal PM source-receptor relationships in a complex urban air shed.

Morishita M, Keeler GJ, Kamal AS, Wagner JG, Harkema JR, Rohr AC. 2011b. Source identification of ambient PM2.5 for inhalation exposure studies in Steubenville, Ohio using highly time-resolved measurements. Atmospheric Environment 45(40): 7688-97.

Abstract: Recent epidemiological and toxicological studies have suggested that short-term elevations of ambient fine particle mass concentrations (aerodynamic diameter <2.5 μm, PM2.5) can increase cardiac and pulmonary health risks. Thus, examining temporal variations of chemical changes in ambient PM2.5 that could pose the greatest health risks and identifying its sources is critical so that the most toxic categories can be controlled. In this study we collected detailed air quality data in Steubenville, Ohio in August 2006 with the ultimate goal to evaluate associations between cardiovascular (CV) parameters measured in exposed laboratory animals and the chemical and elemental composition of PM2.5. Current approaches using radiotelemetry to measure CV parameters in conscious laboratory animals are capable of collecting continuous recordings. To provide a robust and analogous dataset that can be better matched with CV responses, we have incorporated a highly time-resolved sampling method to characterize trace elements and thereby obtain more robust input data to determine potential emission sources. We applied positive matrix factorization (PMF) to trace element concentrations from 30-minute ambient PM2.5 samples in Steubenville, Ohio, an area designated as a non-attainment area for the PM2.5 National Ambient Air Quality Standards by the Environmental Protection Agency. The average ambient PM2.5 filter-based mass concentration during the 8-hour summer exposure study period was 26 +/- 11 μg m-3. Results from PMF indicated that six major factors contributed to the ambient PM2.5 mass during this time: coal combustion/secondary (39 +/- 46%), mobile sources (12 +/- 14%), metal coating/processing (10 +/- 11%), iron and steel manufacturing (5 +/- 5%), Pb factor (5 +/- 8%), and incineration/smelting (1 +/- 3%). The objectives of this paper are (1) to present chemical composition of ambient PM2.5 and its potential emission sources in Steubenville; and (2) to evaluate the PMF modeling results using observed meteorological data. These semi-continuous sampling approaches to determine potential emission sources have significant advantages over similar analyses using samples averaged over 8-24 h, and are being utilized by our group to determine associations of PM with acute CV responses from animal inhalation toxicology field studies.

Murphy DM, Capps SL, Daniel JS, Frost GJ, White WH. 2008. Weekly patterns of aerosol in the United States. Atmospheric Chemistry and Physics 8(10): 2729-39.

Abstract: Data from the Interagency Monitoring of Protected Visual Environments (IMPROVE) network of aerosol samplers and NOAA monitoring sites are examined for weekly cycles. At remote and rural sites, fine particle elemental carbon, crustal elements, and coarse particle mass had pronounced (up to 20%) weekly cycles with minima on Sunday or Monday. Fine particle organic carbon and mass had smaller amplitude cycles, also with Sunday or Monday minima. There was no statistically significant weekly cycle in fine particle sulfate despite a 5 to 15% weekly cycle in power plant SO2 emissions. Although results for nitrate may be more susceptible to sampling artifacts, nitrate also showed a pronounced weekly cycle with an amplitude similar to elemental carbon. The only species found with a weekend maximum was Pb, probably from general aviation on weekends. Aerosol optical properties at NOAA monitoring sites were consistent with the IMPROVE chemical data, with significant weekly cycles in aerosol light absorption but not light scattering. These results support a large role of diesel emissions in elemental carbon aerosol over the entire United States and suggest that a large fraction of the airborne soil dust is anthropogenic. They also suggest that studies of weekly cycles in temperature, cloudiness, precipitation, or other meteorological variables should look for causes more in light-absorbing particles and possible ice nucleation by dust rather than sulfate or total aerosol. There are also implications for personal exposure and epidemiological studies of aerosol health effects.

Okuda T, Katsuno M, Naoi D, Nakao S, Tanaka S, He K et al. 2008. Trends in hazardous trace metal concentrations in aerosols collected in Beijing, China from 2001 to 2006. Chemosphere 72(6): 917-24.

Abstract: Daily observations of hazardous trace metal concentrations in aerosols in Beijing, China were made in the period from 2001 to 2006. We considered coal combustion as a major source of some anthropogenic metals by achieving a correlation analysis and by investigating enrichment factors and relative composition of metals. A possible extra source of some specific metals, such as Cu and Sb, was brake abrasion particles, however, we did not think the transport-related particle was a major source for the hazardous anthropogenic metals even though they could originate from vehicle exhaust and brake/tire abrasion particles. A time-trend

model was used to describe temporal variations of chemical constituent concentrations during the five-year period. Several crustal elements, such as Al, Ti, V, Cr, Mn, Fe, and Co, did not show clear increases, with annual rates of change of -15.2% to 3.6%. On the other hand, serious increasing trends were noted from several hazardous trace metals. Cu, Zn, As, Cd, and Pb, which are derived mainly from anthropogenic sources, such as coal combustion, showed higher annual rate of change (4.9-19.8%, $p<0.001$) according to the regression model. In particular, the Cd and Pb concentrations increased remarkably. We hypothesize that the trend towards increasing concentrations of metals in the air reflects a change that has occurred in the process of burning coal, whereby the use of higher temperatures for coal combustion has resulted in increased emissions of these metals. The increasing use of low-rank coal may also explain the observed trends. In addition, nonferrous metal smelters are considered as a potential, albeit minor, reason for the increasing atmospheric concentrations of anthropogenic hazardous metals in Beijing city.

Orru H, Kimmel V, Kikas Ü, Soon A, Künzli N, Schins RPF et al. 2010. Elemental composition and oxidative properties of PM2.5 in Estonia in relation to origin of air masses - results from the ECRHS II in Tartu. Science of the Total Environment 408(7): 1515-22.

Abstract: Fine particulate matter (PM2.5) was sampled at an urban background site in Tartu, Estonia over one-year period during the ECRHS II study. The elemental composition of 71 PM2.5 samples was analyzed for different chemical elements using energy-dispersive X-ray fluorescence spectrometry (ED-XRF). The oxidative activity of 36 samples was assessed by measuring their ability to generate hydroxyl radicals in the presence of hydrogen peroxide. The origin of air masses was determined by computing 96-hour back trajectories of air masses with the HYSPLIT Model. The trajectories of air masses were divided into four sectors according to geographical patterns: "Russia," "Eastern Europe," "Western Europe," and "Scandinavia." During the study period, approximately 30% of air masses originated from "Scandinavia." The other three sectors had slightly lower values (between 18 and 22%). In spring, summer, and winter, higher total PM levels originated from air masses from continental areas, namely "Russia" and "Eastern Europe" (18.51 ± 7.33 and 19.96 ± 9.23 μg m− 3, respectively). In autumn, the PM levels were highest in "Western Europe". High levels of Fe, Ti, and AlCaSi (Al, Ca, and Si) were also detected in air masses from the Eurasian continent. The oxidative properties were correlated to the origin of air masses. The ·OH values were approximately 1.5 times higher when air masses originated from the direction of "Eastern Europe" or "Russia." The origin of measured particles was evaluated using principal component factor analysis. When comparing the PM2.5 elemental composition with seasonal variation, factor scores, and other studies, the factors represent: (1) combustion of biomass; (2) crustal dust; (3) traffic; and (4) power plants and industrial processes associated with oil burning. The total PM2.5 is driven mainly by biomass and industrial combustion (63%) and other unidentified sources (23%). Other sources of PM, such as crustal dust and traffic, contribute a total of 13%.

Peltier RE, Lippmann M. 2011. Spatial and seasonal distribution of aerosol chemical components in New York City: (1) Incineration, coal combustion, and biomass burning. Journal of Exposure Science and Environmental Epidemiology 21(5): 473-83.

Abstract: We describe spatial and temporal patterns of fine particulate matter (PM2.5) and of 12 of its constituent chemical elements commonly observed in measurements at residential locations in New York City (NYC). These elements, that is, Ni, V, As, Se, S, Cl, Na, K, Pb, Cu, Zn, and Mn, had significant spatial and temporal variability at 10 PM2.5 sampling locations during our winter and summer sampling campaigns. By grouping the elements into traditional source apportionment categories, we show that specific chemical components of PM2.5 considered to have a common source category, such as As and Se for coal combustion, do not always follow the same temporal or spatial pattern. PM2.5 mass had only limited spatial variability and a slight summertime concentration enhancement. Measurements at residential locations were, on average, consistent with EPA sampling network measurements, although we found that during times of low regional concentration, EPA measurements underestimated the PM2.5 concentration at residential locations. These results have implications for improved understanding of exposures to specific sources of PM2.5, and raise some concerns about source profiles used in source-receptor modeling tracer input selection.

Pokorná P, Hovorka J, Kroužek J, Hopke PK. 2013. Particulate matter source apportionment in a village situated in industrial region of Central Europe. Journal of the Air and Waste Management Association 63(12): 1412-21.

Abstract: The bilinear receptor model positive matrix factorization (PMF) was used to apportion particulate matter with an aerodynamic diameter of 1-10 μm (PM1-10) sources in a village, Brezno, situated in an industrial region of northern Bohemia in Central Europe. The receptor model analyzed the data sets of 90- and 60-min integrations of PM1-10 mass concentrations and elemental composition for 27 elements. The 14-day sampling campaigns were conducted in the village in summer 2008 and winter 2010. Also, to ensure seasonal and regional representativeness of the data sets recorded in the village, the spatial-temporal variability of the 24-hr PM10 and PM1-10 within 2008-2010 in winter and summer across the multiple sites was evaluated. There were statistically significant interseasonal differences of the 24-hr PM data, but not intrasummer or intrawinter differences of the 24-hr PM1-10 data across the multiple sites. PMF resolved seven sources of PM1-10. They were high-temperature coal combustion; combustion in local heating boilers; marine aerosol; mineral dust; primary biological/wood burning; road dust, car brakes; and gypsum. The main summer factors were assigned to mineral dust (38.2%) and primary biological/wood burning (33.1%). In winter, combustion factors dominated (80%) contribution to PM1-10. The conditional probability function (CPF) helped to identified local sources of PM1-10. The source of marine aerosol from the North Sea and English Channel was indicated by the Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT). This is the first application of PMF to highly time/size resolved PM data in Czech Republic. The coarse aerosol fraction, PM1-10, was chosen with regard to industrial character of the region, sampling site near the coal strip mine and coal power stations. Contrary to expectation, source apportionment did not show dominance of emissions from the coal strip mine. The results will enable local authorities and state bodies responsible for air quality assessment to focus on sources most responsible for air pollution in this industrial region. Supplemental Materials: Supplemental materials are available for this paper. Go to the publisher's online edition of the Journal of the Air and Waste Management Association for (1) details of measurement campaigns; (2) CPF for each of the sources contributing to PM1-10; (3) factors contribution to PM1-10 resolved by PMF; (4) diurnal pattern of road dust, car brake factor in summer and winter; (5) trajectories during the marine aerosol episode in winter 2010; and (6) temporal temperature, concentration, and wind speed relationships during the summer 2008 campaign and winter 2010 campaign.

Rogula-Kozlowska W, Blaszczak B, Szopa S, Klejnowski K, Sówka I, Zwozdziak A et al. 2013. PM2.5 in the central part of Upper Silesia, Poland: Concentrations, elemental composition, and mobility of components. Environmental Monitoring and Assessment 185(1): 581-601.

Abstract: The paper discusses ambient concentrations of PM2.5 (ambient fine particles) and of 29 PM2.5-related elements in Zabrze and Katowice, Poland, in 2007. The elemental composition of PM2.5 was determined using energy dispersive X-ray fluorescence (EDXRF). The mobility (cumulative percentage of the water-soluble and exchangeable fractions of an element in its total concentration) of 18 PM2.5-related elements in Zabrze and Katowice was computed by using sequential extraction and EDXRF combined into a simple method. The samples were extracted twice: in deionized water and in ammonium acetate. In general, the mobility and the concentrations of the majority of the elements were the same in both cities. S, Cl, K, Ca, Zn, Br, Ba, and Pb in both cities, Ti and Se in Katowice, and Sr in Zabrze had the mobility greater than 70%. Mobility of typical crustal elements, Al, Si, and Ti, because of high proportion of their exchangeable fractions in PM, was from 40 to 66%. Mobility of Fe and Cu was lower than 30%. Probable sources of PM 2.5 were determined by applying principal component analysis and multiple regression analysis and computing enrichment factors. Great part of PM2.5 (78% in Katowice and 36% in Zabrze) originated from combustion of fuels in domestic furnaces (fossil fuels, biomass and wastes, etc.) and liquid fuels in car engines. Other identified sources were: power plants, soil, and roads in Zabrze and in Katowice an industrial source, probably a non-ferrous smelter or/and a steelwork, and power plants.

Rogula-Kozlowska W, Blaszczak B, Szopa S, Klejnowski K, Sówka I, Zwozdziak A et al. 2013. PM2.5 in the central part of Upper Silesia, Poland: Concentrations, elemental composition, and mobility of components. Environmental Monitoring and Assessment 185(1): 581-601.

Abstract: The seasonal changes in ambient mass concentrations and chemical composition of fine particulate matter (PM2.5) were investigated in three locations in Poland. The analyses included PM2.5-bound hazardous benzo(a)pyrene (BaP), As, Ni, Cd, and Pb. The samples of PM2.5 were collected daily in Katowice (southern Poland, urban background site), Gdańsk, and Diabla Góra (northern Poland, urban and regional background sites, respectively) during 1-year-long campaign in 2010. Based on monthly ambient concentrations of PM2.5-bound carbon (organic and elemental), water-soluble ions (Na+, NH4 +, K+, Mg2+, Ca2+, Cl-, NO3-, SO42-), and elements As, Ni, Cd, Pb, Ti, Al, Fe, the chemical mass closure of PM2.5 was checked for each of the four seasons of the year and for the heating and non-heating periods at each site. Also, the annual concentrations of PM2.5 were determined and the annual PM2.5 mass closure checked. At each measuring point, the PM2.5 concentrations were high compared to its Polish yearly permissible value, 25 μg/m3, and its concentrations elsewhere in Europe. The highest annual PM2.5 concentration, 43 μg/m3, occurred in Katowice; it was twice the annual PM2.5 concentration in Gdańsk, and thrice the one in Diabla Góra. The high annual averages were due to very high monthly concentrations in the heating period, which were highest in the winter. PM2.5 consisted mainly of carbonaceous matter (elemental carbon (EC) + organic matter (OM), the sum of elemental carbon, EC, and organic matter, OM; its annual mass contributions to PM2.5 were 43, 31, and 33 % in Katowice, Gdansk, and Diabla Góra, respectively), secondary inorganic aerosol (SIA), the Na_Cl group, and crustal matter (CM)-in the decreasing order of their yearly mass contributions to PM2.5. OM, EC, SIA, Na_Cl, and CM accounted for almost 81 % of the PM2.5 mass in Katowice, 74 % in Gdańsk, and 90 % in Diabla Góra. The annual average toxic metal contribution to the PM2.5 mass was not greater than 0.2 % at each site. In Katowice and Gdańsk, the yearly ambient BaP concentrations were high (15.4 and 3.2 ng/m3, respectively); in rural Diabla Góra, the concentrations of BaP were almost equal to 1 ng/m3, the Polish BaP annual limit. The great seasonal fluctuations of the shares of the component groups in PM2.5 and of the concentrations of PM2.5 and its components are due to the seasonal fluctuations of the emissions of PM and its precursors from hard and brown coal combustion for energy production, growing in a heating season, reaching maximum in winter, and decreasing in a non-heating period. In Gdańsk, northern Poland, especially in the spring and autumn, sea spray might have affected the chemical composition of PM2.5. The greatest hazard from PM2.5 occurs in Katowice, southern Poland, in winter, when very high concentrations of PM2.5 and PM2.5-related carbonaceous matter, including BaP, are maintained by poor natural ventilation in cities, weather conditions, and the highest level of industrialization in Poland. In less industrialized northern Poland, where the aeration in cities is better and rather gaseous than solid fuels are used, the health hazard from ambient PM2.5 is much lower.

Roy P, Kumar Sikdar P, Singh G, Kumar Pal A. 2012. Source apportionment of ambient PM10: A case study from a mining belt of Orissa. Atmósfera 25(3): 311-24.

Abstract: Samples of particulate matter of size 10 micron (PM10) were collected in Talcher, Orissa (India) from six sites with different land-uses. The sampling was done concurrently twice a week during the months of June 2008, November 2008 and January 2009. The ambient mass concentration and the elemental composition in these PM10 samples were determined. The annual average concentrations of PM10 samples at each site were 144 ± 29 μg/m3, 191 ± 61 μg/m3, 90 ± 28 μg/m3, 60 ± 15 μg/m3, 106 ± 35 μg/m3, and 150 ± 36 μg/m3 respectively, indicating severe air pollution levels in Talcher. Variation of particulate matter with meteorological parameters like wind speed, relative humidity and temperature was observed. The study reveals that the particulate matter concentration drops substantially with the rise of wind speed above 1m/s. Elemental concentrations of PM10 were analyzed using an atomic absorption spectrophotometer. Correlation and multivariate analysis techniques, such as principal components analysis, were used for source apportionment to identify the possible sources of PM10 and quantified trace elements. Four factors were isolated by principal components analysis: soil dust or fugitive dust from mining associated activities, emissions from automobiles, emissions from thermal power plant and non-ferrous smelter, and identified as possible sources.

Samek L, Lankosz M. 2011. Seasonal variation of the elemental composition of particulate matter collected in a small town near Warszawa, Poland. Nukleonika 56: 57-64.

Abstract: Four seasonal sampling campaigns successively in April, July, September 2008 and February 2009 took place at Swider, a town located to the south-east of Warszawa, Poland. Three particle size fractions of particulate matter were collected by a NILU (The Norwegian Institute for Air Protection, Norway) sampler. The following elements were determined by the energy dispersive X-ray fluorescence (EDXRF) method: K, Ca, Ti, Cr, Mn, Fe, Cu, Zn, Br and Pb. The highest mean mass concentrations in fine and medium fractions were observed in April 2008 and February 2009. For a coarse fraction, the highest values of mass concentrations were observed in April and September 2008. Ca, Mn and Fe existed mainly in the coarse fraction. These elements probably came from the southern direction. Zn was divided between three fractions equally. In February 2009 the highest Zn concentrations were observed in the medium fraction. Pb existed mainly in the fine and medium fractions. The highest values of Pb concentrations were observed in February 2009. Bromium existed in the fine fraction. Correlations were observed between Ca, Mn and Fe concentrations. Correlation factors were about 0.8 for the coarse fraction. For other analyzed elements, the correlation coefficients were small. Basing on the backward trajectories and elemental concentrations of particulate matter (PM), it was confirmed that in winter the main influence on air quality is caused by pollution coming from coal combustion in local houses, heat and power plants working in urban areas. In summer the main influence on air quality is caused by pollution from sources in rural cultivable areas. The improvement of air quality is possible by decreasing the emission, using coal with a small level of harmful compounds and whole elimination of plant preventive agents and using fertilizers with a small content of unwanted elements.

Santoso M, Lestiani DD, Mukhtar R, Hamonangan E, Syafrul H, Markwitz A et al. 2011. Preliminary study of the sources of ambient air pollution in Serpong, Indonesia. Atmospheric Pollution Research 2(2): 190-6.

Abstract: There has been increasing interest regarding air pollution in the Serpong area of Indonesia, a region near Jakarta, especially with respect to high concentrations of Pb detected in early 2001. Several studies have been conducted, but the appropriate action needed to control this pollution has not been identified because of inadequate identification of the particulate matter sources. In this study, source investigation was performed using the chemical characteristics of ambient airborne particulate matter samples from several locations in Serpong and its surroundings. Sampling of airborne particulate matter was conducted using a Gent stacked filter unit sampler in Serpong between August and November 2008. Black carbon (BC) was determined by reflectance and elemental analysis were performed using particle induced X-ray emission (PIXE). Al, As, Ba, Br, Ca, Cl, Co, Cr, Cu, Fe, Hg, I, K, Mg, Mn, Na, Ni, P, Pb, S, Sc, Si, Se, Sr, Ti, V and Zn were determined. The results showed that the higher Pb concentrations in both fine and coarse particulate matter were observed in the industrial area compared to adjacent residential areas. The Pb percentages in the collected PM2.5 mass in the residential and industrial areas were 3.1% and 4.3%, respectively, while for PM2.5-10, Pb represented 1.9% and 6.0% of the PM mass, respectively. The fine fraction data from two residential areas (Setu and EMC) were analyzed using EPA PMF (version 3) for source apportionment. The source apportionment identified 5 factors, i.e., lead industry and road dust (12%), diesel vehicles (30%), oil and power plant (26%), road dust (17%) and biomass burning mixed with road dust (15%).

Singh K, Tiwari S, Jha AK, Aggarwal SG, Bisht DS, Murty BP et al. 2013. Mass-size distribution of PM10 and its characterization of ionic species in fine (PM2.5) and coarse (PM10-2.5) mode, New Delhi, India. Natural Hazards 68(2): 775-89.

Abstract: Size distribution of PM10 mass aerosols and its ionic characteristics were studied for 2 years from January 2006 to December 2007 at central Delhi by employing an 8-stage Andersen Cascade Impactor sampler. The mass of fine (PM2.5) and coarse (PM10-2.5) mode particles were integrated from particle mass determined in different stages. Average concentrations of mass PM10 and PM2.5 were observed to be 306 ± 182 and 136 ± 84 μg m-3, respectively, which are far in excess of annual averages stipulated by the Indian National Ambient Air Quality Standards (PM10: 60 μg m-3 and PM2.5: 40 μg m-3). The highest concentrations of PM10-2.5 (coarse) and PM2.5 (fine) were observed 505 ± 44 and 368 ± 61 μg m-3, respectively, during summer (June 2006) period, whereas the lower concentrations of PM10-2.5 (35 ± 9 μg m-3) and PM2.5 (29 ± 13 μg m-3) were observed during monsoon (September 2007). In summer, because of

frequent dust storms, coarse particles are more dominant than fine particles during study period. However, during winter, the PM2.5 contribution became more pronounced as compared to summer probably due to enhanced emissions from anthropogenic activities, burning of biofuels/biomass and other human activities. A high ratio (0.58) of PM2.5/PM10 was observed during winter and low (0.24) during monsoon. A strong correlation between PM10 and PM2.5 (r 2 = 0.93) was observed, indicating that variation in PM10 mass is governed by the variation in PM2.5. Major cations (NH4 +, Na+, K+, Ca2+ and Mg2+) and anions (F-, Cl-, SO4 2- and NO3 -) were analyzed along with pH. Average concentrations of SO4 2- and NO3 - were observed to be 12.93 ± 0.98 and 10.33 ± 1.10 μg m-3, respectively. Significant correlation between SO4 2- and NO3 - in PM1.0 was observed indicating the major sources of secondary aerosol which may be from thermal power plants located in the southeast and incomplete combustion by vehicular exhaust. A good correlation among secondary species (NH+, NO3 - and SO4 2-) suggests that most of NH4 + is in the form of ammonium sulfate and ammonium nitrate in the atmosphere. During winter, the concentration of Ca2+ was also higher; it may be due to entrainment of roadside dust particles, traffic activities and low temperature. The molar ratio (1.39) between Cl- and Na+ was observed to be close to that of seawater (1.16). The presence of higher Cl- during winter is due to western disturbances and probably local emission of Cl- due to fabric bleaching activity in a number of export garment factories in the proximity of the sampling site.

Sivaramasundaram K, Muthusubramanian P. 2010. A preliminary assessment of PM10 and TSP concentrations in Tuticorin, India. Air Quality, Atmosphere and Health 3: 95-102.

Abstract: The respirable particulate matter (RPM; PM10) and total suspended particulate matter (TSP) concentrations in ambient air in Tuticorin, India, were preliminarily estimated. Statistical analyses on so-generated database were performed to infer frequency distributions and to identify dominant meteorological factor affecting the pollution levels. Both the RPM and TSP levels were well below the permissible limits set by the US Environmental Protection Agency. As expected, lognormal distribution always fit the data during the study period. However, fit with the normal was also acceptable except for very few seasons. The RPM concentrations ranged between 20. 9 and 198. 2 μg/m3, while the TSP concentrations varied from 51. 5 to 333. 3 μg/m3 during the study period. There was a better correlation between PM10-100 and TSP concentrations than that of PM10 (RPM) and TSP concentrations, but the correlation of RPM fraction was also acceptable. It was found that wind speed was the most important meteorological factor affecting the concentrations of the pollutants of present interest. Significant seasonal variations in the pollutant concentrations of present interest were found at 5% significance level except for TSP concentrations in the year 2006.

Song Y, Dai W, Wang X, Cui M, Su H, Xie S et al. 2008. Identifying dominant sources of respirable suspended particulates in Guangzhou, China. Environmental Engineering Science 25(7): 959-68.

Abstract: Respirable suspended particulates (RSP, i.e., particles with an aerodynamic diameter of 10 μm or less) were measured in 2004 and 2005 at seven sites in the rapidly developing Guangzhou area of China. The average RSP concentration was 126 μg m-3, a high level that could be very harmful to human health. The chemical species composition of the RSP, including organic and elemental carbon, water-soluble ions, and elemental compositions, was also analyzed. The organics and sulfate may be the major components of RSP mass concentrations. Positive matrix factorization (PMF) was used to identify the sources of RSP as secondary sulfates (32%), secondary nitrates (6%), biomass burning (15%), coal fly ash/cement (18%), sea salt (3%), crustal dust (5%), vehicle exhaust (6%), and coal-fired power plants (3%). Reducing coal combustion and controlling vehicle emissions would alleviate RSP pollution, as most of the precursors were components of coal burning emissions and vehicular exhaust.

Stevens RG, Pierce JR, Brock CA, Reed MK, Crawford JH, Holloway JS et al. 2012. Nucleation and growth of sulfate aerosol in coal-fired power plant plumes: Sensitivity to background aerosol and meteorology. Atmospheric Chemistry and Physics 12: 189-206.

Abstract: New-particle formation in the plumes of coal-fired power plants and other anthropogenic sulfur sources may be an important source of particles in the atmosphere. It remains unclear, however, how best to

reproduce this formation in global and regional aerosol models with grid-box lengths that are 10s of kilometers and larger. The predictive power of these models is thus limited by the resultant uncertainties in aerosol size distributions. In this paper, we focus on sub-grid sulfate aerosol processes within coal-fired power plant plumes: the sub-grid oxidation of SO2 with condensation of H2SO4 onto newly-formed and pre-existing particles. We have developed a modeling framework with aerosol microphysics in the System for Atmospheric Modelling (SAM), a Large-Eddy Simulation/Cloud-Resolving Model (LES/CRM). The model is evaluated against aircraft observations of new-particle formation in two different power-plant plumes and reproduces the major features of the observations. We show how the downwind plume aerosols can be greatly modified by both meteorological and background aerosol conditions. In general, new-particle formation and growth is greatly reduced during polluted conditions due to the large pre-existing aerosol surface area for H2SO4 condensation and particle coagulation. The new-particle formation and growth rates are also a strong function of the amount of sunlight and NOx since both control OH concentrations. The results of this study highlight the importance for improved sub-grid particle formation schemes in regional and global aerosol models.

Stone E, Schauer J, Quraishi TA, Mahmood A. 2010. Chemical characterization and source apportionment of fine and coarse particulate matter in Lahore, Pakistan. Atmospheric Environment 44(8): 1062-70.

Abstract: Lahore, Pakistan is an emerging megacity that is heavily polluted with high levels of particle air pollution. In this study, respirable particulate matter (PM2.5 and PM10) were collected every sixth day in Lahore from 12 January 2007 to 19 January 2008. Ambient aerosol was characterized using well-established chemical methods for mass, organic carbon (OC), elemental carbon (EC), ionic species (sulfate, nitrate, chloride, ammonium, sodium, calcium, and potassium), and organic species. The annual average concentration (±one standard deviation) of PM2.5 was 194 ± 94 μg m−3 and PM10 was 336 ± 135 μg m−3. Coarse aerosol (PM10−2.5) was dominated by crustal sources like dust (74 ± 16%, annual average ± one standard deviation), whereas fine particles were dominated by carbonaceous aerosol (organic matter and elemental carbon, 61 ± 17%). Organic tracer species were used to identify sources of PM2.5 OC and chemical mass balance (CMB) modeling was used to estimate relative source contributions. On an annual basis, non-catalyzed motor vehicles accounted for more than half of primary OC (53 ± 19%). Lesser sources included biomass burning (10 ± 5%) and the combined source of diesel engines and residual fuel oil combustion (6 ± 2%). Secondary organic aerosol (SOA) was an important contributor to ambient OC, particularly during the winter when secondary processing of aerosol species during fog episodes was expected. Coal combustion alone contributed a small percentage of organic aerosol (1.9 ± 0.3%), but showed strong linear correlation with unidentified sources of OC that contributed more significantly (27 ± 16%). Brick kilns, where coal and other low quality fuels are burned together, are suggested as the most probable origins of unapportioned OC. The chemical profiling of emissions from brick kilns and other sources unique to Lahore would contribute to a better understanding of OC sources in this megacity.

Stroud CA, Moran MD, Makar PA, Gong S, Gong W, Zhang J, et al. 2012. Evaluation of chemical transport model predictions of primary organic aerosol for air masses classified by particle component-based factor analysis. Atmospheric Chemistry and Physics 12, 8297-8321.

Abstract: In Observations from the 2007 Border Air Quality and Meteorology Study (BAQS-Met 2007) in Southern Ontario, Canada, were used to evaluate predictions of primary organic aerosol (POA) and two other carbonaceous species, black carbon (BC) and carbon monoxide (CO), made for this summertime period by Environment Canada's AURAMS regional chemical transport model. Particle component-based factor analysis was applied to aerosol mass spectrometer measurements made at one urban site (Windsor, ON) and two rural sites (Harrow and Bear Creek, ON) to derive hydrocarbon-like organic aerosol (HOA) factors. A novel diagnostic model evaluation was performed by investigating model POA bias as a function of HOA mass concentration and indicator ratios (e.g. BC/HOA). Eight case studies were selected based on factor analysis and back trajectories to help classify model bias for certain POA source types. By considering model POA bias in relation to co-located BC and CO biases, a plausible story is developed that explains the model biases for all three species. At the rural sites, daytime mean PM1 POA mass concentrations were under-predicted compared to observed HOA concentrations. POA under-predictions were accentuated when the

transport arriving at the rural sites was from the Detroit/Windsor urban complex and for short-term periods of biomass burning influence. Interestingly, the daytime CO concentrations were only slightly under-predicted at both rural sites, whereas CO was over-predicted at the urban Windsor site with a normalized mean bias of 134%, while good agreement was observed at Windsor for the comparison of daytime PM1 POA and HOA mean values, 1.1 μg m−3 and 1.2 μg m−3, respectively. Biases in model POA predictions also trended from positive to negative with increasing HOA values. Periods of POA over-prediction were most evident at the urban site on calm nights due to an overly-stable model surface layer. This model behaviour can be explained by a combination of model under-estimation of vertical mixing at the urban location, under-representation of PM emissions for on-road traffic exhaust along major urban roads and highways, and a more structured allocation of area POA sources such as food cooking and dust emissions to urban locations. A downward trend in POA bias was also observed at the urban site as a function of the BC/HOA indicator ratio, suggesting a possible association of POA under-prediction with under-representation of diesel combustion sources. An investigation of the emission inventories for the province of Ontario and the nearby US state of Indiana also suggested that the top POA area emission sources (food cooking, organic-bound to dust, waste disposal burning) dominated over mobile and point sources, again consistent with a mobile under-estimation. We conclude that more effort should be placed at reducing uncertainties in the treatment of several large POA emission sources, in particular food cooking, fugitive dust, waste disposal burning, and on-road traffic sources, and especially their spatial surrogates and temporal profiles. This includes using higher spatial resolution model grids to better resolve the urban road network and urban food cooking locations. We also recommend that additional sources of urban-scale vertical mixing in the model, such as a stronger urban heat island effect and vehicle-induced turbulence, would help model predictions at urban locations, especially at night time.

Tecer LH, Tuncel G, Karaca F, Alagha O, Suren P, Zararsiz A et al. 2012. Metallic composition and source apportionment of fine and coarse particles using positive matrix factorization in the southern Black Sea atmosphere. Atmospheric Research 118: 153-69.

Abstract: In this study, coarse- (PM2.5-10) and fine (PM2.5) fraction aerosol samples were collected using a dichotomous sampler, and their metallic composition (Mg, Al, Ti, Ca, Cr, Cu, Fe, K, Mn, Ni, Pb, and Zn) were analyzed using X-ray fluorescence. The average crustal enrichment factor (EFc) values of Pb, Cu, SO42-, and Zn are greater than 10 for both coarse- and fine-fraction aerosols, which indicates that anthropogenic sources account for the concentrations of these four elements in both the fractions. In this study, positive matrix factorization (PMF) was used for the source apportionment of PM2.5 mass in the Zonguldak atmosphere. A total of six factors were identified, which can be interpreted as either emission sources or physically meaningful factors. The goodness of the six-factor solution for the PMF model was tested by comparing the measured and the modeled PM2.5 masses. An excellent agreement was found between the measured and the modeled fine masses, which indicates that the six-factor-PMF solution adopted in this study accurately accounts for the observed PM2.5 mass in the city of Zonguldak, the city is located at the middle of the Black Sea coasts of Turkey.

Terzi E, Anatolaki C, Samara C, Tsitouridou R. 2008. Mass closure of total suspended particles over the coal burning power production area of western Macedonia, Greece. Journal of Atmospheric Chemistry 59: 171-86.

Abstract: Ambient suspended particles (TSP) were collected from January to June 2001 at seven sampling sites in western Macedonia, Greece, where four thermal power stations are located. TSP samples were chemically characterized for minerals (Fe, Al, Mg, Ca, K, Ti and Si), trace elements (P, Cd, Cr, Cu, Mn, Pb, V, Zn, Te, Co, Ni, Se, Sr, As, and Sb), water-soluble ions Cl−, NO3−, SO42−, Na+, K+, NH4+, Ca2+, Mg2+), carbonaceous compounds (OC/EC) and polycyclic aromatic hydrocarbons (PAHs). These classes of compounds were consequently compared with PM mass concentrations of TSP in order to perform mass closure. PM chemical compositions exhibited differences at the seven sites. Minerals were found to be more abundant at four sites, electrolytes dominated the composition at two of the sites while carbonaceous material was most abundant only at one site. The fraction unaccounted for ranged between 22 and 34%. Spatial variations of atmospheric concentrations showed significantly higher levels of minerals, some trace metals

and TC at the site that was closest to the power plants. At the same site ions exhibited high correlations with minerals and the majority of trace elements.

Verma SK, Deb MK, Suzuki Y, Tsai YI. 2010. Ion chemistry and source identification of coarse and fine aerosols in an urban area of eastern central India. Atmospheric Research 95: 65-76.

Abstract: This work focuses on size segregated atmospheric aerosol mass concentrations and water soluble inorganic components in Chhattisgarh, the eastern central India. Investigation on the monitoring of ambient air levels of atmospheric particulates were done around a large source of primary anthropogenic particulate emissions: the industrial area and coal based power plants. Chemical characterization was carried out for aerosol samples collected in urban area, Raipur, (21°14'N, 81°38'E) of Chhattisgarh region over a period of one year, using cascade impactor. Annual mean of mass concentration for coarse (PM2.5–10) and fine (PM2.5) aerosols were monitored to be 238.1 ± 89.9 and 167.0 ± 75.3 μg m− 3 respectively This work deals with the seasonal variation and meteorological influences of inorganic components of the aerosols viz. NO3−, Cl− and SO42−, Mg2+, Na+, K+, Ca2+ and NH4+. The annual mean concentration of the inorganic components were monitored to be 3.8 ± 2.5, 8.9 ± 2.7, 10.2 ± 1.5, 2.6 ± 0.6, 8.7 ± 7.2, 4.6 ± 1.8, 16.4 ± 6.9 and 0.4 ± 0.5 μg m− 3 respectively in coarse particles and 8.2 ± 7.1, 6.8 ± 3.6, 46.5 ± 32.8, 1.7 ± 0.6, 7.4 ± 3.6, 5.9 ± 3.4, 10.2 ± 2.9, and 8.8 ± 7.7 μg m− 3 respectively in fine particles, for the above ions. The average distribution of nitrate and sulphate in PM2.5–10 were found to be 1.6 and 4.2% and in PM2.5 were 4.9 and 27.9% respectively indicating the dominance of sulphate in both PM2.5–10 and PM2.5 particles. Here, industrial emission plays important role for contribution of PM2.5 particle loading in the atmosphere. The cation–anion rational analysis indicated that the PM2.5–10 particles were mostly neutralized and PM2.5 particle were acidic. The major ions were mainly in the form of NaCl > CaSO4 > K2SO4 > MgSO4 > KCl > NH4Cl > Ca(NO3)2 > KNO3 > MgCl2 > Mg(NO3)2 > NH4NO3 > (NH4)2SO4 in coarse aerosol particles and (NH4)2SO4 > K2SO4 > CaSO4 > NaCl > NH4NO3 > CaCl2 > KNO3 > MgCl2 > Ca(NO3)2 > KCl > NH4Cl in fine particles.

Wu G, Du X, Wu X, Fu X, Kong S, Chen J et al. 2013. Chemical composition, mass closure and sources of atmospheric PM10 from industrial sites in Shenzhen, China. Journal of Environmental Sciences 25(8): 1626-35.

Abstract: Concentrations of atmospheric PM10 and chemical components (including twenty-one elements, nine ions, organic carbon (OC) and elemental carbon (EC)) were measured at five sites in a heavily industrial region of Shenzhen, China in 2005. Results showed that PM10 concentrations exhibited the highest values at 264 microg/m3 at the site near a harbor with the influence of harbor activities. Sulfur exhibited the highest concentrations (from 2419 to 3995 ng/m3) of all the studied elements, which may be related to the influence of coal used as fuel in this area for industrial plants. This was verified by the high mass percentages of SO4(2-), which accounted for 34.3%-39.7% of the total ions. NO3-/SO4(2-) ratios varied from 0.64-0.71, which implies coal combustion was predominant compared with vehicle emission. The anion/cation ratios range was close to 0.95, indicating anion deficiency in this region. The harbor site showed the highest OC and EC concentrations, with the influence of emission from vessels. Secondary organic carbon accounted for about 22.6%-38.7% of OC, with the highest percentage occurring at the site adjacent to a coal-fired power plant and wood plant. The mass closure model performed well in this heavily industrial region, with significant correlation obtained between chemically determined and gravimetrically measured PM10 mass. The main constituents of PM10 were found to be organic materials (30.9%-69.5%), followed by secondary inorganic aerosol (7.9%-25.0%), crustal materials (6.7%-13.8%), elemental carbon (3.5%-10.8%), sea salt (2.4%-6.2%) and trace elements (2.0%-4.9%) in this heavily industrialized region. Principal component analysis indicated that the main sources for particulate matter in this industrial region were crustal materials and coal/wood combustion, oil combustion, secondary aerosols, industrial processes and vehicle emission.

Xu X, Barsha NAF, Li J. 2008. Analyzing regional influence of particulate matter on the City of Beijing, China. Aerosol and Air Quality Research 8: 78-93.

Abstract: The concentration levels of particulate matter (PM) in the city of Beijing (39.92°N, 116.46°E), China are dependant on the long-range transport of PM in addition to local stationary and mobile sources. To

analyze the regional influences of PM10 on the city of Beijing for the year 2004, 366 back trajectories were generated using Hybrid Single-Particle Langragian Integrated Trajectory modeling. The trajectories were then characterized by regions traversed 24 hrs back in time. The comparative impact scores of the trajectories were calculated based on the emission rates of PM10 and its precursors in each region the trajectories traversed as well its distance to Beijing. For the purpose of the subject analysis, the 366 days in 2004 were categorized as good (< 50 μg/m3), moderate (50-150 μg/m3), and poor (> 150 μg/m3) air quality groups based on daily PM10 concentrations. Besides Hebei which surrounds Beijing in all directions, our results identified Inner Mongolia, Shanxi, and Mongolia as regions having greater influence on Beijing air quality due to the prevailing westerly and northwesterly winds. Overall, the higher the overall impact score of a particular trajectory cluster, the larger the probability of having poor air quality days and the smaller the probability of having good air quality days. The analysis also indicates that on an annual basis, when air masses travel from Shanxi, which is home to many coal-fired power plants, Beijing tends to have poor air quality due to high PM10 concentrations. In comparison, when air masses originating over Inner Mongolia, where anthropogenic emissions are low, Beijing tends to have good PM air quality. However, our case study showed that during the spring, air masses originating over Inner Mongolia and Mongolia tend to carry dust and sand to Beijing, leading to poor PM air quality.

Xue YH, Wu JH, Feng YC, Dai L, Bi XH, Li X et al. 2010. Source characterization and apportionment of PM10 in Panzhihua, China. Aerosol and Air Quality Research 10: 367-77.

Abstract: A total of 258 particulate matter (PM10) filter samples and 69 source samples applicable to receptor model source apportionment were collected and chemically analyzed from February to August 2007 in Panzhihua, China. Contributive sources were identified and the chemical profiles were reported for resuspended dust, paved and unpaved road dust, coalfired power plant exhaust, emissions from coking plants and other industrial sources in Panzhihua. All samples were analyzed for 19 elements (Na-Pb), two ions (NO3 - and SO4 2-) and organic and total carbon. Elevated abundances of geological components (Al, Si, Ca and Fe) from fugitive dust materials and elements (Ti, Cr, Mn, Cu and Zn) from special industry plants were found in the profiles. The contributions to the ambient PM10 levels at six sites in three seasons (spring, summer and winter) were estimated using a chemical mass balance receptor model. The concentration of PM 10 was high (150 μg/m3) on winter days and low in summer and spring (133 and 129 μg/m3, respectively). Apportionment results indicate that coal combustion ash, iron and steel industry dust, vehicle exhaust and secondary SO4 2- were major contributors, accounting for about 70% of PM10. More attention should be paid to particulate matter emitted by iron and steel manufacturing facilities in view of high contribution and potentially toxic metals.

Yatkin S, Bayram A. 2008a. Determination of major natural and anthropogenic source profiles for particulate matter and trace elements in Izmir, Turkey. Chemosphere 71(4): 685-96.

Abstract: Samples of PM10 and PM2.5 were collected from several natural and anthropogenic sources using in-stack cyclone, grab sampling/resuspension chamber and ambient air samplers. The chemical characterization of the samples was achieved containing Al, Ba, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Sr, V and Zn using an inductively coupled plasma-optical emission spectrometer (ICP-OES). The elemental fractions (weight percent by mass), standard deviations and uncertainties were reported. The elemental compositions of PM emitted from mineral industries and cement kiln were dominated by terrestrial elements, particularly Ca, whereas the profile of top-soil mainly contained Al and Ca. The profiles of industrial sources were generally typical for related ones; however, significant differences were obtained for some of them. Similarly, the profiles of fuel burning emissions have significant differences compared to profiles obtained all around the world.

Yatkin S, Bayram A. 2008b. Source apportionment of PM10 and PM2.5 using positive matrix factorization and chemical mass balance in Izmir, Turkey. Science of the Total Environment 390(1): 109-23.

Abstract: Atmospheric particulate matter (PM) fractions (PM10 and PM2.5) were sampled concurrently between June 2004 and May 2005 at two sites (urban and suburban) in Izmir, Turkey. The elemental

composition of PM (Al, Ba, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Sr, V, and Zn) was determined using inductively coupled plasma-optical emission spectrometer. Elemental compositions of several PM sources were also characterized. Positive matrix factorization (PMF) and chemical mass balance modeling (CMB) were applied to determine the PM sources and their contributions to air concentrations. The major contributors to PM were fossil fuel burning, traffic emissions, mineral industries and marine salt according to the PMF results. However, undetermined parts were more than 40%. On the other hand, the contributions to PM could be determined completely by CMB, and the dominant contributor was traffic with >70% at the two sites. Fossil fuel burning, mineral industries, marine salt and natural gas-fired power plant were the minor contributors.

Yerramilli A, Dodla VBR, Challa VS, Myles L, Pendergrass WR, Vogel CA et al. 2012. An integrated WRF/HYSPLIT modeling approach for the assessment of PM2.5 source regions over the Mississippi Gulf Coast region. Air Quality, Atmosphere and Health 5(4): 401-12.

Abstract: Fine particulate matter (PM2.5) is majorly formed by precursor gases, such as sulfur dioxide (SO2) and nitrogen oxides (NOx), which are emitted largely from intense industrial operations and transportation activities. PM2.5 has been shown to affect respiratory health in humans. Evaluation of source regions and assessment of emission source contributions in the Gulf Coast region of the USA will be useful for the development of PM2.5 regulatory and mitigation strategies. In the present study, the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model driven by the Weather Research & Forecasting (WRF) model is used to identify the emission source locations and transportation trends. Meteorological observations as well as PM2.5 sulfate and nitric acid concentrations were collected at two sites during the Mississippi Coastal Atmospheric Dispersion Study, a summer 2009 field experiment along the Mississippi Gulf Coast. Meteorological fields during the campaign were simulated using WRF with three nested domains of 36, 12, and 4 km horizontal resolutions and 43 vertical levels and validated with North American Mesoscale Analysis. The HYSPLIT model was integrated with meteorological fields derived from the WRF model to identify the source locations using backward trajectory analysis. The backward trajectories for a 24-h period were plotted at 1-h intervals starting from two observation locations to identify probable sources. The back trajectories distinctly indicated the sources to be in the direction between south and west, thus to have origin from local Mississippi, neighboring Louisiana state, and Gulf of Mexico. Out of the eight power plants located within the radius of 300 km of the two monitoring sites examined as sources, only Watson, Cajun, and Morrow power plants fall in the path of the derived back trajectories. Forward dispersions patterns computed using HYSPLIT were plotted from each of these source locations using the hourly mean emission concentrations as computed from past annual emission strength data to assess extent of their contribution. An assessment of the relative contributions from the eight sources reveal that only Cajun and Morrow power plants contribute to the observations at the Wiggins Airport to a certain extent while none of the eight power plants contribute to the observations at Harrison Central High School. As these observations represent a moderate event with daily average values of 5-8 μg m-3 for sulfate and 1-3 μg m-3 for HNO3 with differences between the two spatially varied sites, the local sources may also be significant contributors for the observed values of PM2.5.

Grey literature

Bangert M, Vogel B, Junkermann W, Brachert L, Schaber K. 2013. The impact of flue gas cleaning technologies in coal-fired power plants on the CCN distribution and cloud properties in Germany. In: International Conference on Nucleation and Atmospheric Aerosols, 778-81.

Abstract: Gas-cleaning technologies used in modern coal-fired power plants cause an unintended nucleation of H2SO4 aerosol droplets during the cleaning process. As a result, high concentrations of ultra-fine aerosol droplets are emitted into the atmosphere. In this study, the impact of these emissions on the atmospheric

aerosol distribution, on the cloud condensation nuclei number concentration, and consequently on cloud properties is investigated. Therefore, a sophisticated modeling framework is used combining regional simulations of the atmospheric aerosol distribution and its impact on cloud properties with detailed process simulations of the nucleation during the cleaning process inside the power plant. Furthermore, the simulated aerosol size distributions downwind of the coal-fired power plants are compared with airborne aerosol measurements performed inside the plumes.

Hibberd MF, Selleck PW, Keywood MD, Cohen DD, Stelcer E, Atanacio, AJ. 2013. Upper Hunter Particle Characterisation Study. Commonwealth Scientific and Industrial Research Organisation, Australia. Available at http://www.environment.nsw.gov.au/resources/aqms/UHFPCSFinal.pdf.

Abstract: *No abstract available.*

Excerpt from Executive Summary:
[This study provides an analysis of the composition of PM2.5 (particulate matter with a diameter of less than 2.5 micrometres) in the two main population centres in the Upper Hunter, namely Muswellbrook and Singleton, during 2012.The finer PM2.5 particles have been studied because they are of greatest concern owing to their impact on health.
Samples were collected for 24 hours every third day and analysed for the components of PM2.5, specifically twenty elements, fourteen soluble ions, two anhydrous sugars (levoglucosan and mannosan) that are found in woodsmoke, organic carbon (OC), and black carbon (BC), as well as gravimetric mass.
The chemical composition of all the samples from each site was analysed using a mathematical technique called Positive Matrix Factorisation (PMF), which is widely used in air pollution source apportionment studies. This identified eight factors (also called 'fingerprints') which represent the mix of components that tend to vary together in time. Further analysis, using information about known sources and knowledge of atmospheric chemistry as well as wind sector and seasonal analysis, was undertaken to identify the most likely source of emissions for each factor and hence the contribution that each source makes to the measured PM2.5 concentrations.]

Lu P, Wu J, Pan WP. 2010. Particulate matter emissions from a coal-fired power plant. In: 4th International Conference on Bioinformatics and Biomedical Engineering, 1-4.

Abstract: Particulate matter emissions of filterable particulate matter (FPM), condensible PM (CPM), PM10, and PM2.5 at FGD inlet and stack in a coal-fired power plant were measured by EPA method 201A and method 202. The results indicated that emissions of total particulate matter (TPM) are 40.99 mg/m3 and 120.58 mg/m3, and the filterable PMs are the highest emissions at both sampling locations which accounted for 76.3% and 75.4% of TPM, the PM10 are 14.73 mg/m3 and 88.23 mg/m3, the PM2.5 are 3.17 mg/m3 and 52.15 mg/m3 at FGD inlet and stack, respectively. The concentration of PMs in flue gas increases significantly after the flue gas passing through the FGD unit. The increase values of PM10/FPM and PM2.5/FPM ratios are 106% and 266%, respectively, but the CPM/TPM ratio is almost at the same level (23.7-24.6 mg/m3) after the flue gas passing through the FGD. The test indicated that FGD operation has a significant effect on particulate matters emission due to releasing finer particles and part volatile metals in FGD slurry. Some measures should be taken to control PM emissions for a utility boiler equipped with FGD unit.

Ozgen S, Cernuschi S, Giugliano M, Signorini S. 2012. Nanoparticle emissions from a woody biomass power plant (15 Mw). In: 20th European Biomass Conference and Exhibition, 1375-8.

Abstract: Biomass energy is attracting more and more attention because it is a potentially CO2 neutral and renewable energy source. Nonetheless biomass combustion is reported to be an important source of ambient fine particulate matter (PM). Though large scale combustion installations such as power plants have efficient flue gas cleaning systems and are continuously monitored for stack gas conventional PM mass concentrations, ultrafine (UFP: dp <100 nm) and nanoparticle (NP: dp < 50 nm) number emissions from these installations remain largely unmeasured. For this purpose stack measurements of ultrafine particle emissions were conducted on a grate-firing woody biomass power plant with the evaluation extended also to the investigation

of the contribution on these emissions of any material of condensable origin, arising from cooling and dilution effects immediately following flue gas release into the atmosphere.

Pitchford M, Green MC, Morris R, Emery C, Sakata R, Swab C, Mairose PT. 2008. Columbia River Gorge Air Quality Study: Science Summary Report. Available at http://www.swcleanair.org/gorgedata/FinalScienceSummaryReportFeb8-08.pdf.

Abstract: In order to implement the May 2000 Gorge National Scenic Area Management Plan amendment, plans were made to conduct technical assessment activities designed to answer a series of questions concerning the nature and causes of haze in the Gorge. These activities included collection and analysis of additional monitoring data, development of an emissions inventory for the region, and application of regional meteorological and air quality modeling of two typical multi-day Gorge haze episodes during 2004. Separate reports were prepared for these activities. The purpose of this Science Summary Report is to combine the information from these reports with other available information to address the questions concerning haze in the Gorge.

Stevens R, Lonsdale C, Brock C, Makar P, Knipping E, Reed M et al. 2013. Aerosol nucleation in coal-fired power-plant plumes. In: Nucleation and Atmospheric Aerosols: 19th International Conference, AIP Conference Proceedings, 1527, 417-420.

Abstract: New-particle nucleation within coal-fired power-plant plumes can have large effects on particle number concentrations, particularly near source regions, with implications for human health and climate. In order to resolve the formation and growth of particles in these plumes, we have integrated TwO-Moment Aerosol Sectional (TOMAS) microphysics in the System for Atmospheric Modelling (SAM), a large-eddy simulation/cloud-resolving model (LES/CRM). We have evaluated this model against aircraft observations for three case studies, and the model reproduces well the major features of each case. Using this model, we have shown that meteorology and background aerosol concentrations can have strong effects on new-particle formation and growth in coal-fired power-plant plumes, even if emissions are held constant. We subsequently used the model to evaluate the effects of SO2 and NOx pollution controls on new-particle formation in coal-fired power-plant plumes. We found that strong reductions in NOx emissions without concurrent reductions in SO2 emissions may increase new-particle formation, due to increases in OH formation within the plume. We predicted the change in new-particle formation due to changes in emissions between 1997 and 2010 for 330 coal-fired power plants in the US, and we found a median decrease of 19% in new-particle formation. However, the magnitude and sign of the aerosol changes depend greatly on the relative reductions in NOx and SO2 emissions in each plant. More extensive plume measurements for a range of emissions of SO2 and NOx and in varying background aerosol conditions are needed, however, to better quantify these effects.

3.3.3 PM - modeled emissions (emission inventories)

White literature

Griffiths S, Booth V, Lennard R. 2011. Implications for UK coal-fired power stations of a move to a particulate matter standard based on PM2.5. International Journal of Environment and Pollution 44(1-4): 252-60.

Abstract: The contribution of UK coal-fired power stations to ambient PM2.5 concentrations has been assessed using short- and long-range modelling. The results suggested a minimal contribution from power stations to both local and regional concentrations of PM2.5 relative to the standards in the proposed European Directive on Ambient Air Quality and only a modest contribution in terms of overall UK PM2.5 levels. Secondary particulate showed a different concentration pattern to primary particulate, the latter being focused on urban areas with high populations. This has important implications for exposure if, as toxicological studies suggest, the toxic component lies predominantly within primary fraction.

Lei Y, Zhang Q, He KB, Streets DG. 2011. Primary anthropogenic aerosol emission trends for China, 1990-2005. Atmospheric Chemistry and Physics 11(3): 931-54.

Abstract: An inventory of anthropogenic primary aerosol emissions in China was developed for 1990-2005 using a technology-based approach. Taking into account changes in the technology penetration within industry sectors and improvements in emission controls driven by stricter emission standards, a dynamic methodology was derived and implemented to estimate inter-annual emission factors. Emission factors of PM2.5 decreased by 7%-69% from 1990 to 2005 in different industry sectors of China, and emission factors of TSP decreased by 18%-80% as well, with the measures of controlling PM emissions implemented. As a result, emissions of PM2.5 and TSP in 2005 were 11.0 Tg and 29.7 Tg, respectively, less than what they would have been without the adoption of these measures. Emissions of PM2.5, PM10 and TSP presented similar trends: they increased in the first six years of 1990s and decreased until 2000, then increased again in the following years. Emissions of TSP peaked (35.5 Tg) in 1996, while the peak of PM10 (18.8 Tg) and PM2.5 (12.7 Tg) emissions occurred in 2005. Although various emission trends were identified across sectors, the cement industry and biofuel combustion in the residential sector were consistently the largest sources of PM2.5 emissions, accounting for 53%-62% of emissions over the study period. The non-metallic mineral product industry, including the cement, lime and brick industries, accounted for 54%-63% of national TSP emissions. There were no significant trends of BC and OC emissions until 2000, but the increase after 2000 brought the peaks of BC (1.51 Tg) and OC (3.19 Tg) emissions in 2005. Although significant improvements in the estimation of primary aerosols are presented here, there still exist large uncertainties. More accurate and detailed activity information and emission factors based on local tests are essential to further improve emission estimates, this especially being so for the brick and coke industries, as well as for coal-burning stoves and biofuel usage in the residential sector.

Sahu SK, Beig G, Parkhi NS. 2011. Emissions inventory of anthropogenic PM2.5 and PM10 in Delhi during Commonwealth Games 2010. Atmospheric Environment 45(34): 6180-90.

Abstract: As part of the System of Air quality Forecasting and Research (SAFAR) project developed for air quality forecasting during the Commonwealth Games (CWG) – 2010, a high resolution Emission Inventory (EI) of PM10 and PM2.5 has been developed for the metropolitan city Delhi for the year 2010. The comprehensive inventory involves detailed activity data and developed for a domain of 70 km × 65 km with a 1.67 km × 1.67 km resolution covering Delhi and surrounding region using Geographical Information System (GIS) technique. The major sectors considered are, transport, thermal power plants, industries, residential and commercial cooking along with windblown road dust which is found to play a major role for Delhi environment. It has been found that total emissions of PM10 and PM2.5 including wind blown dust over the study area are found to be 236 Gg yr-1 and 94 Gg yr-1 respectively. The contribution of windblown road dust is found to be as high as 131 Gg yr-1 for PM10.

Tainio M, Sofiev M, Hujo M, Tuomisto JT, Loh M, Jantunen MJ et al. 2009. Evaluation of the European population intake fractions for European and Finnish anthropogenic primary fine particulate matter emissions. Atmospheric Environment 43(19): 3052-9.

Abstract: The intake fraction (iF) has been defined as the integrated incremental intake of a pollutant released from a source category or region summed over all exposed individuals. In this study we evaluated the iFs in the population of Europe for emissions of anthropogenic primary fine particulate matter (PM2.5) from sources in Europe, with a more detailed analysis of the iF from Finnish sources. Parameters for calculating the iFs include the emission strengths, the predicted atmospheric concentrations, European population data, and the average breathing rate per person. Emissions for the whole of Europe and Finland were based on the inventories of the European Monitoring and Evaluation Programme (EMEP) and the Finnish Regional Emission Scenario (FRES) model, respectively. The atmospheric dispersion of primary PM2.5 was computed using the regional-scale dispersion model SILAM. The iFs from Finnish sources were also computed separately for six emission source categories. The iFs corresponding to the primary PM2.5 emissions from the European countries for the whole population of Europe were generally highest for the densely populated Western European countries, second highest for the Eastern and Southern European countries, and lowest for the Northern European and Baltic countries. For the entire European population, the iF values varied from the lowest value of 0.31 per million for emissions from Cyprus, to the highest value of 4.42 per million for emissions from Belgium. These results depend on the regional distribution of the population and the prevailing long-term meteorological conditions. Regarding Finnish primary PM2.5 emissions, the iF was highest for traffic emissions (0.68 per million) and lowest for major power plant emissions (0.50 per million). The results provide new information that can be used to find the most cost-efficient emission abatement strategies and policies.

Wang L, Hao J, He K, Wang S, Li J, Zhang Q et al. 2008. A modeling study of coarse particulate matter pollution in Beijing: regional source contributions and control implications for the 2008 Summer Olympics. Journal of the Air and Waste Management Association 58(8): 1057-69.

Abstract: In the last 10 yr, Beijing has made a great effort to improve its air quality. However, it is still suffering from regional coarse particulate matter (PM10) pollution that could be a challenge to the promise of clean air during the 2008 Olympics. To provide scientific guidance on regional air pollution control, the Mesoscale Modeling System Generation 5 (MM5) and the Models-3/Community Multiscale Air Quality Model (CMAQ) air quality modeling system was used to investigate the contributions of emission sources outside the Beijing area to pollution levels in Beijing. The contributions to the PM10 concentrations in Beijing were assessed for the following sources: power plants, industry, domestic sources, transportation, agriculture, and biomass open burning. In January, it is estimated that on average 22% of the PM10 concentrations can be attributed to outside sources, of which domestic and industrial sources contributed 37 and 31%, respectively. In August, as much as 40% of the PM10 concentrations came from regional sources, of which approximately 41% came from industry and 31% from power plants. However, the synchronous analysis of the hourly concentrations, regional contributions, and wind vectors indicates that in the heaviest pollution periods the local emission sources play a more important role. The implications are that long-term control strategies should be based on regional-scale collaborations, and that emission abatement of local sources may be more effective in lowering the PM10 concentration levels on the heavy pollution days. Better air quality can be attained during the Olympics by placing effective emission controls on the local sources in Beijing and by controlling emissions from industry and power plants in the surrounding regions.

Grey Literature

Dabo G, Zhu L. 2013. Tracing Back the Smog: Source Analysis and Control Strategies for PM2.5 Pollution in Beijing-Tianjin-Hebei. Greenpeace, China Environmental Press. Available at http://www.greenpeace.org/eastasia/Global/eastasia/publications/reports/climate-energy/2013/Tracing%20back%20the%20smog%20(English%20full%20report).pdf.

Abstract: *No abstract available.*

Excerpt from Executive Summary:
[Severe air pollution and its associated health impacts have become of major concern in China, and pollution control measures targeting heavily polluted areas are top of the agenda at all levels of government. In September 2013, the State Council issued the Airborne Pollution Prevention and Control Action Plan (2013-17), pledging to improve air quality in the Beijing-Tianjin-Hebei area (hereinafter referred to as the "Jingjinji" region), the Yangtze River Delta and the Pearl River Delta. Soon afterwards, the Ministry of Environmental Protection (MEP) released a detailed implementation plan, aiming to reduce PM2.5 levels in Jingjinji by 25% and keep PM2.5 concentration in Beijing from exceeding a level of 60 μg/m3 by 2017. However, even if PM2.5 is reduced by 25% every five years, the National Air Quality Standard Level II of 35 μg/m3 will not be achieved until 2030.
As clear and concrete pollution reduction goals at the central and local government levels are being set, public concern for a deteriorating living environment continue to mount. Due to a lack of detailed analysis on PM2.5 composition and emission sources, little information is available on trends in PM2.5 concentrations, and answers to the questions how much air pollution should be reduced and how to accomplish this reduction remain unclear. The reality is that achieving the proposed PM2.5 target remains a challenging task, especially considering the need for control measures that reflect the various characteristics of the region. Therefore Greenpeace has been co-operating with a team from the University of Leeds, UK, led by Dr. Dabo Guan, with the aim to study PM2.5 sources and control strategies in Jingjinji, since the end of 2012.
This project report is the first of its kind to comprehensively analyze PM2.5 sources in the Jingjinji region and to assess to what extend the region should do to reach the air quality targets set by the MEP. The report aims to provide insight into PM2.5 pollution in the region, to fuel public debate, and more importantly, to inform and influence decision-makers and stakeholders and provide rationale and support for actions that reduce PM2.5 levels.]

3.4 Carbon dioxide and greenhouse gases

3.4.1 CO2 and GHG - health effects

No abstracts

3.4.2 CO2 and GHG - measured emissions (flue gas or ambient air)

White literature

Alavijeh HS, Kiyoumarsioskouei A, Asheri MH, Naemi S, Alavije HS, Tabrizi HB. 2013. Greenhouse gas emission measurement and economic analysis of Iran natural gas fired power plants. Energy Policy 60: 200-7.

Abstract: This study attempts to examine the natural gas fired power plants in Iran. The required data from natural gas fired power plants were gathered during 2008. The characteristics of thirty two gas turbine power plants and twenty steam power plants have been measured. Their emission factor values were then compared with the standards of Energy Protection Agency, Euro Union and World Bank. Emission factors of gas turbine and steam power plants show that gas turbine power plants have a better performance than steam power plants. For economic analysis, fuel consumption and environmental damages caused by the emitted pollutants are considered as cost functions; and electricity sales revenue are taken as benefit functions. All of these functions have been obtained according to the capacity factor. Total revenue functions show that gas turbine and steam power plants are economically efficient at 98.15% and 90.89% of capacity factor, respectively; this indicates that long operating years of power plants leads to reduction of optimum capacity factor. The stated method could be implemented to assess the economic status of a country's power plants where as efficient capacity factor close to one means that power plant works in much better condition.

Bovensmann H, Buchwitz M, Burrows JP, Reuter M, Krings T, Gerilowski K et al. 2010. A remote sensing technique for global monitoring of power plant CO2 emissions from space and related applications. Atmospheric Measurement Techniques 3(4): 781-811.

Abstract: Carbon dioxide (CO2) is the most important anthropogenic greenhouse gas (GHG) causing global warming. The atmospheric CO2 concentration increased by more than 30% since pre-industrial times – primarily due to burning of fossil fuels – and still continues to increase. Reporting of CO2 emissions is required by the Kyoto protocol. Independent verification of reported emissions, which are typically not directly measured, by methods such as inverse modeling of measured atmospheric CO2 concentrations is currently not possible globally due to lack of appropriate observations. Existing satellite instruments such as SCIAMACHY/ENVISAT and TANSO/GOSAT focus on advancing our understanding of natural CO2 sources and sinks. The obvious next step for future generation satellites is to also constrain anthropogenic CO2 emissions. Here we present a promising satellite remote sensing concept based on spectroscopic measurements of reflected solar radiation and show, using power plants as an example, that strong localized CO2 point sources can be detected and their emissions quantified. This requires mapping the atmospheric CO2 column distribution at a spatial resolution of 2×2 km2 with a precision of 0.5% (2 ppm) or better. We indicate that this can be achieved with existing technology. For a single satellite in sun-synchronous orbit with a swath width of 500 km, each power plant (PP) is overflown every 6 days or more frequent. Based on the MODIS cloud mask data product we conservatively estimate that typically 20 sufficiently cloud free overpasses per PP can be achieved every year. We found that for typical wind speeds in the range of 2–6 m/s the statistical uncertainty of the retrieved PP CO2 emission due to instrument noise is in the range 1.6–4.8 MtCO2/yr for single overpasses. This corresponds to 12–36% of the emission of a mid-size PP (13 MtCO2/yr). We have also determined the sensitivity to parameters which may result in systematic errors such as atmospheric transport and aerosol related parameters. We found that the emission error depends linearly on wind speed, i.e., a 10% wind speed error results in a 10% emission error, and that neglecting enhanced aerosol concentrations in the PP plume may result in errors in the range 0.2–2.5 MtCO2/yr, depending on PP aerosol emission. The discussed concept has the potential to contribute to an independent verification of

reported anthropogenic CO2 emissions and therefore could be an important component of a future global anthropogenic GHG emission monitoring system. This is of relevance in the context of Kyoto protocol follow-on agreements but also allows detection and monitoring of a variety of other strong natural and anthropogenic CO2 and CH4 emitters. The investigated instrument is not limited to these applications as it has been specified to also deliver the data needed for global regional-scale CO2 and CH4 surface flux inverse modeling.

Calcagnile L, Quarta G, D'Elia M, Ciceri G, Martinotti V. 2011. Radiocarbon AMS determination of the biogenic component in CO2 emitted from waste incineration. Nuclear Instruments and Methods in Physics Research, Section B: Beam Interactions with Materials and Atoms 269(24): 3158-62.

Abstract: The thermal utilization of waste for energy production is gaining importance in European countries. Nevertheless, the combustion of waste leads to significant CO2 emissions in the atmosphere which, depending on the fraction of biogenic and fossil materials, have to be only partially accounted for the national greenhouse gas inventory. For this reason the development of proper methodologies for the measurement of the biogenic fraction in the combusted waste is an active research field. In fact the determination of the radiocarbon concentration in the carbon dioxide stack emissions allows to have a direct indication of the biogenic component in the burned fuel. We present the results of the AMS radiocarbon analyses carried out on carbon dioxide sampled at the stack of three power plants located in Northern Italy burning natural gas, landfill biogas and SRF (Solid Recovered Fuel) derived from MSW (Municipal Solid Waste). The sampling apparatus and the applied processing protocols are described together with the calculation procedures used to determine, from the measured radiocarbon concentrations, the proportion of biogenic and fossil component in the flue gas and in the combusted fuel. The results confirm the high potentialities of this approach in the analysis of industrial CO2 emissions.

Cho CS, Sa JH, Lim KK, Youk TM, Kim SJ, Lee SK et al. 2012. Development of methane and nitrous oxide emission factors for the biomass fired circulating fluidized bed combustion power plant. The Scientific World Journal 2012: 989242.

Abstract: This study makes use of this distinction to analyze the exhaust gas concentration and fuel of the circulating fluidized bed (CFB) boiler that mainly uses wood biomass, and to develop the emission factors of Methane (CH4), Nitrous oxide (N2O). The fuels used as energy sources in the subject working sites are Wood Chip Fuel (WCF), RDF and Refused Plastic Fuel (RPF) of which heating values are 11.9 TJ/Gg, 17.1 TJ/Gg, and 31.2 TJ/Gg, respectively. The average concentrations of CH4 and N2O were measured to be 2.78 ppm and 7.68 ppm, respectively. The analyzed values and data collected from the field survey were used to calculate the emission factor of CH4 and N2O exhausted from the CFB boiler. As a result, the emission factors of CH4 and N2O are 1.4 kg/TJ (0.9-1.9 kg/TJ) and 4.0 kg/TJ (2.9-5.3 kg/TJ) within a 95% confidence interval. Biomass combined with the combustion technology for the CFB boiler proved to be more effective in reducing the N2O emission, compared to the emission factor of the CFB boiler using fossil fuel.

Krings T, Gerilowski K, Buchwitz M, Reuter M, Tretner A, Erzinger J et al. 2011. MAMAP - a new spectrometer system for column-averaged methane and carbon dioxide observations from aircraft: retrieval algorithm and first inversions for point source emission rates. Atmospheric Measurement Techniques 4: 1735-58.

Abstract: MAMAP is an airborne passive remote sensing instrument designed to measure the dry columns of methane (CH4) and carbon dioxide (CO2). The MAMAP instrument comprises two optical grating spectrometers: the first observing in the short wave infrared band (SWIR) at 1590-1690 nm to measure CO2 and CH4 absorptions, and the second in the near infrared (NIR) at 757-768 nm to measure O-2 absorptions for reference/normalisation purposes. MAMAP can be operated in both nadir and zenith geometry during the flight. Mounted on an aeroplane, MAMAP surveys areas on regional to local scales with a ground pixel resolution of approximately 29 m x 33 m for a typical aircraft altitude of 1250 m and a velocity of 200 km h(-1). The retrieval precision of the measured column relative to background is typically <= 1% (1 sigma). MAMAP measurements are valuable to close the gap between satellite data, having global coverage but with a

rather coarse resolution, on the one hand, and highly accurate in situ measurements with sparse coverage on the other hand. In July 2007, test flights were performed over two coal-fired power plants operated by Vattenfall Europe Generation AG: Janschwalde (27.4 Mt CO2 yr(-1)) and Schwarze Pumpe (11.9 Mt CO2 yr-1), about 100 km southeast of Berlin, Germany. By using two different inversion approaches, one based on an optimal estimation scheme to fit Gaussian plume models from multiple sources to the data, and another using a simple Gaussian integral method, the emission rates can be determined and compared with emissions reported by Vattenfall Europe. An extensive error analysis for the retrieval's dry column results (XCO2 and XCH4) and for the two inversion methods has been performed. Both methods - the Gaussian plume model fit and the Gaussian integral method - are capable of deriving estimates for strong point source emission rates that are within +/- 10% of the reported values, given appropriate flight patterns and detailed knowledge of wind conditions.

Lee S, Kim J, Lee J, Jeon EC. 2012. A study on methane and nitrous oxide emissions characteristics from anthracite circulating fluidized bed power plant in Korea. The Scientific World Journal 2012: 468214.

Abstract: In order to tackle climate change effectively, the greenhouse gas emissions produced in Korea should be assessed precisely. To do so, the nation needs to accumulate country-specific data reflecting the specific circumstances surrounding Korea's emissions. This paper analyzed element contents of domestic anthracite, calorific value, and concentration of methane (CH4) and nitrous oxide (N2O) in the exhaust gases from circulating fluidized bed plant. The findings showed the concentration of CH4 and N2O in the flue gas to be 1.85 and 3.25 ppm, respectively, and emission factors were 0.486 and 2.198 kg/TJ, respectively. The CH4 emission factor in this paper was 52% lower than default emission factor presented by the IPCC. The N2O emission factor was estimated to be 46% higher than default emission factor presented by the IPCC. This discrepancy can be attributable to the different methods and conditions of combustion because the default emission factors suggested by IPCC take only fuel characteristics into consideration without combustion technologies. Therefore, Korea needs to facilitate research on a legion of fuel and energy consumption facilities to develop country-specific emission factors so that the nation can have a competitive edge in the international climate change convention in the years to come.

Lee S, Kim J, Lee J, Lee S, Jeon EC. 2013. A study on the evaluations of emission factors and uncertainty ranges for methane and nitrous oxide from combined-cycle power plant in Korea. Environmental Science and Pollution Research International 20(1): 461-8.

Abstract: In this research, in order to develop technology/country-specific emission factors of methane (CH4) and nitrous oxide (N2O), a total of 585 samples from eight gas-fired turbine combined cycle (GTCC) power plants were measured and analyzed. The research found that the emission factor for CH4 stood at "0.82 kg/TJ", which was an 18 % lower than the emission factor for liquefied natural gas (LNG) GTCC "1 kg/TJ" presented by Intergovernmental Panel on Climate Change (IPCC). The result was 8 % up when compared with the emission factor of Japan which stands at "0.75 kg/TJ". The emission factor for N2O was "0.65 kg/TJ", which is significantly lower than "3 kg/TJ" of the emission factor for LNG GTCC presented by IPCC, but over six times higher than the default N2O emission factor of LNG. The evaluation of uncertainty was conducted based on the estimated non-CO2 emission factors, and the ranges of uncertainty for CH4 and N2O were between -12.96 and +13.89 %, and -11.43 and +12.86 %, respectively, which is significantly lower than uncertainties presented by IPCC. These differences proved that non-CO2 emissions can change depending on combustion technologies; therefore, it is vital to establish country/technology-specific emission factors.

Mohn J, Szidat S, Fellner J, Rechberger H, Quartier R, Buchmann B et al. 2008. Determination of biogenic and fossil CO2 emitted by waste incineration based on (CO2)-C-14 and mass balances. Bioresource Technology 99(14): 6471-9.

Abstract: A field application of the radiocarbon (C-14) method was developed to determine the ratio of biogenic vs. fossil CO2 emissions from waste-to-energy plants (WTE). This methodology can be used to assign the Kyoto relevant share of fossil CO2 emissions, which is highly relevant for emission budgets and

emission trading. Furthermore, heat and electricity produced by waste incinerators might be labelled depending on the fossil or biogenic nature of the primary energy source. The method development includes representative on-site CO2 absorption and subsequent release in the laboratory. Furthermore, a reference value for the 14C content of pure biogenic waste (f(M.bio)) was determined as 1.130 +/- 0.038. Gas samples for (CO2)-C-14 analysis were taken at three WTEs during one month each. Results were compared to an alternative approach based on mass and energy balances. Both methods were in excellent agreement and indicated a fraction of biogenic CO2 slightly above 50%.

Mohn J, Szidat S, Zeyer K, Emmenegger L. 2012. Fossil and biogenic CO2 from waste incineration based on a yearlong radiocarbon study. Waste Management 32(8): 1516-20.

Abstract: We describe the first long-term implementation of the radiocarbon (14C) method to study the share of biogenic (%Bio C) and fossil (%Fos C) carbon in combustion CO2. At five Swiss incinerators, a total of 24 three-week measurement campaigns were performed over 1 year. Temporally averaged bag samples were analyzed for 14CO2 by accelerator mass spectrometry. Significant differences between the plants in the share of fossil CO2 were observed, with annual mean values from 43.4 ± 3.9% to 54.5 ± 3.1%. Variations can be explained by the waste composition of the respective plant. Based on our dataset, an average value of 48 ± 4%Fos C was determined for waste incineration in Switzerland. No clear annual trend in %Fos C was observed for four of the monitored incinerators, while one incinerator showed considerable variations, which are likely due to the separation and temporary storage of bulky goods.

Palstra SW, Meijer HA. 2010. Carbon-14 based determination of the biogenic fraction of industrial CO2 emissions - application and validation. Bioresource Technology 101(10): 3702-10.

Abstract: The (14)C method is a very reliable and sensitive method for industrial plants, emission authorities and emission inventories to verify data estimations of biogenic fractions of CO2 emissions. The applicability of the method is shown for flue gas CO2 samples that have been sampled in 1-h intervals at a coal- and wood-fired power plant and a waste incineration plant. Biogenic flue gas CO2 fractions of 5-10% and 48-50% have been measured at the power plant and the waste incineration plant, respectively. The reliability of the method has been proven by comparison of the power plant results with those based on carbon mass input and output data of the power plant. At industrial plants with relatively low biogenic CO2 fraction (<10%) the results need to be corrected for sampled (14)CO2 from atmospheric air.

Velazco VA, Buchwitz M, Bovensmann H, Reuter M, Schneising O, Heymann J et al. 2011. Towards space based verification of CO2 emissions from strong localized sources: fossil fuel power plant emissions as seen by a CarbonSat constellation. Atmospheric Measurement Techniques 4: 2809-22.

Abstract: Carbon dioxide (CO2) is the most important man-made greenhouse gas (GHG) that cause global warming. With electricity generation through fossil-fuel power plants now being the economic sector with the largest source of CO2, power plant emissions monitoring has become more important than ever in the fight against global warming. In a previous study done by Bovensmann et al. (2010), random and systematic errors of power plant CO2 emissions have been quantified using a single overpass from a proposed CarbonSat instrument. In this study, we quantify errors of power plant annual emission estimates from a hypothetical CarbonSat and constellations of several CarbonSats while taking into account that power plant CO2 emissions are time-dependent. Our focus is on estimating systematic errors arising from the sparse temporal sampling as well as random errors that are primarily dependent on wind speeds. We used hourly emissions data from the US Environmental Protection Agency (EPA) combined with assimilated and re-analyzed meteorological fields from the National Centers of Environmental Prediction (NCEP). CarbonSat orbits were simulated as a sun-synchronous low-earth orbiting satellite (LEO) with an 828-km orbit height, local time ascending node (LTAN) of 13:30 (01:30 p.m. LT) and achieves global coverage after 5 days. We show, that despite the variability of the power plant emissions and the limited satellite overpasses, one CarbonSat has the potential to verify reported US annual CO2 emissions from large power plants (>= 5 MtCO2 yr(-1)) with a systematic error of less than similar to 4.9% and a random error of less than similar to 6.7% for 50% of all the power plants. For 90% of all the power plants, the systematic error was less than similar to 12.4% and the random error was less than similar to 13 %. We additionally investigated two different satellite configurations

using a combination of 5 CarbonSats. One achieves global coverage everyday but only samples the targets at fixed local times. The other configuration samples the targets five times at two-hour intervals approximately every 6th day but only achieves global coverage after 5 days. From the statistical analyses, we found, as expected, that the random errors improve by approximately a factor of two if 5 satellites are used. On the other hand, more satellites do not result in a large reduction of the systematic error. The systematic error is somewhat smaller for the CarbonSat constellation configuration achieving global coverage everyday. Therefore, we recommend the CarbonSat constellation configuration that achieves daily global coverage.

Grey Literature

Thorpe AK, Roberts DA, Dennison PE, Bradley ES, Funk CC. 2012. Point source emissions mapping using the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS). In: Proceedings of SPIE 8390: Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XVIII, 839013.

Abstract: The Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) measures reflected solar radiation in the shortwave infrared and has been used to map methane (CH4) using both a radiative transfer technique [1] and a band ratio method [2]. However, these methods are best suited to water bodies with high sunglint and are not well suited for terrestrial scenes. In this study, a cluster-tuned matched filter algorithm originally developed by Funk et al. [3] for synthetic thermal infrared data was used for gas plume detection over more heterogeneous backgrounds. This approach permits mapping of CH4, CO2 (carbon dioxide), and N2O (nitrous oxide) trace gas emissions in multiple AVIRIS scenes for terrestrial and marine targets. At the Coal Oil Point marine seeps offshore of Santa Barbara, CA, strong CH4 anomalies were detected that closely resemble results obtained using the band ratio index. CO2 anomalies were mapped for a fossil-fuel power plant, while multiple N2O and CH4 anomalies were present at the Hyperion wastewater treatment facility in Los Angeles, CA. Nearby, smaller CH4 anomalies were also detected immediately downwind of hydrocarbon storage tanks and centered on a flaring stack at the Inglewood Gas Plant. Improving these detection methods might permit gas detection over large search areas, e. g. identifying fugitive CH4 emissions from damaged natural gas pipelines or hydraulic fracturing. Further, this technique could be applied to other trace gasses with distinct absorption features and to data from planned instruments such as AVIRISng, the NEON Airborne Observation Platform (AOP), and the visible-shortwave infrared (VSWIR) sensor on the proposed HyspIRI satellite.

3.4.3 CO2 and GHG - modeled emissions (emission inventories)

White literature

Ari I, Aydinalp Koksal M. 2011. Carbon dioxide emission from the Turkish electricity sector and its mitigation options. Energy Policy 39: 6120-35.

Abstract: In this study, electricity generation associated CO2 emissions and fuel-specific CO2 emission factors are calculated based on the IPCC methodology using the data of fossil-fueled power plants that ran between 2001 and 2008 in Turkey. The estimated CO2 emissions from fossil-fueled power plants between 2009 and 2019 are also calculated using the fuel-specific CO2 emission factors and data on the projected generation capacity of the power plants that are planned to be built during this period. Given that the total electricity supply (planned+existing) will not be sufficient to provide the estimated demand between 2011 and 2019, four scenarios based on using different fuel mixtures are developed to overcome this deficiency. The results from these scenarios show that a significant decrease in the amount of CO2 emissions from electricity generation can be achieved if the share of the fossil-fueled power plants is lowered. The Renewable Energy Scenario is found to result in the lowest CO2 emissions between 2009 and 2019. The associated CO2 emissions calculated based on this scenario are approximately 192 million tons lower than that of the Business As Usual Scenario for the estimation period.

Chen W, Teng R, Xu R, Xiang X, Zeng R, Domptail K et al. 2009. CCS scenarios optimisation by spatial multi-criteria analysis: Application to multiple source-sink matching in the Bohai Basin (North China). Energy Procedia 1(1): 4167-74.

Abstract: Methods, based on spatial analysis of the different criteria to be taken into consideration for building scenarios of CO2 Capture and Storage (CCS), have been developed and applied to real case studies in the Hebei Province (northeast China). The total CO2 emissions from point sources in the province amount to 220Mt/y, mainly from power plants, and from iron-steel, cement, ammonia plants, and refineries. Storage opportunities can be found in the Bohai Basin, characterised by a strong tectonic subsidence during the Tertiary, with several kilometres of accumulated clastic sediments. Two complementary methods were designed to best match sources and sinks, accounting for the cost of transport, injection and storage: an algorithm working on pairs of sources and sinks, and a spatial analyse on costs grids using functions of ArcGIS software which takes into account the additional costs of pipeline construction due to landform and land use.

Ganga S, Gurjar BR, Kumari R. 2011. Urban and country level greenhouse gas emissions and carbon footprints: A comparative study of a megacity, Delhi and India. Journal of Environmental Science and Engineering 53(2): 137-42.

Abstract: This paper describes the contribution and comparison of carbon footprints of megacity Delhi with that of India over the period from 1990 to 2000. Two published studies were taken as base to calculate carbon footprint in terms of CO2 equivalents (CO2-e) by taking into account CO2, CH4 and N2O emissions mainly from transport, power plants, domestic, industries, agriculture and waste sectors. It is found that carbon footprints have increased more in India (-45%) in comparison to Delhi (-33%) between 1990-2000. However, the average per capita carbon footprints at India level is less than for Delhi. Also, carbon footprint per km area in Delhi is - 40 times to that for India. In India (2000) the contribution to carbon footprint's share primarily comes from power plants, industries and agriculture sector whereas it comes from power plants and transport in case of Delhi. Various control measures taken into account in Delhi during 1990-2000 have resulted in decreasing share of CO2 in the total greenhouse gas (GHG) emissions in comparison to what appears at India level. It indicates that suitable policy measures and norms are required to be implemented at India level to control other GHGs along with CO2 to reduce net carbon footprints at the country level.

Gurney KR, Mendoza DL, Zhou Y, Fischer ML, Miller CC, Geethakumar S et al. 2009. High resolution fossil fuel combustion CO2 emission fluxes for the United States. Environmental Science and Technology 43(14): 5535-41.

Abstract: Quantification of fossil fuel CO2 emissions at fine space and time resolution is emerging as a critical need in carbon cycle and climate change research. As atmospheric CO2 measurements expand with the advent of a dedicated remote sensing platform and denser in situ measurements, the ability to close the carbon budget at spatial scales of ~100 km^2 and daily time scales requires fossil fuel CO2 inventories at commensurate resolution. Additionally, the growing interest in U.S. climate change policy measures are best served by emissions that are tied to the driving processes in space and time. Here we introduce a high resolution data product (the "Vulcan" inventory: www.purdue.edu/eas/carbon/vulcan/) that has quantified fossil fuel CO2 emissions for the contiguous U.S. at spatial scales less than 100 km^2 and temporal scales as small as hours. This data product, completed for the year 2002, includes detail on combustion technology and 48 fuel types through all sectors of the U.S. economy. The Vulcan inventory is built from the decades of local/regional air pollution monitoring and complements these data with census, traffic, and digital road data sets. The Vulcan inventory shows excellent agreement with national-level Department of Energy inventories, despite the different approach taken by the DOE to quantify U.S. fossil fuel CO2 emissions. Comparison to the global 1° × 1° fossil fuel CO2 inventory, used widely by the carbon cycle and climate change community prior to the construction of the Vulcan inventory, highlights the space/time biases inherent in the population-based approach.

Gurney KR, Razlivanov I, Song Y, Zhou Y, Benes B, Abdul-Massih M. 2012. Quantification of fossil fuel CO2 emissions on the building/street scale for a large U.S. city. Environmental Science and Technology 46(21): 12194-202.

Abstract: In order to advance the scientific understanding of carbon exchange with the land surface, build an effective carbon monitoring system, and contribute to quantitatively based U.S. climate change policy interests, fine spatial and temporal quantification of fossil fuel CO2 emissions, the primary greenhouse gas, is essential. Called the "Hestia Project", this research effort is the first to use bottom-up methods to quantify all fossil fuel CO2 emissions down to the scale of individual buildings, road segments, and industrial/electricity production facilities on an hourly basis for an entire urban landscape. Here, we describe the methods used to quantify the on-site fossil fuel CO2 emissions across the city of Indianapolis, IN. This effort combines a series of data sets and simulation tools such as a building energy simulation model, traffic data, power production reporting, and local air pollution reporting. The system is general enough to be applied to any large U.S. city and holds tremendous potential as a key component of a carbon-monitoring system in addition to enabling efficient greenhouse gas mitigation and planning. We compare the natural gas component of our fossil fuel CO2 emissions estimate to consumption data provided by the local gas utility. At the zip code level, we achieve a bias-adjusted Pearson r correlation value of 0.92 ($p < 0.001$).

Kennedy C, Steinberger J, Gasson B, Hansen Y, Hillman T, Havránek M et al. 2009. Greenhouse gas emissions from global cities. Environmental Science and Technology 43(19): 7297-302.

Abstract: The world's population is now over 50% urban, and cities make an important contribution to national greenhouse gas (GHG) emissions. Many cities are developing strategies to reduce their emissions. Here we ask how and why emissions differ between cities. Our study of ten global cities shows how a balance of geophysical factors (climate, access to resources, and gateway status) and technical factors (power generation, urban design, and waste processing) determine the GHGs attributable to cities. Within the overall trends, however, there are differences between cities with more or less public transit; while personal income also impacts heating and industrial fuel use. By including upstream emissions from fuels, GHG emissions attributable to cities exceed those from direct end use by up to 25%. Our findings should help foster intercity learning on reducing GHG emissions.

Li L, Chen C, Xie S, Huang C, Cheng Z, Wang H et al. 2010. Energy demand and carbon emissions under different development scenarios for Shanghai, China. Energy Policy 38(9): 4797-807.

Abstract: In this paper, Shanghai's CO2 emissions from 1995 to 2006 were estimated following the IPCC guidelines. The energy demand and CO2 emissions were also projected until 2020, and the CO2 mitigation potential of the planned government policies and measures that are not yet implemented but will be enacted or adopted by the end of 2020 in Shanghai were estimated. The results show that Shanghai's total CO2 emissions in 2006 were 184 million tons of CO2. During 1995-2006, the annual growth rate of CO2 emissions in Shanghai was 6.22%. Under a business-as-usual (BAU) scenario, total energy demand in Shanghai will rise to 300 million tons of coal equivalent in 2020, which is 3.91 times that of 2005. Total CO2 emissions in 2010 and 2020 will reach 290 and 630 million tons, respectively, under the BAU scenario. Under a basic-policy (BP) scenario, total energy demand in Shanghai will be 160 million tons of coal equivalent in 2020, which is 2.06 times that of 2005. Total CO2 emissions in 2010 and 2020 in Shanghai will be 210 and 330 million tons, respectively, 28% and 48% lower than those of the business-as-usual scenario. The results show that the currently planned energy conservation policies for the future, represented by the basic-policy scenario, have a large CO2 mitigation potential for Shanghai.

Oda T, Maksyutov S. 2011. A very high-resolution (1 km x 1 km) global fossil fuel CO2 emission inventory derived using a point source database and satellite observations of nighttime lights. Atmospheric Chemistry and Physics 11(2): 543-56.

Abstract: Emissions of CO2 from fossil fuel combustion are a critical quantity that must be accurately given in established flux inversion frameworks. Work with emerging satellite-based inversions requires spatiotemporally-detailed inventories that permit analysis of regional natural sources and sinks. Conventional approaches for disaggregating national emissions beyond the country and city levels based on population

distribution have certain difficulties in their application. We developed a global 1 km x 1 km annual fossil fuel CO2 emission inventory for the years 1980–2007 by combining a worldwide point source database and satellite observations of the global nightlight distribution. In addition to estimating the national emissions using global energy consumption statistics, emissions from point sources were estimated separately and were spatially allocated to exact locations indicated by the point source database. Emissions from other sources were distributed using a special nightlight dataset that had fewer saturated pixels compared with regular nightlight datasets. The resulting spatial distributions differed in several ways from those derived using conventional population-based approaches. Because of the inherent characteristics of the nightlight distribution, source regions corresponding to human settlements and land transportation were well articulated. Our distributions showed good agreement with a high-resolution inventory across the US at spatial resolutions that were adequate for regional flux inversions. The inventory can be extended to the future using updated data, and is expected to be incorporated into models for operational flux inversions that use observational data from the Japanese Greenhouse Gases Observing SATellite (GOSAT).

Petron G, Tans P, Frost G, Chao D, Trainer M. 2008. High-resolution emissions of CO2 from power generation in the USA. Journal of Geophysical Research-Biogeosciences 113, G4.

Abstract: Electricity generation accounts for close to 40% of the U. S. CO2 emissions from fossil fuel burning, making it the economic sector with the largest source of CO2. Since the late 1990s, the Environmental Protection Agency Clean Air Markets Division (EPA CAMD) has kept a repository of hourly CO2 emission data for most power plants in the conterminous United States. In this study, the CAMD CO2 data are used to derive a high spatiotemporal resolution CO2 emissions inventory for the electricity generation sector (inventory available on request). Data from 1998 to 2006 have been processed. This unique inventory can be used to improve the understanding of the carbon cycle at fine temporal and spatial scales. The CAMD data set provides the first quantitative estimates of the diurnal and seasonal cycles of the emissions as well as the year to year variability. Emissions peak in the summertime owing to the widespread use of air conditioning. Summertime emissions are in fact highly correlated with the daily average temperature. In conjunction with the EPA Emissions and Generation Resource Integrated Database (eGRID), we have derived high-resolution maps of CO2 emissions by fossil fuel burned (coal, gas, oil) for the year 2004. The CAMD data set also reflects regional anomalies in power generation such as the August 2003 blackout in the northeastern United States and the 2000-2001 increase in production in California. We recommend that all sectors of the economy report similar high-resolution CO2 emissions because of their great usefulness both for carbon cycle science and for greenhouse gases emissions mitigation and regulation.

Shrestha RM, Anandarajah G, Liyanage MH. 2009. Factors affecting CO2 emission from the power sector of selected countries in Asia and the Pacific. Energy Policy 37(6): 2375-84.

Abstract: This study analyzes the key factors behind the CO2 emissions from the power sector in fifteen selected countries in Asia and the Pacific using the Log-Mean Divisia Index method of decomposition. The roles of changes in economic output, electricity intensity of the economy, fuel intensity of power generation and generation structure are examined in the evolution of CO2 emission from the power sector of the selected countries during 1980–2004. The study shows that the economic growth was the dominant factor behind the increase in CO2 emission in ten of the selected countries (i.e., Australia, China, India, Japan, Malaysia, Pakistan, South Korea, Singapore, Thailand and Vietnam, while the increasing electricity intensity of the economy was the main factor in three countries (Bangladesh, Indonesia and Philippines). Structural changes in power generation were found to be the main contributor to changes in the CO2 emission in the case of Sri Lanka and New Zealand.

Sugar L, Kennedy C, Leman E. 2012. Greenhouse gas emissions from Chinese cities. Journal of Industrial Ecology 16(4): 552-63.

Abstract: As some of the most rapidly urbanizing places in the world, China's cities have a unique relationship with global climate change. The economies found in Chinese cities are extremely resource and energy intensive; as a result, they produce significant levels of greenhouse gas (GHG) emissions. This article provides comprehensive and detailed emissions inventories for Shanghai, Beijing, and Tianjin, which were

found to be responsible for 12.8, 10.7, and 11.9 tonnes of carbon dioxide equivalent per capita (t CO2-eq/capita), respectively, in 2006. The majority of emissions were from electricity production, heating and industrial fuel use, and ground transportation. The prevalence of coal in the energy supply mix (including up to 98% in Tianjin) was a fundamental cause of high energy emissions. Non-energy emissions from industrial processes were also significant, including emissions from cement and steel production. The GHG inventories for Shanghai, Beijing, and Tianjin point to sectors requiring the most attention in terms of low-carbon growth. Compared to ten other global cities, Chinese cities are among the highest per capita emitters, alluding to the important challenge China faces of reducing emissions while improving the quality of life for urban residents. Accordingly, this article concludes with a discussion of the opportunities and issues concerning low-carbon growth in China, including the potential for renewable energy and the difficulties associated with emissions relocation and policy adoption.

Wang R, Tao S, Ciais P, Shen HZ, Huang Y, Chen H et al. 2013. High-resolution mapping of combustion processes and implications for CO2 emissions. Atmospheric Chemistry and Physics 13(10): 5189-203.

Abstract: High-resolution mapping of fuel combustion and CO2 emission provides valuable information for modeling pollutant transport, developing mitigation policy, and for inverse modeling of CO2 fluxes. Previous global emission maps included only few fuel types, and emissions were estimated on a grid by distributing national fuel data on an equal per capita basis, using population density maps. This process distorts the geographical distribution of emissions within countries. In this study, a sub-national disaggregation method (SDM) of fuel data is applied to establish a global 0.1°×0.1° geo-referenced inventory of fuel combustion (PKU-FUEL) and corresponding CO2 emissions (PKU-CO2) based upon 64 fuel sub-types for the year 2007. Uncertainties of the emission maps are evaluated using a Monte Carlo method. It is estimated that CO2 emission from combustion sources including fossil fuel, biomass, and solid wastes in 2007 was 11.2 Pg C yr -1 (9.1 Pg C yr-1 and 13.3 Pg Cyr-1 as 5th and 95th percentiles). Of this, emission from fossil fuel combustion is 7.83 Pg C yr-1, which is very close to the estimate of the International Energy Agency (7.87 Pg Cyr-1). By replacing national data disaggregation with sub-national data in this study, the average 95th minus 5th percentile ranges of CO2 emission for all grid points can be reduced from 417 to 68.2 Mg km-2 yr-1. The spread is reduced because the uneven distribution of per capita fuel consumptions within countries is better taken into account by using sub-national fuel consumption data directly. Significant difference in per capita CO2 emissions between urban and rural areas was found in developing countries (2.08 vs. 0.598 Mg C/(cap. x yr)), but not in developed countries (3.55 vs. 3.41 Mg C/(cap. x yr)). This implies that rapid urbanization of developing countries is very likely to drive up their emissions in the future.

Zhao Y, Nielsen CP, McElroy MB. 2012. China's CO2 emissions estimated from the bottom up: Recent trends, spatial distributions, and quantification of uncertainties. Atmospheric Environment 59: 214-23.

Abstract: China's emissions of anthropogenic CO2 are estimated using a bottom-up emission inventory framework based on a detailed categorization of economic sectors and provincial economic and energy data. It includes a newly compiled database of CO2 emission factors employing the latest field study results from China. Total annual emissions are estimated to have risen from 7126 to 9370 Mt CO2 from 2005 to 2009. Recent policies to conserve energy and reduce emissions have been effective in limiting CO2 emissions from power and iron & steel plants, but have had little effect on those from cement production. The uncertainties of China's CO2 emissions are quantified for the first time using Monte-Carlo simulation, producing a 95% confidence interval (CI) of -9% to +11% for total emissions in 2005. The largest contributors to sector-level emission uncertainty are emission factors for most industrial sources and activity levels for power plants, transportation, and residential & commercial sources. Application of province-level energy consumption and China-specific emission factors in some sectors results in higher annual emission estimates for 2005-2008 as compared with other studies, although most of those are within the 95% CIs of this study.

Grey Literature

Abrams C. 2009. America's Biggest Polluters: Carbon Dioxide Emissions from Power Plants in 2007. Environment America Research and Policy Center. Available at http://www.environmentamerica.org/reports/ame/americas-biggest-polluters-carbon-dioxide-emissions-power-plants-2007.

Abstract: *No abstract available.*

Excerpt from Executive Summary:
[This report examines CO2 emissions of America's power plants. We analyze 2007 plant-by-plant data from the Environmental Protection Agency's Acid Rain Program; 2007 is the most recent year for which final data is available. The report finds that America's power is dirty – and also very old – and that these two qualities tend to go hand-in-hand. Key findings include the following for 2007:
America's power is old: Two-thirds of fossil-fuel electricity was generated by plants built before 1980. We are reliant on plants more than 30 years old for the majority of our electricity. The oldest plants in the nation – which have been in operation for as long as 70 years – are located in Indiana, Wisconsin, New York, Iowa, and North Carolina. These dinosaur plants were built in the same decade that the television first became commercially available.
America's power is dirty: In 2007, power plants released 2.56 billion tons of CO2, equivalent to the amount produced by 449 million of today's cars. This represents 42 percent of the total U.S. CO2 emissions in 2007.
Georgia, Alabama, and Indiana are home to the dirtiest power plants. Along with Texas, Michigan, and Arizona, these states are home to power plants that each emitted more than 20 million tons of carbon dioxide pollution – equivalent to the pollution from 3.5 million of today's cars – in 2007. Georgia and Texas both have two plants that belong to this elite dirty club.
Texas, Ohio, Florida, Indiana, and Pennsylvania emitted the most CO2 pollution from power plants. Texas power plants emitted nearly twice the amount of CO2 emitted by power plants in Ohio and Florida, the next highest polluting states.
The oldest and dirtiest often go hand-in-hand: The oldest power plants are dirty. Plants built before 1980 produced 73 percent of U.S. CO2 emissions from power plants. These represent just less than half of all plants, indicating that the older half of plants pollute a disproportionate amount.
The dirtiest power plants are old. Of plants that produced more than five million tons of CO2 pollution in 2007, 83 percent were built before 1980. This subset of 129 plants, just 10 percent of plants—the oldest of the dirtiest—generated almost half of our electricity and produced half of the CO2 emissions from power plants in 2007.
Older means dirtier on average. For each year older a coal generator is on average, it created 0.001 more tons of CO2 for each Megawatt-hour of electricity it produced in 2007. The relationship is slightly stronger for natural gas.]

Alberta Environment and Sustainable Resource Development. 2013. Report on 2011 Greenhouse Gas Emissions. Edmonton, AB. Available at http://esrd.alberta.ca/focus/alberta-and-climate-change/regulating-greenhouse-gas-emissions/documents/8849.pdf.

Abstract: *No abstract available.*

Excerpt from Executive Summary:
[Alberta's Specified Gas Reporting Program has collected facility greenhouse gas emissions data since 2003, and is a core component of Alberta's 2008 Climate Change Strategy. In 2005 (for 2004 emissions data collection), Alberta harmonized its Specified Gas Reporting Program with the Government of Canada's Greenhouse Gas Emissions Reporting Program. Since then, Alberta has jointly collected greenhouse gas data from Alberta's largest industrial emitters with the Government of Canada. Alberta facilities report their emissions data to Environment Canada through the federal reporting program and the results are forwarded to Alberta Environment and Sustainable Resource Development, allowing both provincial and federal reporting requirements to be satisfied. To improve the value of data collected through the reporting program,

and to further enhance the synergy with the Specified Gas Emitters Regulation, in 2010 Alberta lowered the emissions threshold level for mandatory reporting from 100,000 tonnes carbon dioxide equivalent (tCO2e) in a calendar year to 50,000 tCO2e. For the 2010 calendar year and subsequent years, any facilities whose emissions exceed 50 kilotonnes (kt) in a calendar year are required to report their greenhouse gas emissions to comply with the Specified Gas Reporting Regulation.

Results of the 2011 Reporting Program:
For the 2011 calendar year, 164 facilities located in Alberta reported greenhouse gas emissions (this includes 17 facilities that reported voluntarily or were over the threshold due to biomass CO2). The total reported emissions for these facilities equaled 123.3 megatonnes (Mt) in carbon dioxide equivalent, from sources of carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride. Since the Government of Canada's Greenhouse Gas Emissions Reporting Program began collecting data in 2004, reported Alberta greenhouse gas emissions have increased by 15.1 per cent and the number of reporting facilities has increased by 66, largely due to the change in emissions threshold.
Between 2010 and 2011, the number of Alberta facilities emitting over 50 kt CO2e decreased by six from 153 to 147, while total reported emissions increased by 0.54 per cent from 122.3 Mt to 123.0 Mt. Carbon dioxide accounted for 96.2 per cent of the total emissions with the remainder coming from methane (2.7 per cent), nitrous oxide (1.2 per cent), hydrofluorocarbons (<0.01 per cent), perfluorocarbons (<0.0001 per cent), and sulphur hexafluoride (<0.001 per cent).
Reported industrial emissions accounted for 51 per cent of Alberta's total emissions. Among Alberta's industrial sectors, oil sands operations (consisting of oil sands mining and upgrading, oil sands in situ extraction, and all emissions associated with cogeneration of heat and electricity) represented the largest share of 2011 reported emissions. The breakdown of 2011 reported emissions was as follows:

-Oil Sands Operations – 39.8 per cent (23.4 per cent from oil sands mining and upgrading and 16.4 per cent from oil sands in situ extraction) of total reported emissions
-Electric Power Generation – 35.4 per cent of total reported emissions
-Conventional Oil and Gas Extraction – 6.6 per cent of total reported emissions
-Chemical Manufacturing – 5.8 per cent of total reported emissions.]

Dutzik T, Ridlington E, Figdor E. 2009. Too Much Pollution: State and National Trends in Global Warming Emissions from 1990 to 2007. Environment America Research and Policy Center. Available at http://www.environmentamerica.org/reports/ame/too-much-pollution-state-and-national-trends-global-warming-emissions-1990-2007.

Abstract: *No abstract available.*

Excerpt from Executive Summary:
[This report analyzes the most recent data available from the federal Department of Energy to calculate emissions of carbon dioxide from the use of oil, coal and natural gas at the national and state level from 1990 to 2007. Our analysis finds that:
Emissions of carbon dioxide, the leading global warming pollutant, from fossil fuel consumption increased by 19 percent in the United States from 1990 to 2007. Nationally, the rate of emissions growth has slowed in recent years, and emissions peaked in many states in 2004 and 2005.
Seventeen states saw declines in carbon dioxide emissions from fossil fuel use between 2004 and 2007. Those emission reductions—while far short of what will be needed to address the threat of global warming—could be a sign of a new trend, particularly if the United States adopts strong policies to move the nation toward a clean energy future.
States that are highly reliant on coal-fired power plants, have energy-intensive industries, and/or have high levels of pollution from cars and trucks tend to produce the most carbon dioxide pollution from fossil fuel use.
Texas remained the nation's number one emitter of carbon dioxide from fossil fuel use in 2007, followed by California, Pennsylvania, Ohio and Florida. Wyoming produced the most carbon dioxide pollution per capita,

followed by North Dakota, West Virginia, Alaska and Louisiana. Rhode Island produced the least carbon dioxide per capita in 2007, followed by New York, Vermont, Idaho and California.
Electricity generation and transportation are by far the largest sources of carbon dioxide emissions in the United States, responsible for 40 percent and 33 percent of fossil fuelrelated emissions, respectively, in 2007. Power plants and transportation were also the fastest-growing sources of emissions between 1990 and 2007.]

Environment Canada. 2013. National Inventory Report 1990–2011: Greenhouse Gas Sources and Sinks in Canada. Available at https://www.ec.gc.ca/Publications/default.asp?lang=En&xml=A07ADAA2-E349-481A-860F-9E2064F34822.

Abstract: *No abstract available.*

Excerpt from Executive Summary:
[The ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC) is to achieve stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. In support of this goal the Convention commits all Parties to develop, periodically update, publish and make available to the Conference of the Parties national inventories of anthropogenic emissions by sources and removals by sinks of all GHGs not controlled by the Montreal Protocol. Development, publication and maintenance of a national inventory is a key obligation of UNFCCC signatories. Canada's National Inventory Submission is the annual communication through which Canada meets its annual reporting obligations under the Convention and serves as the authoritative indicator and basis of comparison of national performance. It is a source of reliable, detailed information for Canadians on key emission trends for specific sources, sectors and regions; and provides a core set of data for setting baseline emissions and further analysis.]
[In 2011, the most recent annual dataset in this report, Canada's total greenhouse gas emissions were estimated to be 702 megatonnes carbon dioxide equivalent (Mt $CO2eq^2$), an increase of approximately 1 Mt (0.14%) from the 2010 level of 701 Mt. Since 2005, Canadian GHG emissions have decreased by 36 Mt (4.8%). Changes in emission trends since the early 2000s can be attributed to increases in efficiency, the modernization of industrial processes, and structural changes in the composition of the economy, which are long-term trends that have had an increased impact on emissions since the late 1990s.]

Environmental Integrity Project. 2013. U.S. Power Plant Global Warming Emissions Rising in 2013, After Years of Decline. Available at http://www.environmentalintegrity.org/news_reports/documents/CoalCO2Report_May23_2013_Final_001.pdf.

Abstract: *No abstract available.*

Excerpt from Introduction:
[Carbon dioxide emissions from electric power plants totaled 2.206 billion tons in 2012, according to U.S. Environmental Protection Agency data, a decline of 13.1% from the 2.539 billion tons reported for this sector in 2005. For perspective, the Waxman-Markey global warming bill rejected by Congress in 2009 would have capped power plant emissions of this global warming pollutant at 17% below 2005 levels – but not until 2020. Electricity generation accounted for about 39.5% of total U.S. greenhouse gas pollution in 2012 from fossil fuel consumption.
Carbon dioxide emissions are likely to increase in 2013, however, as rising natural gas prices encourage more use of coal. CO2 emissions from the electric power sector jumped 7.14% in the first three months of 2013 compared to the first quarter of 2012, with coal based generation increasing just over 13% between the two quarters. The U.S. Energy Information Administration projects an 8.7% increase in net generation from coal plants this year compared to last, recovering some of the ground lost between 2005 and 2012, when electricity from coal declined nearly 25%.]

Fouad RH, Al-Ghandoor A, Al-Khateeb M, Bata H. 2008. Restructuring of the Jordanian utility sector and its associated GHG emissions: A future projection. In: International Conference on Power Control and Optimization, 74-84.

Abstract: As a small, non-oil producing, Middle Eastern country of a young and growing population and rapid urbanization, Jordan, like many countries all over the world, was and is still facing the problem of meeting the rapidly increasing demand of electricity. The main objective of this study is to review many current aspects of the Jordanian electricity sector, including electricity generation, electricity consumption, energy related emissions, and future possibilities, based on time series forecasting, through the term of the Clean Development Mechanism (CDM) arrangement under the Kyoto Protocol, in which the Hashemite Kingdom of Jordan had signed lately, which allows industrialized countries with a greenhouse gas reduction commitment to invest in projects that reduce emissions in developing countries as an alternative to more expensive emission reductions in their own countries. Several scenarios are proposed in this study, based on projected electricity consumption data until year 2028. Without attempting to replace the currently existing fossil-fuel based power plant technologies in Jordan by clean ones, electricity consumption and associated GHG emissions are predicted to rise by 138% by year 2028; however, if new clean technologies are adopted gradually over the same period, electricity consumption as well as GHG emissions will ascend at a lower rate.

US Energy Information Administration. 2011. Emissions of Greenhouse Gases in the United States 2009. US Department of Energy, Washington, DC. Available at http://www.eia.gov/environment/emissions/ghg_report/pdf/0573(2009).pdf.

Abstract: This report uses activity data on coal and natural gas consumption and electricity sales and losses by sector from the January 2011 Monthly Energy Review (MER). In keeping with current international practice, this report presents data on greenhouse gas emissions in million metric tons carbon dioxide equivalent. The data can be converted to carbon equivalent units by multiplying by 12/44. Data on ozone-depleting gases with high global warming potentials (high-GWP gases) are directly from the U.S. Environmental Protection Agency (EPA). For this report, updated EPA values were available for hydrofluorocarbons (HFCs). However, no updates were available for perfluorocarbons (PFCs) or sulfur hexafluoride (SF6), and last year's values are used instead. Historical data in the chapter tables are revised from the data contained in the previous EIA report, Emissions of Greenhouse Gases in the United States 2008, DOE/EIA-0573(2008) (Washington, DC, December 2009).

US Energy Information Administration. 2013. State-Level Energy-Related Carbon Dioxide Emissions, 2000-2010. US Department of Energy, Washington, DC. Available at http://www.eia.gov/environment/emissions/state/analysis/pdf/stateanalysis.pdf.

Abstract: *No abstract available.*

Overview:

[Energy-related carbon dioxide emissions vary significantly across states, whether considered on an absolute or per capita basis. The overall size of a state, as well as the available fuels, types of businesses, climate, and population density, play a role in both total and per capita emissions. Additionally, each state's energy system reflects circumstances specific to that state. For example, some states are located near abundant hydroelectric supplies, while others contain abundant coal resources. This paper presents a basic analysis of the factors that contribute to a state's carbon dioxide profile. This analysis neither attempts to assess the effect of state policies on absolute emissions levels or on changes over time, nor does it intend to imply that certain policies would be appropriate for a particular state.

The term "energy-related carbon dioxide emissions" as used in this paper, includes emissions released at the location where fossil fuels are used. For feedstock application, carbon stored in products such as plastics are not included in reported emissions for the states where they are produced.

It is also important to recognize that the state-level carbon dioxide emissions data presented in this paper count emissions based on the location where the energy is consumed as a fuel. To the extent that fuels are used in one state to generate electricity that is consumed in another state, emissions are attributed to the former rather than the latter. An analysis that attributed "responsibility" for emissions with consumption

rather than production of electricity, which is beyond the scope of the present paper, would yield different results.]

US Environmental Protection Agency. 2013. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2011. EPA 430-R-13-001. Washington, DC. Available at http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2013-Main-Text.pdf.

Abstract: *No abstract available.*

Excerpt from Executive Summary:
[An emissions inventory that identifies and quantifies a country's primary anthropogenic sources and sinks of greenhouse gases is essential for addressing climate change. This inventory adheres to both (1) a comprehensive and detailed set of methodologies for estimating sources and sinks of anthropogenic greenhouse gases, and (2) a common and consistent mechanism that enables Parties to the United Nations Framework Convention on Climate Change (UNFCCC) to compare the relative contribution of different emission sources and greenhouse gases to climate change.]
[In 2011, total U.S. greenhouse gas emissions were 6,702.3 Tg, or million metric tons, CO2 Eq. Total U.S. emissions have increased by 8.4 percent from 1990 to 2011, and emissions decreased from 2010 to 2011 by 1.6 percent (108.0 Tg CO2 Eq.). The decrease from 2010 to 2011 was due to a decrease in the carbon intensity of fuels consumed to generate electricity due to a decrease in coal consumption, with increased natural gas consumption and a significant increase in hydropower used. Additionally, relatively mild winter conditions, especially in the South Atlantic Region of the United States where electricity is an important heating fuel, resulted in an overall decrease in electricity demand in most sectors. Since 1990, U.S. emissions have increased at an average annual rate of 0.4 percent.]

Zhang LX, Wang CB, Yang ZF, Chen B. 2010. Carbon emissions from energy combustion in rural China. In: Procedia Environmental Sciences, International Conference on Ecological Informatics and Ecosystem Conservation 2: 980-9.

Abstract: Carbon emissions from rural energy combustion have not been successfully addressed in the existing accounting system since incomplete data of rural energy consumption and exclusion of emissions from combustion of biofuels in the sectoral or national totals to avoid double counting. Presented in this paper were estimations of CO2 emissions from fuel combustions in rural areas of China from 1979 to 2007 and analysis of their contributions to national energy related CO2 emissions, to highlight the important role rural energy plays in regard to climate change and potential capacity for carbon abatement in rural areas. The temporal variations of CO2 emission in rural areas was also analyzed with regard to total emissions, intensity and source structure, which could provide a novel perspective to our GHGs reduction strategies and related policy making. The results showed that the CO2 emissions in rural China have constantly increased from 8.89 x 10(8) tons in 1979 to 28.74 x 10(8) tons in 2007. Commercial energy has become the dominant force of CO2 emissions in rural China, most of which is mainly derived from the consumption of coal and electricity. The proportion of carbon emissions from rural areas to nationwide underwent an inverted U-curve trend if biomass energy was ignored, with a peak at 47.40% in 2000. The situation becomes absolutely different when considering about biomass. For a long time (from 1979 to 2001), rural energy related carbon emissions has maintained a greatly high proportion in total carbon emissions with a fluctuations between 45.13% and 56.31%. The proportion of carbon emission in rural areas has declined since 2002, but still up 40.99% in 2007.

3.5 Multiple pollutants

3.5.1 Multiple pollutants - health effects

Mauderly JL, Barrett EG, Gigliotti AP, McDonald JD, Reed MD, Seagrave J, et al. 2011. Health effects of subchronic inhalation exposure to simulated downwind coal combustion emissions. Inhalation Toxicology 23(6): 349-362.

Funding Agency: National Environmental Respiratory Center, US Department of Energy (Office of Freedom Car and Vehicle Technologies, National Energy Technology Laboratory), US Environmental Protection Agency (Office of Research and Development)	
Study Location: N/A	**Study Design:** Animal toxicology study
Fuel Type: Coal	**Chemicals:** CO, NH3, NO, NO2, PM, SO2, Total hydrocarbons

Abstract: Context: There have been no animal studies of the health effects of repeated inhalation of mixtures representing downwind pollution from coal combustion. Environmental exposures typically follow atmospheric processing and mixing with pollutants from other sources. Objective: This was the fourth study by the National Environmental Respiratory Center to create a database for responses of animal models to combustion-derived pollutant mixtures, to identify causal pollutants-regardless of source. Methods: F344 and SHR rats and A/J, C57BL/6, and BALB/c mice were exposed 6 h/day 7 days/week for 1 week to 6 months to three concentrations of a mixture simulating key components of "downwind" coal combustion emissions, to the highest concentration filtered to remove particulate matter (PM), or to clean air. Emissions from low-sulfur subbituminous coal were modified to create a mixture recommended by an expert workshop. Sulfur dioxide, nitrogen oxides, and PM were the dominant components. Non animal-derived PM mass concentrations of nominally 0, 100, 300, and 1000 μg/m3 were mostly partially neutralized sulfate. Results: Only 17 of 270 species-gender-time-outcome comparisons were significantly affected by exposure; some models showed no effects. There was strong evidence that PM participated meaningfully in only three responses. Conclusion: On a total mass or PM mass basis, this mixture was less toxic overall than diesel and gasoline exhausts or wood smoke. The largely sulfate PM contributed to few effects and was the sole cause of none. The study did not allow identification of causal pollutants, but the potential role of NOx in some effects is suggested by the literature.

Strengths and Limitations:

Strengths: Detailed and thorough study. Sufficient sample size. Utilized laboratory-generated pollutant mixture to represent downwind coal power-plant plumes. Utilized 3 concentrations of coal combustion atmosphere at 2 exposure durations. Exposure concentrations measured daily. Compared effects in 5 rodent types. Assessed a variety of health outcomes.
Limitations: Unable to determine if effect of PM was independent or synergistic with other components in the coal combustion mixture. Long-term SO2 and NO2 exposure levels were higher than levels in most US locations (for the high dose level).

Study Score and Ranking:

0.92; High

Pan SY, Morrison H, Gibbons L, Zhou J, Wen SW, DesMeules M, et al. 2011. Breast cancer risk associated with residential proximity to industrial plants in Canada. Journal of Occupational and Environmental Medicine 53(5): 522-529.

Funding Agency: Public Health Agency of Canada, Canadian Cancer Registries Epidemiology Research Group	
Study Location: Canada	**Study Design:** Case-control
Fuel Type: N/A	**Chemicals:** N/A

Abstract: Objective: The relationship between breast cancer risk and residential proximity to paper mills, pulp mills, petroleum refineries, steel mills, thermal power plants, alum smelters, nickel smelters, lead smelters, copper smelters, and zinc smelters was assessed. Methods: We conducted a population-based case-control study of 2343 cases with breast cancer and 2467 controls using residential proximity at some time between 1960 and 5 years before the completion of questionnaire in Canada. Results: Adjusted odds ratios were statistically significantly increased for residing near steel mills (0.8 to 3.2 km) and thermal power plants (<0.8 km) in premenopausal women, petroleum refinery (0.8 to 3.2 km) and pulp mills (0.8 to 3.2 km) in postmenopausal women, and for 10 or more years of residing near thermal power plants of 0.8 km. Conclusions: Our preliminary results suggested possible weak associations between breast cancer and proximity to steel mills, pulp mills, petroleum refineries, and thermal power plants.

Strengths and Limitations:

Strengths: Large sample size. Multi-centre population-based study (covering 8 provinces). Objective outcome measure. Comprehensive questionnaire.
Limitations: Weak exposure assessment (reside near thermal power plant). Potential recall bias. Data collected in 1996-1997. Moderate response rates (65-70%).

Study Score and Ranking:

0.88; High

Peters A, Breitner S, Cyrys J, Stolzel M, Pitz M, Wolke G, Heinrich J, Kreyling W, Kuchenhoff H, Wichmann HE. 2009. The influence of improved air quality on mortality risks in Erfurt, Germany. Research Report Health Effects Institute 137: 5-77.

Funding Agency: Health Effects Institute	
Study Location: Germany	**Study Design:** Time-series
Fuel Type: Brown coal (lignite), Natural gas	**Chemicals:** CO, NO, NO2, O3, PM2.5, PM10, SO2

Abstract: Around the world, daily variations in ambient air pollution have been consistently associated with variations in daily mortality. The aim of the study presented here was to assess the effects of ambient air pollution on daily mortality during a period of tremendous changes in air quality in the city of Erfurt, in eastern Germany, from October 1991 to March 2002. Data on particle size distributions were obtained from September 1995 to March 2002 at a research monitoring station. For particles from 0.01 μm to 2.5 μm in diameter, number concentrations (NCs)* and mass concentrations (MCs) were calculated. Particles with diameters less than or equal to 0.10 μm are defined as ultrafine particles (UFP). Data on the gaseous pollutants NO2, CO, SO2, and O3 and on PM10 (particulate matter [PM] with aerodynamic diameter less than or equal to 10 μm) were obtained from a government air-monitoring station. Data on changes in energy consumption, car fleet composition, and population were collected from local authorities. Death certificates of persons living in and dying in Erfurt were abstracted, and daily mortality counts were calculated. Poisson regression models were used to analyze the data, applying penalized splines (also known as P-splines) to model nonlinear relationships in the confounders. Model selection was done without air pollutants in the models, based on a combination of goodness-of-fit criteria and avoidance of autocorrelation in error terms. Final models included P-splines of time trend, meteorologic data, and influenza epidemics as well as day of the week with an indicator variable. Results are presented as change per interquartile range (IQR), i.e., change in the relative risk of mortality associated with a change in the concentration from the 25th to the 75th percentile of a given pollutant. Air pollutants were considered both as linear terms and as P-splines to assess the exposure-response functions. Changes in effect estimates over time were calculated using fully Bayesian time-varying coefficient models. This method was selected over four other approaches tested in simulation studies. Air-pollution concentrations decreased substantially in Erfurt during the decade under observation. The strongest changes were observed for SO2, for which annual concentrations decreased from 64 μg/m3 in 1992 to 4 μg/m3 in 2001. Concentrations of PM10, PM2.5 (particulate matter with aerodynamic diameter less than or equal to 2.5 μm), and CO decreased by more than 50%. NO2, O3, and ultrafine particles also decreased, though to a lesser extent. Based on visual inspection of the data on the changes in ambient air-pollution concentrations during the study period, we defined three study subperiods: A first subperiod from 1991 to 1995; a second, transitional subperiod from 1995 to 1998; and a third subperiod from 1998 to 2002. Generally, air-pollution concentrations decreased substantially from the first subperiod to the second, and some additional decreases occurred from the second subperiod to the third. During the second, transitional subperiod, natural gas replaced coal as the main energy source in Erfurt. In addition, the number of cars with catalytic converters increased over time, as did the number of cars in general. To facilitate the interpretation of the results, we organized the air pollutants into four groups: (1) NO2, CO, and ultrafine particles, (2) PM10 and PM2.5, (3) SO2, and (4) O3. We observed a 1.6% increased risk for daily mortality (CI, -0.4% to 3.5%) for an increase of 19.7 μg/m3 in NO2 (lag day 3), a 1.9% increased risk (CI, 0.2%-3.6%) for an increase of 0.48 mg/m3 in CO (lag day 4), and a 2.9% increased risk (CI, 0.3%-5.5%) for an increase of 9743/cm3 in ultrafine particles (lag day 4). No consistent associations were observed for PM10, PM2.5, or SO2. For O3, a 4.6% increased risk for daily mortality (CI, 1.1%-8.3%) was associated with a 43.8 μg/m3 maximum 8-hr concentration of O3 per day (lag day 2). For all four pollutants, exposure-response functions suggested no deviation from linearity. However, in time-varying models the strongest associations were observed for NO2, CO, and ultrafine particles during the transition subperiod, from 1995 to 1998, when O3 concentrations were lowest. Changes in source characteristics or ambient air-pollution concentrations were not able to explain these observations in a straightforward manner. However, the observations suggested that changes such as the introduction of three-way catalytic converters in cars and the substitution natural gas for coal might have been beneficial. Overall we concluded that: 1. Economic and political changes and the adoption of new technologies in eastern Germany resulted in distinct improvements in ambient air quality; 2. Urban air pollution in Erfurt changed within one decade from the eastern mixture toward that of western Europe ("western mixture"), which is dominated by

concentrations of NOx, O3, fine particles, and ultrafine particles with low concentrations of SO2; 3. There was an association between daily mortality and ultrafine particles and combustion-related gases (lag days 3 or 4); 4. Ultrafine particles seemed to be the best pollution indicator and to point to the role of local combustion in the pollution mixture; 5. Regression coefficients showed variation over time for NO2, CO, ultrafine particles, and O3 that could not be explained by nonlinearity in the exposure-response functions; 6. Mortality associated with pollution was lower at the end of the 1990s than during the 1990s, except for mortality associated with O3; and 7. Mortality associated with pollution was strongest in the second, transitional subperiod, from 1995 to 1998, when changes in source characteristics had taken place but the benefits of improved ambient air quality had not yet been completely achieved.

Strengths and Limitations:

Strengths: Study well-designed and thorough. Examined mortality and pollution data over ~10 years (utilizing a unique opportunity to examine the population before and after a change in power plant fuel). Assessed several different pollutants.
Limitations: Limited statistical power due to small city size and low number of deaths per day. Limited individual data. Some missing pollutant data. Many economic and pollution changes occurred over the 10-year period, and other factors (eg. change in domestic heating) may have had a greater influence on air quality than the power plant.

Study Score and Ranking:

0.88; High

Wong CM, Rabl A, Thach TQ, Chau YK, Chan KP, Cowling BJ, et al. 2012. Impact of the 1990 Hong Kong legislation for restriction on sulfur content in fuel. Research Report Health Effects Institute 170: 5-91.

Funding Agency: Health Effects Institute	
Study Location: Hong Kong	**Study Design:** Time-series
Fuel Type: N/A	**Chemicals:** NO2, O3, PM10 (+ species), SO2

Abstract: Introduction: After the implementation of a regulation restricting sulfur to 0.5% by weight in fuel on July 1, 1990, in Hong Kong, sulfur dioxide (SO2*) levels fell by 45% on average and as much as 80% in the most polluted districts (Hedley et al. 2002). In addition, a reduction of respiratory symptoms and an improvement in bronchial hyperresponsiveness in children were observed (Peters et al. 1996; Wong et al. 1998). A recent time-series study (Hedley et al. 2002) found an immediate reduction in mortality during the cool season at six months after the intervention, followed by an increase in cool-season mortality in the second and third years, suggesting that the reduction in pollution was associated with a delay in mortality. Proportional changes in mortality trends between the 5-year periods before and after the intervention were measured as relative risks and used to assess gains in life expectancy using the life table method (Hedley et al. 2002). To further explore the relation between changes in pollution-related mortality before and after the intervention, our study had three objectives: (1) to evaluate the short-term effects on mortality of changes in the pollutant mix after the Hong Kong sulfur intervention, particularly with changes in the particulate matter (PM) chemical species; (2) to improve the methodology for assessment of the health impact in terms of changes in life expectancy using linear regression models; and (3) to develop an approach for analyzing changes in life expectancy from Poisson regression models. A fourth overarching objective was to determine the relation between short- and long-term benefits due to an improvement in air quality. Methods: For an assessment of the short-term effects on mortality due to changes in the pollutant mix, we developed Poisson regression Core Models with natural spline smoothers to control for long-term and seasonal confounding variations in the mortality counts and with covariates to adjust for temperature (T) and relative humidity (RH). We assessed the adequacy of the Core Models by evaluating the results against the Akaike Information Criterion, which stipulates that, at a minimum, partial autocorrelation plots should be between -0.1 and 0.1, and by examining the residual plots to make sure they were free from patterns. We assessed the effects for gaseous pollutants (NO2, SO2, and O3), PM with an aerodynamic diameter ≤ 10 μm (PM10), and its chemical species (aluminum [Al], iron [Fe], manganese [Mn], nickel [Ni], vanadium [V], lead [Pb], and zinc [Zn]) using the Core Models, which were developed for the periods 5 years (or 2 years in the case of the sensitivity analysis) before and 5 years after the intervention, as well as in the10-year (or 7-year in the case of the sensitivity analysis) period pre- and post-intervention. We also included an indicator to separate the pre- and post-intervention periods, as well as the product of the indicator with an air pollution concentration variable. The health outcomes were mortality for all natural causes and for cardiovascular and respiratory causes, at all ages and in the 65 years or older age group. To assess the short- and long-term effects, we developed two methods: one using linear regression models reflecting the age-standardized mortality rate $D(j)$ at day j, divided by a reference D_{ref}; and the other using Poisson regression models with daily mortality counts as the outcome variables. We also used both models to evaluate the relation between outcome variables and daily air pollution concentrations in the current day up to all previous days in the past 3 to 4 years. In the linear regression approach, we adjusted the data for temperature and relative humidity. We then removed season as a potential confounder, or deseasonalized them, by calculating a standard seasonal mortality rate profile, normalized to an annual average of unity, and dividing the mortality rates by this profile. Finally, to correct for long-term trends, we calculated a reference mortality rate $D_{ref}(j)$ as a moving average of the corrected and deseasonalized $D(j)$ over the observation window. Then we regressed the outcome variable $D(j)/D_{ref}$ on an entire exposure sequence $\{c(i)\}$ with lags up to 4 years in order to obtain impact coefficient $f(i)$ from the regression model shown below: [*equation omitted*]. The change in life expectancy (LE) for a change of units (Δc) in the concentration of pollutants on T_{day} – representing the short interval (i.e., a day) – was calculated from the following equation (ΔL(pop) = average loss in life expectancy of an entire population): [*equation omitted*]. In the Poisson regression approach, we fitted a distributed-lag model for exposure to previous days of up to 4 years in order to obtain the cumulative lag effect $\Sigma\beta_i$. We fit the linear regression model of $\log(LE^*/LE) = \gamma(SMR - 1) + \alpha$ to estimate the parameter gamma by gamma, where LE* and LE are life expectancy for an exposed and an unexposed population, respectively, and SMR represents the standardized mortality ratio. The life expectancy change per Δc increase in concentration is [*equation*

omitted]. Results: In our assessment of the changes in pollutant levels, the mean levels of SO2, Ni, and V showed a statistically significant decline, particularly in industrial areas. Ni and V showed the greatest impact on mortality, especially for respiratory diseases in the 5-year pre-intervention period for both the all-ages and 65+ groups among all chemical species. There were decreases in excess risks associated with Ni and V after the intervention, but they were nonsignificant. Using the linear regression approach, with a window of 1095 days (3 years), the losses in life expectancy with a 10-μg/m3 increase in concentrations, using two methods of estimation (one with adjustment for temperature and RH before the regression against pollutants, the other with adjustment for temperature and RH within the regression against pollutants), were 19.2 days (95% CI, 12.5 to 25.9) and 31.4 days (95% CI, 25.6 to 37.2) for PM10; and 19.7 days (95% CI, 15.2 to 24.2) and 12.8 days (95% CI, 8.9 to 16.8) for SO2. The losses in life expectancy in the current study were smaller than the ones implied by Elliott and colleagues (2007) and Pope and colleagues (2002) as expected since the observation window in our study was only 3 years whereas these other studies had windows of 16 years. In particular, the coefficients used by Elliott and colleagues (2007) for windows of 12 and 16 years were non-zero, which suggests that our window of at most 3 years cannot capture the full life expectancy loss and the effects were most likely underestimated. Using the Poisson regression approach, with a window of 1461 days (4 years), we found that a 10-μg/m3 increase in concentration of PM10 was associated with a change in life expectancy of -69 days (95% CI, -140 to 1) and a change of -133 days (95% CI, -172 to -94) for the same increase in SO2. The effect estimates varied as expected according to most variations in the sensitivity analysis model, specifically in terms of the Core Model definition, exposure windows, constraint of the lag effect pattern, and adjustment for smoking prevalence or socioeconomic status. Conclusions: Our results on the excess risks of mortality showed exposure to chemical species to be a health hazard. However, the statistical power was not sufficient to detect the differences between the pre- and post-intervention periods in Hong Kong due to the data limitations (specifically, the chemical species data were available only once every 6 days, and data were not available from some monitoring stations). Further work is needed to develop methods for maximizing the information from the data in order to assess any changes in effects due to the intervention. With complete daily air pollution and mortality data over a long period, time-series analysis methods can be applied to assess the short- and long-term effects of air pollution, in terms of changes in life expectancy. Further work is warranted to assess the duration and pattern of the health effects from an air pollution pulse (i.e., an episode of a rapid rise in air pollution) so as to determine an appropriate length and constraint on the distributed-lag assessment model.

Strengths and Limitations:

Strengths: Study well-designed and thorough. Examined mortality and pollution data over 10 years (utilizing an opportunity to examine the population before and after a restriction on sulphur in fuel). Assessed several different pollutants.

Limitations: Lacked statistical power to detect the differences between the pre- and post-intervention period (due to missing pollutant data). Limited individual data. Fuel restriction applied to multiple sources; contribution of power plant emissions to pollution levels not known.

Study Score and Ranking:

0.88; High

Aoun J, Saleh N, Waked M, Salame J, Salameh P. 2013. Lung cancer correlates in Lebanese adults: A pilot case-control study. Journal of Epidemiology and Global Health 3(4): 235-244.

Funding Agency: Not stated	
Study Location: Lebanon	**Study Design:** Case-control
Fuel Type: Diesel	**Chemicals:** N/A

Abstract: Background: Lung cancer is one of the most prevalent types of cancers. However, there are no epidemiological studies concerning lung cancer and its risk factors in Lebanon. This study was carried out to determine the association between lung cancer and its most common risk factors in a sample of the Lebanese population. Methods: A hospital-based case-control study was conducted. Patients were recruited in a tertiary health care center. A questionnaire in Arabic was designed to assess the possible risk factors for lung cancer. Results: For females, cigarette smoking (ORa = 9.76) and using fuel for heating (ORa = 9.12) were found to be the main risk factors for lung cancer; for males, cigarette smoking (ORa = 156.98), living near an electricity generator (ORa = 13.26), consuming low quantities of fruits and vegetables (ORa = 10.54) and a family history of cancer (ORa = 8.75) were associated with lung cancer. Waterpipe smoking was significantly correlated with lung cancer in the bivariate analysis. Conclusion: In this pilot study, it was found that in addition to smoking, outdoor and indoor pollution factors were potential risk factors of lung cancer. Additional studies would be necessary to confirm these findings.

Strengths and Limitations:

Strengths: High participation rates (>95%). Considered several personal and environmental risk factors for lung cancer.

Limitations: Hospital-based study (may not be representative sample of population). Weak exposure assessment (ever lived near power plant). No pollutant data. Small sample size. Potential recall bias. Not known if interview blinded to case/control status.

Study Score and Ranking:

0.65; Moderate

Barrett EG, Day KC, Gigliotti AP, Reed MD, McDonald JD, Mauderly JL, Seilkop SK. 2011. Effects of simulated downwind coal combustion emissions on pre-existing allergic airway responses in mice. Inhalation Toxicology 23(13): 792-804.

Funding Agency: National Environmental Respiratory Center, US Department of Energy (Office of Freedom Car and Vehicle Technologies), US Department of Transportation, US Environmental Protection Agency

Study Location: N/A	**Study Design:** Animal toxicology study
Fuel Type: Coal	**Chemicals:** CO, NO, NO2, PM, SO2, VOC

Abstract: Context: Coal-fired power plant emissions can contribute a significant portion of the ambient air pollution in many parts of the world. Objective: We hypothesized that exposure to simulated downwind coal combustion emissions (SDCCE) may exacerbate pre-existing allergic airway responses. Methods: Mice were sensitized and challenged with ovalbumin (OVA). Parallel groups were sham-sensitized with saline. Mice were exposed 6 h/day for 3 days to air (control, C) or SDCCE containing particulate matter (PM) at low (L; 100 μg/m3), medium (M; 300 μg/m3), or high (H; 1000 μg/m3) concentrations, or to the H level with PM removed by filtration (high-filtered, HF). Immediately after SDCCE exposure, mice received another OVA challenge (pre-OVA protocol). In a second (post-OVA) protocol, mice were similarly sensitized but only challenged to OVA before air/SDCCE. Measurement of airway hyperresponsiveness (AHR), bronchoalveolar lavage (BAL), and blood collection were performed ~24 h after the last exposure. Results: SDCCE significantly increased BAL macrophages and eosinophils in OVA-sensitized mice from the post-OVA protocol. However, there was no effect of SDCCE on BAL macrophages or eosinophils in OVA-sensitized mice from the pre-OVA protocol. BAL neutrophils were elevated following SDCCE in both protocols in nonsensitized mice. These changes were not altered by filtering out the PM. In the post-OVA protocol, SDCCE decreased OVA-specific IgG1 in OVA-sensitized mice but increased levels of total IgE, OVA-specific IgE and OVA-specific IgG1 and IgG2a in nonsensitized animals. In the pre-OVA protocol, SDCCE increased OVA-specific IgE in both sensitized and non-sensitized animals. Additionally, BAL IL-4, IL-13, and IFN-γ levels were elevated in sensitized mice. Conclusion: These results suggest that acute exposure to either the particulate or gaseous phase of SDCCE can exacerbate various features of allergic airway responses depending on the timing of exposure in relation to allergen challenge.

Strengths and Limitations:

Strengths: Sufficient sample size. Utilized laboratory-generated pollutant mixture to represent downwind coal power-plant plumes. Utilized 3 concentrations of coal combustion atmosphere.
Limitations: No discussion of blinding. Allocation of animals to exposure group not discussed.

Study Score and Ranking:

0.77; Moderate

Campen MJ, Lund AK, Doyle-Eisele ML, McDonald JD, Knuckles TL, Rohr AC, et al. 2010. A comparison of vascular effects from complex and individual air pollutants indicates a role for monoxide gases and volatile hydrocarbons. Environmental Health Perspectives 118(7): 921-927.

Funding Agency: Electric Power Research Institute, National Environmental Respiratory Center, National Institute of Environmental Health Sciences, US Department of Energy (Office of Freedom Car and Vehicle Technologies), US Environmental Protection Agency	
Study Location: N/A	**Study Design:** Animal toxicology study
Fuel Type: Coal	**Chemicals:** CO, NO, NO2, PM, Total hydrocarbons

Abstract: Background: Emerging evidence suggests that the systemic vasculature may be a target of inhaled pollutants of vehicular origin. We have identified several murine markers of vascular toxicity that appear sensitive to inhalation exposures to combustion emissions. Objective: We sought to examine the relative impact of various pollutant atmospheres and specific individual components on these markers of altered vascular transcription and lipid peroxidation. Methods: Apolipoprotein E knockout (ApoE(-/-)) mice were exposed to whole combustion emissions (gasoline, diesel, coal, hardwood), biogenically derived secondary organic aerosols (SOAs), or prominent combustion-source gases [nitric oxide (NO), NO2, carbon monoxide (CO)] for 6 hr/day for 7 days. Aortas were assayed for transcriptional alterations of endothelin-1 (ET-1), matrix metalloproteinase-9 (MMP-9), tissue inhibitor of metalloproteinase-2 (TIMP-2), and heme oxygenase-1 (HO-1), along with measures of vascular lipid peroxides (LPOs) and gelatinase activity. Results: We noted transcriptional alterations with exposures to gasoline and diesel emissions. Interestingly, ET-1 and MMP-9 transcriptional effects could be recreated by exposure to CO and NO, but not NO2 or SOAs. Gelatinase activity aligned with levels of volatile hydrocarbons and also monoxide gases. Neither gases nor particles induced vascular LPO despite potent effects from whole vehicular emissions. Conclusions: In this head-to-head comparison of the effects of several pollutants and pollutant mixtures, we found an important contribution to vascular toxicity from readily bioavailable monoxide gases and possibly from volatile hydrocarbons. These data support a role for traffic-related pollutants in driving cardiopulmonary morbidity and mortality.

Strengths and Limitations:

Strengths: Sufficient sample size. Developed laboratory-generated pollutant mixture to represent downwind coal power-plant plumes. Assessed several different markers of vascular toxicity.
Limitations: Not clear why the particular exposure duration and concentrations were chosen. Only single dose level (concentration/duration) of coal combustion atmosphere. No discussion of blinding. Allocation of animals to exposure group not discussed. For the coal combustion atmospheres, most outcomes measured showed no response.

Study Score and Ranking:

0.77; Moderate

Di Ciaula A. 2012. Emergency visits and hospital admissions in aged people living close to a gas-fired power plant. European Journal of Internal Medicine 23(2): e53-8.

Funding Agency: Not stated	
Study Location: Italy	**Study Design:** Time-series (prospective)
Fuel Type: Natural gas	**Chemicals:** NO2, PM10

Abstract: Background: Combustion of natural gas for energy generation produces less pollutants than coke/oil. However, little is known about the short-term effect of pollution generated by gas-fired power plants on the health of elderly people. Methods: During three months, daily emergency visits/hospital admissions of subjects living within 3 km from a gas-fueled power plant were counted and related to ambient concentrations of nitrogen dioxide (NO2) and particulate matter of median aerometric diameter <10 μm (PM10). A generalized additive model served to correlate visits/hospital admissions to pollutants, controlling for meteorological confounders. Results: Mean air concentrations of PM10 and NO2 were higher after-than before the start of operation of the plant, with the highest concentrations recorded within 1 km. Although pollutants were below the limits set by the European legislation, in elderly people there was a positive correlation between the number of emergency visits and daily air concentrations of PM10 and NO2, as measured at 1 and 3 km from the plant. In subjects aged 70 years or more, the number of hospital admissions was positively correlated with PM10 levels measured within 3 km from the power plant, whereas in older subjects (≥80 year) it was also significantly linked with the lowest air concentration of PM10 (measured at 6 km from the plant). Discussion: Combustion of natural gas for energy generation produces a rise in air concentration of PM10 and NO2 close to the plant, with a concentration-dependent increment of daily emergency visits and hospital admissions in elderly people, and with an age-dependent susceptibility.

Strengths and Limitations:

Strengths: Objective outcome measure. NO2 and PM10 measured at 3 sites in the area.
Limitations: No individual data (age only). Assessed immediate impacts only (0-day lag). Causes for hospital admissions not known. Did not discuss other possible sources of pollution in the area.

Study Score and Ranking:

0.71; Moderate

García-Pérez J, Pollán M, Boldo E, Pérez-Gómez B, Aragonés N, Lope V et al. 2009. Mortality due to lung, laryngeal and bladder cancer in towns lying in the vicinity of combustion installations. Science of the Total Environment 407(8): 2593-602.

Funding Agency: Spain Health Research Fund (Fondo de Investigación Sanitaria)	
Study Location: Spain	**Study Design:** Ecological
Fuel Type: Coal, Natural gas, Oil	**Chemicals:** N/A

Abstract: Background: Installations that burn fossil fuels to generate power may represent a health problem due to the toxic substances which they release into the environment. Objectives: To investigate whether there might be excess mortality due to tumors of lung, larynx and bladder in the population residing near Spanish combustion installations included in the European Pollutant Emission Register. Methods: Ecologic study designed to model sex-specific standardized mortality ratios for the above three tumors in Spanish towns, over the period 1994-2003. Population exposure to pollution was estimated on the basis of distance from town of residence to pollution source. Using mixed Poisson regression models, we analyzed: risk of dying from cancer in a 5-kilometer zone around installations that commenced operations before 1990; effect of type of fuel used; and risk gradient within a 50-kilometer radius of such installations. Results: Excess mortality (relative risk, 95% confidence interval) was detected in the vicinity of pre-1990 installations for lung cancer (1.066, 1.041-1.091 in the overall population; 1.084, 1.057-1.111 in men), and laryngeal cancer among men (1.067, 0.992-1.148). Lung cancer displayed excess mortality for all types of fuel used, whereas in laryngeal and bladder cancer, the excess was associated with coal-fired industries. There was a risk gradient effect in the proximity of a number of installations. Conclusions: Our results could support the hypothesis of an association between risk of lung, laryngeal and bladder cancer mortality and proximity to Spanish combustion installations.

Strengths and Limitations:

Strengths: Considered population data over a 10-year period. Large sample size (>200,000 deaths). Objective measure of health outcome (mortality data registry). Accounted for some sociodemographic factors for each town (population size; illiteracy, farmers and unemployed; average persons per home; mean income).
Limitations: Hypothesis-generating study (not suitable study design to assess causation or effect at the individual level). Weak exposure assessment (distance from town centre to facility). No individual data available (eg. smoking status, occupation, length of time residing in community). Occupationally exposed workers likely to live near facility. Potential ecological bias.

Study Score and Ranking:

0.63; Moderate

Gohlke JM, Thomas R, Woodward A, Campbell-Lendrum D, Prüss-Üstün A, Hales S et al. 2011. Estimating the global public health implications of electricity and coal consumption. Environmental Health Perspectives 119(6): 821-6.

Funding Agency: National Institute of Environmental Health Sciences (Intramural Research Program of the National Institutes of Health)	
Study Location: 41 countries	**Study Design:** Ecological
Fuel Type: N/A	**Chemicals:** N/A

Abstract: Background: The growing health risks associated with greenhouse gas emissions highlight the need for new energy policies that emphasize efficiency and low-carbon energy intensity. Objectives: We assessed the relationships among electricity use, coal consumption, and health outcomes. Methods: Using time-series data sets from 41 countries with varying development trajectories between 1965 and 2005, we developed an autoregressive model of life expectancy (LE) and infant mortality (IM) based on electricity consumption, coal consumption, and previous year's LE or IM. Prediction of health impacts from the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) integrated air pollution emissions health impact model for coal-fired power plants was compared with the time-series model results. Results: The time-series model predicted that increased electricity consumption was associated with reduced IM for countries that started with relatively high IM (> 100/1,000 live births) and low LE (< 57 years) in 1965, whereas LE was not significantly associated with electricity consumption regardless of IM and LE in 1965. Increasing coal consumption was associated with increased IM and reduced LE after accounting for electricity consumption. These results are consistent with results based on the GAINS model and previously published estimates of disease burdens attributable to energy-related environmental factors, including indoor and outdoor air pollution and water and sanitation. Conclusions: Increased electricity consumption in countries with IM < 100/1,000 live births does not lead to greater health benefits, whereas coal consumption has significant detrimental health impacts.

Strengths and Limitations:

Strengths: Considered population data over a 40-year period. Large sample size. Compared findings from the ecological analysis with two different modeling approaches for estimating health-impacts (to demonstrate consistency in observed relationships). Data were presented for all 41 countries (in the supplement).
Limitations: Weak exposure assessment (country-level electricity usage). No individual data. Missing data in the databases (gaps filled using linear interpolation). Potential for confounding by others factors (eg. wealth, education). Potential ecological bias.

Study Score and Ranking:

0.63; Moderate

Liu X, Lessner L, Carpenter DO. 2012. Association between residential proximity to fuel-fired power plants and hospitalization rate for respiratory diseases. Environmental Health Perspectives 120(6): 807-810.

Funding Agency: Institute for Health and the Environment (University at Albany)	
Study Location: New York	**Study Design:** Semi-ecological
Fuel Type: Coal, Landfill gas, Natural gas, Oil, Solid waste	**Chemicals:** N/A

Abstract: Background: Air pollution is known to cause respiratory disease. Unlike motor vehicle sources, fuel-fired power plants are stationary. Objective: Using hospitalization data, we examined whether living near a fuel-fired power plant increases the likelihood of hospitalization for respiratory disease. Methods: Rates of hospitalization for asthma, acute respiratory infection (ARI), and chronic obstructive pulmonary disease (COPD) were estimated using hospitalization data for 1993-2008 from New York State in relation to data for residences near fuel-fired power plants. We also explored data for residential proximity to hazardous waste sites. Results: After adjusting for age, sex, race, median household income, and rural/urban residence, there were significant 11%, 15%, and 17% increases in estimated rates of hospitalization for asthma, ARI, and COPD, respectively, among individuals > 10 years of age living in a ZIP code containing a fuel-fired power plant compared with one that had no power plant. Living in a ZIP code with a fuel-fired power plant was not significantly associated with hospitalization for asthma or ARI among children < 10 years of age. Living in a ZIP code with a hazardous waste site was associated with hospitalization for all outcomes in both age groups, and joint effect estimates were approximately additive for living in a ZIP code that contained a fuel-fired power plant and a hazardous waste site. Conclusions: Our results are consistent with the hypothesis that exposure to air pollution from fuel-fired power plants and volatile compounds coming from hazardous waste sites increases the risk of hospitalization for respiratory diseases.

Strengths and Limitations:

Strengths: Large sample size. Data covered a 16-year period. Analysis included children. Investigators were able to account for some potential confounders (age, sex, race/ethnicity, urban/rural residence, median household income (zip-code level)).

Limitations: Weak exposure assessment (no pollutant data). Limited individual data. Only hospitalizations were evaluated (no data on emergency department or physician office visits).

Study Score and Ranking:

0.79; Moderate

Merritt TD, Cretikos MA, Smith W, Durrheim DN. 2013. The health of Hunter Valley communities in proximity to coal mining and power generation, general practice data, 1998-2010. New South Wales Public Health Bulletin 24(2): 57-64

Funding Agency: New South Wales Department of Health	
Study Location: Australia	**Study Design:** Ecological
Fuel Type: Coal	**Chemicals:** N/A

Abstract: Aim: An analysis of general practice data for rural communities in close proximity to coal mining and coal-fired power generation in the Hunter Valley region of NSW was conducted to identify unusual patterns of illness. Methods: Bettering the Evaluation and Care of Health general practice consultation data from the Hunter Valley region for 1998-2010 were compared with data from all other rural NSW residents. Results: There were no significantly higher rates of problems managed or medications prescribed for Hunter Valley region residents compared with the rest of rural NSW. Rates of respiratory problem management in the Hunter Valley region did not change significantly over time, while for all other rural NSW areas these rates significantly decreased. Conclusion: There was no evidence of significantly elevated health issues for residents in the Hunter Valley region of NSW. The diverging trend for respiratory problem management over time is worthy of further exploration.

Strengths and Limitations:

Strengths: Use of state registries for health data. Assessed a variety of health outcomes. Detailed presentation of results. Smoking data available for subsample of subjects (33%).
Limitations: Weak exposure assessment. Limited individual data. Region is also an intensive coal mining area.

Study Score and Ranking:

0.67; Moderate

New South Wales Department of Health. 2010. Respiratory and cardiovascular diseases and cancer among residents in the Hunter New England Area Health Service. Available at http://www0.health.nsw.gov.au/pubs/2010/hne_respi_cardio.html**.**

Funding Agency: New South Wales Department of Health	
Study Location: Australia	**Study Design:** Ecological
Fuel Type: Coal	**Chemicals:** N/A

Abstract: *No abstract available.*

Excerpt from Introduction:
[This report focuses on those diseases and causes of death that have been found to be associated with exposure to air pollutants. Analysis has also been undertaken on some diseases about which the community of the Hunter New England Area Health Service (HNEAHS) of New South Wales (NSW) has expressed a concern. This report uses reliable, routinely collected health data to: 1) assess the health of the residents of the HNEAHS of NSW 2) to compare the health of the residents of the HNEAHS to the health of residents in other parts of NSW 3) examine variation in health within HNEAHS in relation to the distribution of coal mining and coal-powered electrical power generation activity within this area.]

Strengths and Limitations:

Strengths: Use of state registries for health data. Ambient pollutant data for exposed area presented in companion report. Assessed a variety of health outcomes. Detailed presentation of results.
Limitations: Exploratory study. Weak exposure assessment. No individual data. Region is also an intensive coal mining area.

Study Score and Ranking:

0.67; Moderate

Parodi S, Santi I, Marani E, Casella C, Puppo A, Vercelli M, Stagnaro E. 2014. Risk of non-Hodgkin's lymphoma and residential exposure to air pollution in an industrial area in northern Italy: a case-control study. Archives of Environmental and Occupational Health 69(3): 139-147.

Funding Agency: Savona Local Health Centre 2 (ASL2 Savonese)	
Study Location: Italy	**Study Design:** Case-control
Fuel Type: Fossil fuel	**Chemicals:** Benzene, NO2, PM2.5, PM10, SO2

Abstract: The aim of this study was to evaluate the risk of non-Hodgkin's lymphoma (NHL) in an adult population residing in an area in northern Italy exposed to industrial air pollution from a big power plant, a coke oven, 2 chemical factories, and some minor plants. The design was a population-based case-control study and information about residential history and the main risk factors for NHL was obtained interviewing 133 cases and 279 controls using a structured questionnaire. Three exposure categories (heavy, moderate, and slight) were defined on the basis of the location of the major facilities with respect to the subject residence. NHL risk was not associated either with location or duration of residence in the heavily polluted area. However, the unavoidable limitations of this study prevent us from drawing definitive conclusions.

Strengths and Limitations:

Strengths: Population-based study. Objective outcome measure. Comprehensive questionnaire. Considered many potential confounders. Ambient pollutant data available to confirm zones of exposure.
Limitations: Weak exposure assessment (reside near industry). Multiple sources of industrial pollution; minimal discussion of power plants. Potential recall bias. Moderate response rates that differed between cases (74%) and controls (63%). Not known if interviewer blinded to case/control status.

Study Score and Ranking:

0.65; Moderate

Peluso M, Munnia A, Ceppi M, Giese R.W, Catelan D, Rusconi F, Godschalk RW, Biggeri A. 2013. Malondialdehyde-deoxyguanosine and bulky DNA adducts in schoolchildren resident in the proximity of the Sarroch industrial estate on Sardinia Island, Italy. Mutagenesis 28(3): 315-321.

Funding Agency: Associazione Italiana per la Ricerca sul Cancro, Progetto Sarroch Ambiente e Salute (Municipality of Sarroch, Italy), United States National Institute of Environmental Health Sciences

Study Location: Italy	**Study Design:** Cross-sectional
Fuel Type: Oil	**Chemicals:** PAH, VOC (benzene, ethylbenzene)

Abstract: Air quality is a primary environmental concern in highly industrialised areas, with potential health effects in children residing nearby. The Sarroch industrial estate in Cagliari province, Sardinia Island, Italy, hosts the world's largest power plant and the second largest European oil refinery and petrochemical park. This industrial estate produces a complex mixture of air pollutants, including benzene, heavy metals and polycyclic aromatic hydrocarbons. Thus, we conducted a cross-sectional study to evaluate the prevalence of malondialdehyde-deoxyguanosine adducts in the nasal epithelium of 75 representative children, aged 6-14 years, attending primary and secondary schools in Sarroch in comparison with 73 rural controls. Additionally, the levels of bulky DNA adducts were analysed in a subset of 62 study children. DNA damage was measured by (32)P-postlabelling methodologies. The air concentrations of benzene and ethyl benzene were measured in the school gardens of Sarroch and a rural village by diffusive samplers. Outdoor measurements were also performed in other Sarroch areas and in the proximity of the industrial estate. The outdoor levels of benzene and ethyl benzene were significantly higher in the school gardens of Sarroch than in the rural village. Higher concentrations were also found in other Sarroch areas and in the vicinity of the industrial park. The mean levels of malondialdehyde-deoxyguanosine adducts per 10^8 normal nucleotides +/- standard error (SE) were 74.6+/-9.1 and 34.1+/-4.4 in the children from Sarroch and the rural village, respectively. The mean ratio was 2.53, 95% confidence interval (CI): 1.71-2.89, $P < 0.001$, versus rural controls. Similarly, the levels of bulky DNA adducts per 10^8 normal nucleotides +/- SE were 2.9+/-0.4 and 1.6+/-0.2 in the schoolchildren from Sarroch and the rural village, respectively. The means ratio was 1.90, 95% CI: 1.25-2.89, $P = 0.003$ versus rural controls. Our study indicates that children residing near the industrial estate have a significant increment of DNA damage.

Strengths and Limitations:

Strengths: Objective outcome measure. VOCs measured at 7 outdoor sites (including school grounds in both communities).

Limitations: Small sample size. Limited individual data. Considered child smoking status (smokers were excluded), but not parental smoking status. Did not adjust for potential confounders. No outdoor monitoring of PAH. Contribution of power plant emissions to total pollution not known. No discussion of blinding (for DNA adduct analysis).

Study Score and Ranking:

0.65; Moderate

Possamai FP, Ávila Júnior S, Parisotto EB, Moratelli AM, Inacio DB, Garlet TR, Dal-Pizzol F, Wilhelm Filho D. 2010. Antioxidant intervention compensates oxidative stress in blood of subjects exposed to emissions from a coal electric-power plant in South Brazil. Environmental Toxicology and Pharmacology 30(2): 175-180.

Funding Agency: CNPq/MCT-Brazil, UNESC-Brazil	
Study Location: Brazil	**Study Design:** Randomized control trial
Fuel Type: Coal	**Chemicals:** PM

Abstract: In the process of energy generation, particulate matter (PM) emissions derived from coal combustion expose humans to serious occupational diseases, which are associated with overgeneration of reactive oxygen species (ROS). The purpose of the present study is to better understand the relations between PM exposure derived from a coal electric-power plant and the oxidative damage in subjects (n=20 each group) directly (working at the burning area) or indirectly (working at the office or living in the vicinity of the electric-power plant=group of residents) exposed to airborne contamination, before and after daily supplementation with vitamins C (500mg) and E (800mg) during six months, which were compared to non-exposed subjects (control group). Several biomarkers of oxidative stress were examined such as levels of thiobarbituric acid reactive substances (TBARS), protein carbonyls (PC), protein thiols (PT) and vitamin E in plasma, levels of reduced glutathione (GSH) in whole blood, and of activities of superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), glutathione reductase (GR) and glutathione S-transferase (GST) in red cells. Before supplementation, TBARS and PC levels were significantly increased, levels of GSH and vitamin E were decreased, while the activities of SOD and CAT were increased in workers groups and GST were increased in all groups in compared to controls. After the antioxidant supplementation essentially all these biomarkers were normalized to control levels. The antioxidant intervention was able to confer a protective effect of vitamins C and E against the oxidative insult associated with airborne contamination derived from coal burning of an electric-power plant.

Strengths and Limitations:

Strengths: Objective outcome measure. Subjects followed for 6 months.
Limitations: Small sample size. Weak exposure assessment (reside near power plant). No ambient pollutant data. No discussion of blinding. Did not control for potential confounders. No discussion of other pollution sources.

Study Score and Ranking:

0.62; Moderate

Rusconi F, Catelan D, Accetta G, Peluso M, Pistelli R, Barbone F, et al. 2011. Asthma symptoms, lung function, and markers of oxidative stress and inflammation in children exposed to oil refinery pollution. Journal of Asthma 48(1): 84-90.

Funding Agency: Ministry of Education, University and Scientific Research, Ministry of Welfare, Municipality of Sarroch

Study Location: Italy	**Study Design:** Cross-sectional
Fuel Type: Oil	**Chemicals:** Benzene, NO2, O3, PM10, SO2

Abstract: Objectives: Little is known about the effects of exposure to petroleum refinery emissions on respiratory health in children. We evaluated lung function and markers of inflammation and oxidative stress in children and adolescents with and without asthma or wheezing symptoms living in a petrochemical polluted area (Sarroch, Sardinia) versus a reference area (Burcei). Methods: Parents of 275/300 6- to 14-year-old children living in Sarroch and parents of 214/323 children living in Burcei answered a questionnaire on respiratory symptoms and risk factors. Measurements of forced expiratory volume after 1 second (FEV(1)) and of forced expiratory flow rates at 25-75% of vital capacity (FEF(25-75)) were available in 27 and 23 asthma/wheezing-positive subjects and in 7 and 54 asthma/wheezing-negative subjects in Sarroch and in Burcei, respectively; for fractional exhaled nitric oxide (FE(NO)) corresponding figures were 27 and 24 and 8 and 55 in Sarroch and in Burcei, respectively. Malondialdehyde-deoxyguanosine (MDA-dG) adduct levels in nasal mucosa were measured in 12- to 14-year-old adolescents (8 and 14 asthma/wheezing-positive and 20 and 28 asthma/wheezing-negative subjects in Sarroch and in Burcei, respectively). Air pollutants were assessed during 3 weeks, starting 1 week before lung function, FE(NO), and MDA-dG measurements. Generalized linear models were used to estimate the effect of the area of residence adjusting for confounders. Results: Weekly average concentrations of sulfur dioxide were 6.9-61.6 μg/m3 in Sarroch versus 0.3-7.6 μg/m3 in the rural area of Burcei; of nitrogen dioxide, 5.2-28.7 μg/m3 versus 1.7-5.3 μg/m3; and of benzene, 1.8-9.0 μg/m3 versus 1.3-1.5 μg/m3, respectively. Children living in Sarroch versus children living in the reference area showed an increase in wheezing symptoms {adjusted prevalence ratio=1.70 [90% confidence interval (CI)=1.01; 2.86]}; a decrease in lung function [variation in FEV(1)=-10.3% (90% CI=-15.0; -6.0%) and in FEF(25-75)=-12.9% (90% CI=-20.7; -4.3%)]; an increase in bronchial inflammation [variation in FE(NO)=+35% (90% CI=11.7; 80.1%)]; and an increase in MDA-dG adducts of +83% (90% CI=22.9; 174.1%). Conclusions: Data from this small study are consistent with the role of environmental pollutants on lung function and inflammation.

Strengths and Limitations:

Strengths: Objective outcome measure (lung function, DNA adducts). Benzene, NO2, and SO2 measured at >20 outdoor sites (including school grounds in both communities). Adjusted for several potential confounders (eg. active/passive smoking, parental education, traffic, mould in bedroom).

Limitations: Surveys for the exposed and control areas were conducted in different seasons. Questionnaire response rates differed between exposed area (92%) and control area (66%). Small sample size for lung function and DNA adduct testing. No discussion of blinding. Some outcomes self-reported. Contribution of power plant emissions to total pollution not known.

Study Score and Ranking:

0.77; Moderate

Salameh P, Khayat G, Waked M. 2011. Validation of the respiratory toxics exposure score (RTES) for chronic obstructive pulmonary disease screening. International Journal of Occupational Medicine and Environmental Health 24(4): 339-347.

Funding Agency: Boehringer Ingleheim (Lebanon)	
Study Location: Lebanon	**Study Design:** Cross-sectional
Fuel Type: Diesel	**Chemicals:** N/A

Abstract: Objective: Our aim is to evaluate the validity of exhaled carbon monoxide (CO) and of a newly-created score as markers of Chronic Obstructive Pulmonary Disease (COPD). Materials and Methods: The CO level was measured in a derivation subsample of a cross-sectional study and linked to COPD diagnosis; its predictors were evaluated, and a scale was constructed. It was evaluated in a validation subsample and in a clinical setting. Results: Individuals with COPD had higher CO levels than healthy individuals. CO level significant predictors were cigarettes per day, waterpipes per week, lower age, male gender, living close to diesel exhaust, heating home with the use of diesel, and having indoor family smokers. A score composed of CO predictors was able to significantly predict COPD (Ora = 4-7.5). Conclusions: Coupled with the clinical judgment of physicians, this scale would be an excellent low-cost tool for screening COPD, in absence of spirometry.

Strengths and Limitations:

Strengths: Objective outcome measure. Considered several personal and environmental variables.
Limitations: Weak exposure assessment (ever lived near power plant). No pollutant data. Potential recall bias. Focus of study was validation of a screening tool (minimal discussion of power plants).

Study Score and Ranking:

0.71; Moderate

Salameh P, Salame J, Khayat G, Akhdar A, Ziadeh C, Azizi S, et al. 2012a. Exposure to outdoor air pollution and chronic bronchitis in adults: a case-control study. International Journal of Occupational and Environmental Medicine 3(4): 165-177.

Funding Agency: Not stated	
Study Location: Lebanon	**Study Design:** Case-control
Fuel Type: Diesel	**Chemicals:** N/A

Abstract: Background: Although Lebanon is a highly polluted country, so far no study has specifically been designed to assess the association between outdoor air pollution and chronic bronchitis in this country. Objective: To assess the association between exposure to outdoor air pollution and chronic bronchitis in Lebanon. Methods: A pilot case-control study was conducted in two tertiary care hospitals. Cases consisted of patients diagnosed with chronic bronchitis by a pulmonologist and those epidemiologically confirmed. Controls included individuals free of any respiratory signs or symptoms. After obtaining informed consent, a standardized questionnaire was administered. Results: Bivariate, stratified (over smoking status and gender) and multivariate analyses revealed that passive smoking at home (ORa: 2.56, 95% CI: 1.73-3.80) and at work (ORa: 1.89, 95% CI: 1.13-3.17); older age (ORa: 1.75, 95% CI: 1.55-2.39); lower education (ORa: 1.44, 95% CI: 1.21-1.72); living close to a busy road (ORa: 1.95, 95% CI: 1.31-2.89) and to a local power plant (ORa: 1.62, 95% CI: 1.07-2.45); and heating home by hot air conditioning (ORa: 1.85, 95% CI: 1.00-3.43) were moderately associated with chronic bronchitis; an inverse association was found with heating home electrically (ORa: 0.58, 95% CI: 0.39-0.85). A positive dose-effect relationship was observed in those living close to a busy road and to a local diesel exhaust source. Conclusion: Chronic bronchitis is associated with outdoor air pollution.

Strengths and Limitations:

Strengths: High participation rates (98% cases, 90% controls). Considered several personal and environmental risk factors for bronchitis. Observed dose-response relationship between duration of living close to a power plant and bronchitis.

Limitations: Hospital-based study (may not be representative sample of population). Weak exposure assessment (ever lived near power plant). Potential recall bias. Some sociodemographic differences between cases and controls (eg. age, education).

Study Score and Ranking:

0.79; Moderate

Salameh P, Waked M, Khayat G, Dramaix M. 2012b. Waterpipe smoking and dependence are associated with chronic obstructive pulmonary disease: A case-control study. Open Epidemiology Journal 5: 36-44.

Funding Agency: Not stated	
Study Location: Lebanon	**Study Design:** Case-control
Fuel Type: Diesel	**Chemicals:** N/A

Abstract: Introduction: Waterpipe smoking gained popularity during recent years. Although waterpipe smoking exposes people to the same noxious substances found in cigarettes, popular belief considers it harmless. Our objective was to evaluate the association between waterpipe smoking and dependence, and COPD. Methods: We conducted a case-control study in two tertiary care hospitals. Cases were included if diagnosed as COPD by a pulmonologist and confirmed by post-bronchodilator FEV1/FVC<0.7; controls were included if free of any respiratory disease or symptom. After oral consent, a standardized questionnaire was administered and spirometry results were collected. Results: 211 COPD cases and 527 controls were studied. In previous smokers, any smoking type was associated with COPD. The ORs were 29.0[14.3-58.8] (p<0.001) for previous cigarette smoking, 11.7[4.4-31.2] (p<0.001) for previous waterpipe smoking, and 44.1[16.3-4.4] (p<0.001) for previous mixed smoking. In current smokers, the ORs were 20.5[10.2-41.2] (p<0.001) for cigarette smoking, 1.8[0.5-5.9] (p=0.299) for waterpipe smoking, and 9.4[3.81-23.0] (p<0.001) for mixed smoking. Nevertheless, we found in waterpipe current smokers, an OR=8.9[3.9-20.7] (p<0.001) for the association between dependence evaluated by LWDS-11 scale, and COPD. These results were confirmed by stratified and multivariate analysis, after adjustment for cigarette smoking and confounding variables. A cumulative smoking of one waterpipe per week for 20 years (or its equivalent) was predictive of higher risk of COPD. Discussion: Whereas evidence showing harmful effects of waterpipe smoking is sparse, this study showed a high OR between the risk of developing COPD and being an ex-smoker of waterpipe, or a current waterpipe dependent individual. Additional studies are necessary to confirm our results.

Strengths and Limitations:

Strengths: High participation rates (96% cases, 91% controls). Considered several personal and environmental risk factors for bronchitis.
Limitations: Hospital-based study (may not be representative sample of population). Weak exposure assessment (ever lived near power plant). No pollutant data. Potential recall bias. Focus of study was waterpipe use (minimal discussion of power plant exposure). Some sociodemographic differences between cases and controls (eg. age, education).

Study Score and Ranking:

0.63; Moderate

Seagrave J, Campen MJ, McDonald JD, Mauderly JL, Rohr AC. 2008. Oxidative stress, inflammation, and pulmonary function assessment in rats exposed to laboratory-generated pollutant mixtures. Journal of Toxicology and Environmental Health Part A 71(20):1352-62.

Funding Agency: Electric Power Research Institute, National Environmental Respiratory Center, National Institute of Environmental Health Sciences

Study Location: N/A	**Study Design:** Animal toxicology study
Fuel Type: Coal	**Chemicals:** CO, NO, NO2, SO2, PM, Total hydrocarbons

Abstract: Oxidative stress may mediate adverse health effects of many inhaled pollutants. Cardiopulmonary responses of Sprague-Dawley rats to inhalation of whole or filtered gasoline engine exhaust (GEE, FGEE); simulated downwind coal emission atmospheres (SDCAs) from two types of coal, each tested at two concentrations; and two concentrations of re-aerosolized paved road dust (RD) were evaluated. In situ chemiluminescence and thiobarbituric acid-reactive substances (TBARS) were used to evaluate oxidative reactions in the lungs, heart, and liver immediately following exposures. Pulmonary inflammatory responses were measured by bronchoalveolar lavage (BAL) cell counts. Respiratory function parameters during exposure were measured by plethysmography. Only GEE significantly enhanced in situ chemiluminescence (all three organs), but only exposure to the high RD concentration increased TBARS (hearts only). There was a weak trend toward increased macrophages recovered in lavage fluid from both SDCAs, and macrophages were significantly elevated by both FGEE and the lower concentration of RD. Respiratory function effects were small, though the effects of the Central Appalachian low-sulfur SDCA on enhanced pause and the effects of the Powder River Basin SCDA on tidal volume were significant. The discordance between the oxidative stress indicators may relate to the use of a single time point in the context of dynamic changes in compensatory mechanisms. These results further suggest that inflammatory responses measured by BAL cellularity may not always correlate with oxidative stress. Overall, the toxicological effects from exposure to these pollutant mixtures were subtle, but the results show differences in the effects of atmospheres having different physical/chemical characteristics.

Strengths and Limitations:

Strengths: Sufficient sample size. Developed laboratory-generated pollutant mixture to represent downwind coal power-plant plumes. Dose-dependent trend observed for inflammatory response (macrophages in lavage fluid). Findings were compared to results observed in the TERESA (Toxicological Evaluation of Realistic Emissions Source Aerosols) animal studies.

Limitations: Information lacking regarding the exposure chamber conditions and animal handling. Not clear why the particular exposure duration and concentrations were chosen. No discussion of blinding. For the coal combustion atmospheres, observed effects were subtle; most outcomes measured showed no response.

Study Score and Ranking:

0.77; Moderate

Seilkop SK, Campen MJ, Lund AK, McDonald JD, Mauderly JL. 2012. Identification of chemical components of combustion emissions that affect pro-atherosclerotic vascular responses in mice. Inhalation Toxicology 24(5): 270-287.

Commissioning Agency: National Environmental Respiratory Center, US Department of Energy (Office of Freedom Car and Vehicle Technologies, National Energy Technology Laboratory), US Department of Transportation (Federal Highways Administration), US Environmental Protection Agency (Office of Research and Development), California Air Resources Board	
Study Location: N/A	**Study Design:** Animal toxicology study
Fuel Type: Coal	**Chemicals:** CO, NH3, NO, NO2, PM, SO2, VOC

Abstract: Combustion emissions cause pro-atherosclerotic responses in apolipoprotein E-deficient (ApoE/(-)) mice, but the causal components of these complex mixtures are unresolved. In studies previously reported, ApoE(-)/(-) mice were exposed by inhalation 6 h/day for 50 consecutive days to multiple dilutions of diesel or gasoline exhaust, wood smoke, or simulated "downwind" coal emissions. In this study, the analysis of the combined four-study database using the Multiple Additive Regression Trees (MART) data mining approach to determine putative causal exposure components regardless of combustion source is reported. Over 700 physical-chemical components were grouped into 45 predictor variables. Response variables measured in aorta included endothelin-1, vascular endothelin growth factor, three matrix metalloproteinases (3, 7, 9), metalloproteinase inhibitor 2, heme-oxygenase-1, and thiobarbituric acid reactive substances. Two or three predictors typically explained most of the variation in response among the experimental groups. Overall, sulfur dioxide, ammonia, nitrogen oxides, and carbon monoxide were most highly predictive of responses, although their rankings differed among the responses. Consistent with the earlier finding that filtration of particles had little effect on responses, particulate components ranked third to seventh in predictive importance for the eight response variables. MART proved useful for identifying putative causal components, although the small number of pollution mixtures (4) can provide only suggestive evidence of causality. The potential independent causal contributions of these gases to the vascular responses, as well as possible interactions among them and other components of complex pollutant mixtures, warrant further evaluation.

Strengths and Limitations:

Strengths: Sufficient sample size. Utilized laboratory-generated pollutant mixture to represent downwind coal power-plant plumes. Utilized 3 concentrations of coal combustion atmosphere. Analysis of data from several earlier publications to identify the components most responsible for cardiovascular responses.
Limitations: No discussion of blinding. Allocation of animals to exposure group not discussed. The mouse model demonstrated little cardiovascular response to the coal combustion atmosphere. The Multiple Additive Regression Trees data mining technique used was "at the low end of the discriminatory spectrum for confidently predicting likely causal relationships".

Study Score and Ranking:

0.77; Moderate

US Department of Health and Human Services (ATSDR). 2008. Health Consultation: Respiratory Hospitalizations in Areas Surrounding the AES Greenidge Power Plant. pp 44. Available at http://www.atsdr.cdc.gov/hac/pha/AESGreenidgePowerPlant/AES_Greenidge_Power_Plant%20HC%208-15-2008.pdf.

Funding Agency: Agency for Toxic Substances and Disease Registry, New York State Department of Health	
Study Location: Torrey, New York	**Study Design:** Ecological
Fuel Type: Coal (primarily)	**Chemicals:** N/A

Abstract: *No abstract available.*

Excerpt from Introduction:
[The New York State Department of Health (NYS DOH) has a cooperative agreement with the Agency for Toxic Substances and Disease Registry (ATSDR) to perform health assessments, conduct health statistics reviews, and perform epidemiological studies of populations in New York State which may have been exposed to environmental contaminants. In December 2005, Senator Hillary Clinton requested that ATSDR conduct a Public Health Assessment for the area around the AES Greenidge power station in Torrey, New York due to concerns about respiratory illness in the area (Appendix A). Her request was prompted by an informal statistical summary prepared by Dr. David Carpenter, Director of the University at Albany's Institute for Health and the Environment, which found statistically significant elevations of several respiratory diseases in six ZIP codes near the facility (Appendix B). In response, NYS DOH agreed to conduct a health statistics review of respiratory related hospitalizations among residents of the communities surrounding the coal-fired power plant which lies in Yates County, in the Finger Lakes region of Central New York. The link between the air pollutants commonly associated with coal-fired power plants and adverse respiratory health has been well documented in the scientific literature (Brunekreef and Holgate, 2002; Pope, 2000; Brook et al., 2003). While many other health effects have also been associated with some of these same pollutants, the current review focused only on noncancer respiratory illnesses.]

Strengths and Limitations:

Strengths: Considered population data over a 20-year period. Objective health outcome. Used dispersion modeling to predict areas of high, moderate, and low exposure. Report underwent public commenting period.
Limitations: Hypothesis-generating study. Weak exposure assessment. No ambient pollutant measurements. No individual data (except age, gender, race, zip code of residence). Did not account for potential confounders (eg. smoking). Potential ecological bias.

Study Score and Ranking:

0.67; Moderate

Valentic D, Micovic V, Kolaric B, Brncic N, Ljubotina A. 2010. The role of air quality in perception of health of the local population. Collegium Antropologicum 34(Suppl 2): 113-117.

Funding Agency: Not stated	
Study Location: Croatia	**Study Design:** Cross-sectional
Fuel Type: Oil	**Chemicals:** Benzene, Cd, Pb, PM, NO2, SO2

Abstract: The research aim was to investigate and establish the perception of health among population groups with different number of industrial polluters in their living environment. Namely, the Kostrena living area (3250 inhabitants) is situated near big industrial pollutant producers: INA oil refinery Urinj, thermo power plant Rijeka, shipyard "Viktor Lenac", while in Crikvenica living area such pollutant producers do not exist. In this research 146 subjects from Kostrena participated (74 men and 72 women with age average 40.8, SD 9.2 years), and 157 subjects from Crikvenica area (79 men and 78 women with age average 39.4, SD 10.1 years). The perception of health was measured by the means of SF-36 questionnaire variables. Lung function (FEV1, FVC, FEV25/75, PEF), cardiovascular function (systolic and diastolic arterial blood pressure, heart rate were also measured, including body proportion measures by the means of waste and hip circumference and silhouette test, in order to establish the eventual objective physical health parameter difference among examined population groups. Subjects from Kostrena perceived their general health, mental health, and vitality worse than subjects from Crikvenica. Group from Kostrena felt themself more limited in their roles due to emotional problems, perceiving more pain than group from Crikvenica. On the opposite site, social functioning of subjects from Kostrena was better in comparison to Crikvenica group. No signifficant differences between groups were found in physical functioning and in role limitation due to physical problems. In addition, there were no significant differences between groups in objective physical health parameters, such as pulmonary function, arterial blood pressure, pulse, and waist to hip ratio. Subjects using sensoric systems and the mental cognition about harmful environmental factors, perceive their health worse if there are present industrial resources in their environment, even when concentration of the pollutants are within legal ranges.

Strengths and Limitations:

Strengths: Examined several subjective and objective health outcomes (with focus on perception of health). Randomized samples of the exposed and control populations.
Limitations: Weak exposure assessment. Several potential sources of exposure. Did not present ambient pollutant data, but indicated levels were within legal ranges. Relatively small sample size. No discussion of blinding. Did not control for confounders.

Study Score and Ranking:

0.58; Moderate

Waked M, Salame J, Khayat G, Salameh P. 2012. Correlates of COPD and chronic bronchitis in nonsmokers: data from a cross-sectional study. International Journal of Chronic Obstructive Pulmonary Disease 7: 577-585.

Funding Agency: Boehringer Ingleheim (Lebanon)	
Study Location: Lebanon	**Study Design:** Cross-sectional
Fuel Type: Diesel	**Chemicals:** N/A

Abstract: Purpose: Our objective was to assess the prevalence of chronic bronchitis and chronic obstructive pulmonary disease (COPD) and their correlates among a Lebanese nonsmoker group. Material and Methods: A cross-sectional study was conducted between October 2009 and September 2010, using a multistage cluster sample throughout Lebanon including Lebanese residents aged 40 years and above with no exclusion criteria. Pre- and postbronchodilator spirometry measurements were performed and carbon monoxide level was measured in exhaled air. COPD was defined and classified according to the Global Initiative for Chronic Obstructive Lung Disease guidelines or according to the lower limit of normal (forced expiratory volume in 1 second/forced vital capacity postbronchodilator < 5th percentile of the healthy population having the same age and sex). Chronic bronchitis was defined by the declaration of morning cough and expectorations for more than 3 months a year over more than 2 years in individuals with normal spirometry. Results: Out of 2201 individuals, 732 were never-smokers: 25 (3.4%) of them had COPD, and 86 (11.75%) fulfilled the definition of chronic bronchitis. Correlates of COPD included a childhood respiratory disease, house heated by diesel, and older age. On the other hand, correlates of chronic bronchitis included childhood respiratory diseases, living in southern Lebanon versus other regions, heating home by gas, older age, number of smokers at work, and lower height. Conclusion: A substantial percentage of the nonsmoking population may exhibit chronic bronchitis or COPD. The significant correlates mentioned above should be taken into consideration in order to reduce the risk of developing such chronic and debilitating respiratory diseases.

Strengths and Limitations:

Strengths: COPD verified by lung function testing, which was performed by trained technicians. Considered several personal and environmental variables. Multi-centre study.
Limitations: Weak exposure assessment (ever lived near power plant). No pollutant data. Potential recall bias. Chronic bronchitis was self-reported. Minimal discussion of power plants.

Study Score and Ranking:

0.71; Moderate

Gor P, Reyna R, Martinez A, Mejia G, Santos J, Guerrero L. 2008. Air quality and health impacts of emissions in the border region between Northeastern Mexico and Texas. Proceedings of the Air and Waste Management Association Annual Conference and Exhibition 4: 2137-2150.

Funding Agency: National Science Foundation	
Study Location: Texas-Mexico border region	**Study Design:** Time-series
Fuel Type: N/A	**Chemicals:** CO, O3, PM2.5, PM10

Abstract: Ambient air is polluted by various pollutants emitted from power plants, industrial facilities, agricultural operations, motor vehicles, dust from unpaved roads, open burning of trash and many other sources. The Texas-Mexico border region is one of the most rapidly developing areas in the world. Air pollution has been identified as one of the key unfavorable environmental impacts by government entities in both countries. A tool to inform the relationships between environment and health at county-level was developed to help inform decision makers on the status of important factors related to health and environment. The study addressed key issues related to air quality, e.g., health effects. PM2.5 showed slight increasing trend in all Texas border counties while CO concentration was consistently low for all the years. Ozone concentration was stable and no particular trend was observed for Texas border counties. PM10 concentration was greater in Mexican counties compared to Texas border counties. More deaths due to heart disease occurred in Texas border counties than Mexican Counties. A general trend of increase was found for mortality due to heart disease and stroke for all the counties. A definite increasing trend was observed for mortality rates due to lung cancer for Texas border counties.

Strengths and Limitations:

Strengths: Examined mortality and pollution data over a 9-year period. Assessed cause-specific mortality.
Limitations: No individual data. Health and pollutant data incomplete (data for Mexico not fully available). Only compared annual data. Multiple pollution sources in the area; contribution of power plant emissions to pollution levels not known. Conference proceeding.

Study Score and Ranking:

0.46; Low

Juntarawijit C. 2013. Biomass power plants and health problems among nearby residents: A case study in Thailand. International Journal of Occupational Medicine and Environmental Health 26(5): 813-21.

Funding Agency: Ministry of Public Health, Thailand	
Study Location: Thailand	**Study Design:** Cross-sectional
Fuel Type: Biomass (rice husks)	**Chemicals:** NO_2, O_3, PM_{10}, SO_2, TSP, dustfall

Abstract: Objectives: Electricity generation from biomass has become a boom business. However, currently, concerns over their environmental and health impact have emerged. This study aimed to explore these health problems by studying two small biomass power plants in Thailand. Materials and Methods: Data concerning chronic diseases and health symptoms was collected from 392 people by trained interviewers by the use of a questionnaire. Results: Residents living within 1 km from the power plants had a higher prevalence of allergies (Odds ratio = 2.4, 95% CI: 1.5–4.0), asthma (OR = 2.1, 95% CI: 1.0–4.4) and chronic obstructive pulmonary disease (COPD) (OR = 2.7, 95% CI: 1.0–8.4). The risks of other symptoms, itching/rash, eye irritation, cough, stuffy nose, allergic symptoms, sore throat, and difficulty breathing among those living within 0.5 km from the power plants (OR = 2.5–8.5) were even more marked. Conclusions: It has been concluded that with-out a proper control, pollution from the biomass power plants can cause significant health problems to the nearby residents.

Strengths and Limitations:

Strengths: One of the few epidemiology studies assessing health effects associated with living near a biomass power plant. Raw data, confidence intervals, and p-values reported.
Limitations: No information collected on potential confounders (age, gender, occupation, socioeconomic factors). Weak exposure and outcome assessments. No discussion of blinding. Subjects may not be a random sample of population. Response rates not given.

Study Score and Ranking:

0.42; Low

Ortega Jacome GP, Koifman RJ, Rego Monteiro GT, Koifman S. 2010. Environmental exposure and breast cancer among young women in Rio de Janeiro, Brazil. Journal of Toxicology and Environmental Health A 73(13-14): 858-865.

Funding Agency: Brazilian National Research Council (CNPq), Fogarty International Center, State of Rio de Janeiro Research Council (FAPERJ)

Study Location: Brazil	**Study Design:** Case-series/case-control
Fuel Type: N/A	**Chemicals:** N/A

Abstract: Increasing breast cancer rates among young women (<40 years old) have been reported by the population-based cancer registries in Brazil. A case series study was carried out in Rio de Janeiro aiming to obtain epidemiological information allowing the generation of hypotheses to be further evaluated in analytical studies. One hundred and ten women 20-35 years old diagnosed with breast cancer were interviewed to determine the role environment plays in patients cased upon residential location. A comprehensive questionnaire including personal information (medical and lifestyle antecedents, reproductive history, family history of cancer, chemical and radiation exposure) was employed, and the obtained data were further compared with data provided by controls (women without cancer). An unconditional logistic regression was further employed to ascertain the respective odds ratios (OR) and their 95% confidence intervals (CI). Seventy-one percent of cancer cases were sporadic breast cancer, and familial aggregation (first degree relatives) was observed in just 3.5% (5.5% including second-degree relatives). Forty (51.3%) of the cancer cases were reported to have resided at a distance of less than 20 m from an electrical power transformer. Bivariate analysis revealed OR = 5.62 (95% CI 2.63-12) for residential use of pesticides during adulthood, OR = 2.15 (95% CI 1.22-3.77) for dental diagnostic x-rays, and OR= 1.53 (95% 0.77-3.04) for living nearby an electrical power transformer. Further multivariate analysis showed an adjusted OR = 3.5 (95% CI 1.11-11.0) for residential use of pesticides, and an adjusted OR = 2 (95% CI 1.24-3.23) for dental diagnostic x-rays during adulthood. The observed results highlight the importance of exploring the contribution of selected environmental agents possibly involved in breast carcinogenesis among young women.

Strengths and Limitations:

Strengths: Explored a variety of potential environmental exposures. Objective outcome measure.
Limitations: Hypothesis generating study. Relatively small sample size. Weak exposure assessment (reside near electrical power station). Low participation rate of cases (49%). Not known if interview blinded to case/control status.

Study Score and Ranking:

0.42; Low

Pala K, Turkkan A, Gercek H, Osman E, Aytekin H. 2012. Evaluation of respiratory functions of residents around the Orhaneli thermal power plant in Turkey. Asia-Pacific Journal of Public Health 24(1): 48-57.

Funding Agency: None	
Study Location: Turkey	**Study Design:** Cross-sectional
Fuel Type: Lignite	**Chemicals:** N/A

Abstract: The aim of this cross-sectional study was to evaluate the health and respiratory function of residents around the Orhaneli thermal power plant in Turkey. The study was conducted using face-to-face interviews, and respiratory functions were measured with a spirometer. The respiratory functions of 2350 residents, 15 years and older, living in communities near the coal-fired Orhaneli thermal power plant in Turkey were measured. The control group consisted of 469 persons from similar communities without a nearby power plant. The FEV1 (forced expiratory volume after 1 s) and FVC (forced vital capacity) values of the study participants were significantly lower than those of the control group, and residents directly downwind of the plant's smokestack showed greater impairment of respiratory functions compared with residents upwind.

Strengths and Limitations:

Strengths: Objective outcome measure (lung function). Lung function testing performed by trained technicians.
Limitations: Weak exposure assessment. No ambient pollutant data. Potential selection bias as subjects volunteered for the study at a local research centre. Investigators conducting interviews and lung function testing were likely not blinded to exposure status.

Study Score and Ranking:

0.50; Low

Pedeli X, Analitis A, Katsouyanni K. 2013. Air pollution effects from large power plants in northern Greece. In: Contaminated sites and health. Report of two WHO workshops: Syracuse, Italy, 18 November 2011; Catania, Italy, 21–22 June 2012. WHO Regional Office for Europe, Denmark. Available at http://apps.who.int/iris/bitstream/10665/108623/1/e96843.pdf?ua=1.

Funding Agency: Not stated	
Study Location: Greece	**Study Design:** Time-series
Fuel Type: Lignite	**Chemicals:** NO2, PM10

Abstract: *No abstract available.*

Excerpt from report:
[Eordaia is a municipality in the Kozani Peripheral Unit, located in the north-western part of Greece, with a population of 46 540 (2001 census) over an area of 708 km2. In the 1950s, the first power plant became operational, using as fuel the large local deposits of lignite. Today, five big power generation units are operational in Eordaia, comprising the largest power plant complex in Greece and providing about 70% of the country's electric power needs. Due to the use of lignite, this power plant complex is one of the largest polluters in Europe. Annually, 55 million tonnes of lignite are mined in the greater area and 108 kg of dust are emitted. We investigated the health effects of air pollutants (PM10 and NO2), emitted mainly by the power plants, on the population of the area.]

Strengths and Limitations:

Strengths: Examined mortality and pollution data over a 4-year period. Assessed cause-specific mortality. Assessed multiple lags (0-1 days).
Limitations: Very little data provided. No individual data. Weak exposure assessment. Some missing pollutant data. Small number of deaths/day; could not assess different age groups separately. Conference proceeding.

Study Score and Ranking:

0.42; Low

Rodriguez-Garcia JA, Ramos F. 2012. High incidence of acute leukemia in the proximity of some industrial facilities in El Bierzo, northwestern Spain. International Journal of Occupational Medicine and Environmental Health 25(1): 22-30.

Funding Agency: Junta de Castilla y León	
Study Location: Spain	**Study Design:** Case-series
Fuel Type: Coal, Petroleum derivatives	**Chemicals:** N/A

Abstract: Objectives: To estimate the incidence of acute leukemia (AL) in El Bierzo (BZ) and to carry out a cross-association analysis in order to suggest some etiological clues. Materials and Methods: We registered all new AL cases diagnosed 2000-2005. Annual standardized incidence rate (SIR) was calculated by the direct method. A cross-association analysis was performed by non-parametric methods and we checked the potential interaction between putative etiological factors by calculating Chi-square-for-trend. Results: SIR was 5.1 cases per 100 000, surpassing the Spanish, European and world average figures and heterogeneous throughout the region. We detected a negative correlation between acute myeloblastic leukemia (AML) SIR in every municipality and both the air distance to the nearest thermoelectric power plant (TPP) (Rho = -0.409; p = 0.01) and to the point of maximum density of the high-power lines (HPL) network (Rho = -0.329; p = 0.04). Accordingly, SIR was higher in the municipalities situated < 7.5 km away from TPP (9.58 vs. 1.72; p = 0.004) or < 10 km away from HPL (3.90 vs. 3.19; p = 0.045). A positive relation between both factors was observed (Chi-square-for-trend = 9.209; p = 0.006). Conclusions: SIR of AL in BZ is higher than the Spanish average and that of most countries in the world. Residing near TPP or HPL confers a higher risk of AML, with synergistic effect between both factors.

Strengths and Limitations:

Strengths: Data covered a 6-year period. Objective outcome measure.
Limitations: Small sample size. Weak exposure assessment (distance to power plant). No pollutant data. Results were compared to provincial, national and international incidence rates, however, no control group was used in the study.

Study Score and Ranking:

0.46; Low

3.5.2 Multiple pollutants - measured emissions (flue gas or ambient air)

White literature

Al-Jeelani HA. 2009. Air quality assessment at Al-Taneem area in the Holy Makkah City, Saudi Arabia. Environmental Monitoring and Assessment 156(1-4): 211-22.

Abstract: Air quality assessment of the emission from power plant and traffic at Al-Taneem area located at the northern part of the Holy City of Makkah, Saudi Arabia, is investigated. Concentration levels of different pollutants including nitrogen dioxide (NO2), sulfur dioxide (SO2), carbon monoxide (CO), ozone (O3), methane (CH4) and total hydrocarbons (THC) as well as some meteorological parameters (temperature, wind speed and wind direction) during the period from November 2002 to October 2003 were measured and analyzed. The results indicated that nitrogen oxides and carbon monoxide concentrations increase at the starting hours of the day. Sulphur dioxide concentrations were relatively low and constant. Ozone concentration trend showed the changes of the rate of the photochemical reactions. The distribution of the measured concentrations may be used for the development of numerical models and the estimation of air quality parameters in urban environment.

Ali M, Athar M. 2010. Dispersion modeling of noxious pollutants from thermal power plants. Turkish Journal of Engineering and Environmental Sciences 34(2): 105-20.

Abstract: Air dispersion modeling software was used to estimate the air quality impacts of 3 thermal power plants located in Pakistan. The real time emission measurements were carried out for a period of 6 months. The plume concentration for carbon monoxide, oxides of nitrogen, sulfur dioxide, and particulate matter were calculated with reasonable accuracy over long distances to estimate the incremental contribution of these power plants to local air quality. Although the annual average concentration increments from the limited number of power plants studied were relatively small, the long-range transport of emissions of power plants imposes potentially significant health and environmental impacts.

Ali M, Athar M, Khan MA, Niazi SB. 2011. Hazardous emissions from combustion of fossil fuel from thermal power plants based on turbine technologies. Human and Ecological Risk Assessment 17(1): 219-35.

Abstract: Thermal power generation is associated with the emission of hazardous gaseous and particulate pollutants, which is one of the major contributors to deteriorated local ambient air quality. A comprehensive emissions assessment was carried on three thermal power plants and one oil refinery operating on fossil fuel, mainly heavy residual oil. The background ambient air quality was also monitored for criteria pollutants around three thermal power plants and one oil refinery to assess the impact of plant emissions on ambient air quality. Emissions of the critical air pollutants carbon monoxide, carbon dioxide, oxides of nitrogen, sulphur dioxide, particulate matter, lead, and mercury were monitored from the stacks of each plant. The emissions from all the stacks of these plants were monitored for a period of 6 months. The emission concentrations were compared with the National Environmental Quality Standards (NEQS) of Pakistan and with World Bank (WB) guidelines for thermal power plants. The study found that the emissions of sulphur dioxide, oxides of nitrogen, and particulate matter were exceeding the permissible levels in power plants fueled by heavy residual fuel, whereas the power plants that were fueled by mixed fuel (natural gas and heavy residual oil) showed comparatively low emissions of pollutants.

Allen RW, Gombojav E, Barkhasragchaa B, Byambaa T, Lkhasuren O, Amram O, et al. 2013. An assessment of air pollution and its attributable mortality in Ulaanbaatar, Mongolia. Air Quality, Atmosphere, and Health 6(1): 137-150.

Abstract: Epidemiologic studies have consistently reported associations between outdoor fine particulate matter (PM2.5) air pollution and adverse health effects. Although Asia bears the majority of the public health burden from air pollution, few epidemiologic studies have been conducted outside of North America and Europe due in part to challenges in population exposure assessment. We assessed the feasibility of two current exposure assessment techniques, land use regression (LUR) modeling and mobile monitoring, and

estimated the mortality attributable to air pollution in Ulaanbaatar, Mongolia. We developed LUR models for predicting wintertime spatial patterns of NO2 and SO2 based on 2-week passive Ogawa measurements at 37 locations and freely available geographic predictors. The models explained 74% and 78% of the variance in NO2 and SO2, respectively. Land cover characteristics derived from satellite images were useful predictors of both pollutants. Mobile PM2.5 monitoring with an integrating nephelometer also showed promise, capturing substantial spatial variation in PM2.5 concentrations. The spatial patterns in SO2 and PM, seasonal and diurnal patterns in PM2.5, and high wintertime PM2.5/PM10 ratios were consistent with a major impact from coal and wood combustion in the city's low-income traditional housing (ger) areas. The annual average concentration of PM2.5 measured at a centrally located government monitoring site was 75 μg/m3 or more than seven times the World Health Organization's PM2.5 air quality guideline, driven by a wintertime average concentration of 148 μg/m3. PM2.5 concentrations measured in a traditional housing area were higher, with a wintertime mean PM2.5 concentration of 250 μg/m3. We conservatively estimated that 29% (95% CI, 12-43%) of cardiopulmonary deaths and 40% (95% CI, 17-56%) of lung cancer deaths in the city are attributable to outdoor air pollution. These deaths correspond to nearly 10% of the city's total mortality, with estimates ranging to more than 13% of mortality under less conservative model assumptions. LUR models and mobile monitoring can be successfully implemented in developing country cities, thus cost-effectively improving exposure assessment for epidemiology and risk assessment. Air pollution represents a major threat to public health in Ulaanbaatar, Mongolia, and reducing home heating emissions in traditional housing areas should be the primary focus of air pollution control efforts.

Athar M, Ali M, Khan MA. 2013. Dispersion modelling of toxic air pollutants from fossil fuel combustion facilities. International Journal of Environmental Engineering 5(1): 1-31.

Abstract: The emissions of toxic air pollutants from three power plants and one oil refinery were measured for a period of six months and dispersion of pollutants were calculated by using Air Dispersion Modelling Software (ADMS-4). The plume concentration of carbon monoxide, oxides of nitrogen, sulphur dioxide and particulate matter were calculated over long distances to estimate the incremental contribution of these fossil fuel combustion facilities to ambient air. Overall in four plants, the emissions of sulphur dioxide were most critical and 50% of the total exposure was predicted within 20 km distance and the rest of the exposure was observed up to 70 km distances in radii of each plant. Although the annual average concentration increments from a limited number of sources studied were relatively small, but the long-range transport of pollutants created potentially significant health and environmental impacts.

Athar M, Ali M, Khan MA. 2010. Gaseous and particulate emissions from thermal power plants operating on different technologies. Environmental Monitoring and Assessment 166(1-4): 625-39.

Abstract: This paper presents the assessment of gaseous and particulate emissions from thermal power plants operating on different combustion technologies. Four thermal power plants operating on heavy furnace oil were selected for the study, among which three were based on diesel engine technology, while the fourth plant was based on oil-fired steam turbine technology. The stack emissions were monitored for critical air pollutants carbon monoxide, carbon dioxide, oxides of nitrogen, sulfur dioxide, particulate matter, lead, and mercury. The pollutant emissions were measured at optimum load conditions for a period of 6 months with an interval of 1 month. The results of stack emissions were compared with National Environmental Quality Standards of Pakistan and World Bank guidelines for thermal power plants, and few parameters were found higher than the permissible limits of emissions. It was observed that the emissions carbon monoxide, oxides of nitrogen, and particulate matters from diesel engine-based power plants were comparatively higher than the turbine-based power plants. The emissions of sulfur dioxide were high in all the plants, even the plants with different technologies, which was mainly due to high sulfur contents in fuel.

Bhatnagar MKa, Bhatnagar Pb. 2013. Air quality assessment of the surrounding area of a thermal power plant. Journal of Industrial Pollution Control 29(1): 45-8.

Abstract: Energy is linked to the environment so that its production and its use can causes environmental damage. Fossil fuels are put through a burning process called combustion in order to produce energy. Combustion causes the release of various pollutants, such as Carbon monoxide, Sulfur dioxide, NOx and

particulate matters, which pose health risk and may contribute to acid rain and global warming. Keeping these facts in view present work deals with air pollution due to thermal power plant situated at Birsinghpur District Umaria (M.P.). For this purpose Ambient air Quality monitoring and stack monitoring have been done.

Biswas KF, Ghauri BM, Husain L. 2008. Gaseous and aerosol pollutants during fog and clear episodes in South Asian urban atmosphere. Atmospheric Environment 42: 7775-85.

Abstract: We report the first measurements of acidic gases and ammonia (NH3) during fog and clear episodes in Lahore, a highly polluted mega-city of South Asia, along with concentrations of PM2.5 (particles of <2.5 μm aerodynamic diameter) and ions. An annular denuder system was used to measure acidic gases, NH3, and PM2.5 from December 2005 to February 2006 in Lahore, a mega-city in Pakistan. The denuders yielded average concentrations (μg m−3) as follows: ammonia, 50; nitrous acid, 19.6; sulfur dioxide, 19.4; hydrochloric acid, 1.16; nitric acid, 1.00; and oxalic acid, 0.6. The filters yielded average concentrations (μg m−3): PM2.5, 209; sulfate, 19.2; nitrate, 18.9; chloride, 7.43; oxalate, 0.97; ammonium, 16.1; potassium, 3.49; calcium, 0.89; sodium, 0.76; and magnesium, 0.08. Emissions from local sources, e.g., fossil fuel consumption by motorized transport and power plants, farming, burning of agricultural residues, industrial and construction activities contributed the major proportion of pollutants in Lahore. Concentrations of ionic species, e.g., NO3−, SO42−, Na+, NH4+, Mg2+, and Ca2+, and gaseous species, e.g., HCl, HNO3, SO2 and (COOH)2 showed a distinct diurnal variation. Mixing heights and photochemistry played major roles in defining the diurnal pattern. Fog appeared to profoundly enhance the oxidation of sulfur dioxide. High moisture content of fog resulted in uptake of the gases in fog droplets.

Brewer P, Moore T. 2009. Source contributions to visibility impairment in the southeastern and western United States. Journal of the Air and Waste Management Association 59(9): 1070-81.

Abstract: The 1999 Regional Haze Rule requires states to complete comprehensive technical analyses of air pollutants that impair visibility and to define long-term strategies to improve visibility in the nation's 156 visibility-protected federal Class I national parks and wilderness areas. Class I areas in the southeastern United States are among the most impacted in the country; fine particle loadings in the western United States are a fraction of those in the East. In the Southeast, (NH4)2SO4 (ammonium sulfate) predominantly from SO2 (sulfur dioxide) emissions from electric generating utilities and industrial sources contributes 60-70% of the light extinction on the 20% haziest days; particulate organic matter (POM) predominantly from biogenic emissions and biomass burning is the second largest contributor. In the West, the mix of source contributions is more complex. At Class I areas downwind of major urban areas (e.g., California), ammonium nitrate (NH4NO3), predominantly because of mobile sources, is the dominant contributor to haze. For many western Class L areas, POM from wildland fires and fine particles from windblown dust, largely uncontrollable sources, are significant contributors to haze. International emissions are an additional uncontrollable and significant contribution to total sulfate (SO4) and nitrate (NO3) concentrations at the western Class I areas. In the Southeast, SO2 emissions reductions are projected to result in nearly 1:1 regional SO4 reductions; oxides of nitrogen (NOx) emissions reductions have minimal impact on NO3 concentrations and haze. In the West, SO2 emissions reductions result in incremental SO4 reductions, whereas mobile NOx emissions reductions are projected to reduce NO3 and improve visibility at Class I areas affected by urban areas. Because wildfire, dust, and international emissions have large contributions to the haziest days and are mostly uncontrollable in the West, reductions from anthropogenic sources in the West have less effect in improving visibility compared with the Southeast.

Brown SS, Dubé WP, Peischl J, Ryerson TB, Atlas E, Warneke C, et al. 2011. Budgets for nocturnal VOC oxidation by nitrate radicals aloft during the 2006 Texas Air Quality Study. Journal of Geophysical Research 116, D24305.

Abstract: Industrial emissions in Houston, Texas, and along the U.S. Gulf Coast are a large source of highly reactive anthropogenic volatile organic compounds (VOCs), principally alkenes, that affect air quality in that region. Nighttime oxidation by either O3 or NO3 removes these VOCs. This paper presents a regional analysis of nighttime P-3 flights during the 2006 Texas Air Quality Study (TexAQS) to quantify the loss rates and budgets for both NO3 and highly reactive VOC. Mixing ratios and production rates of NO3 were large,

up to 400 parts per trillion by volume (pptv) and 1–2 parts per billion by volume (ppbv) per hour, respectively. Budgets for NO3 show that it was lost primarily to reaction with VOCs, with the sum of anthropogenic VOCs (30–54%) and isoprene (10–50%) being the largest contributors. Indirect loss of NO3 to N2O5 hydrolysis was of lesser importance (14–28%) but was the least certain due to uncertainty in the aerosol uptake coefficient for N2O5. Reaction of NO3 with peroxy radicals was a small but nonzero contribution to NO3 loss but was also uncertain because there were no direct measurements of peroxy radicals. Net VOC oxidation rates were rapid (up to 2 ppbv VOC h−1 in industrial plumes) and were dominated by NO3, which was 3–5 times more important as an oxidant than O3. Plumes of high NO3 reactivity (i.e., short steady state lifetimes, on the order of 1 min) identified the presence of concentrated emissions of highly reactive VOCs from the Houston Ship Channel (HSC), which, depending on the particular VOC, may be efficiently oxidized during overnight transport.

Chakraborty N, Mukheriee I, Santra AK, Chowdhury S, Chakraborty S, Bhattacharya S et al. 2008. Measurement of CO2, CO, SO2, and NO emissions from coal-based thermal power plants in India. Atmospheric Environment 42: 1073-82.

Abstract: Measurements of CO2 (direct GHG) and CO, SO2, NO (indirect GHGs) were conducted on-line at some of the coal-based thermal power plants in India. The objective of the study was three-fold: to quantify the measured emissions in terms of emission coefficient per kg of coal and per kWh of electricity, to calculate the total possible emission from Indian thermal power plants, and subsequently to compare them with some previous studies. Instrument IMR 2800P Flue Gas Analyzer was used on-line to measure the emission rates of CO2, CO, SO2, and NO at 11 numbers of generating units of different ratings. Certain quality assurance (QA) and quality control (QC) techniques were also adopted to gather the data so as to avoid any ambiguity in subsequent data interpretation. For the betterment of data interpretation, the requisite statistical parameters (standard deviation and arithmetic mean) for the measured emissions have been also calculated. The emission coefficients determined for CO2, CO, SO2, and NO have been compared with their corresponding values as obtained in the studies conducted by other groups. The total emissions of CO2, CO, SO2, and NO calculated on the basis of the emission coefficients for the year 2003-2004 have been found to be 465.667, 1.583, 4.058, and 1.129 Tg, respectively.

Cretu M, Teleaba V, Ionescu S, Ionescu A. 2010. Pollution scenarios through atmospheric dispersion modelling based on real measurements - impact on human health. WSEAS Transactions on Environment and Development 6(8): 604-13.

Abstract: Considering the fact that the exposure to ambient air pollution has been associated with a series of adverse health effects, it is important to predict the industrial air pollution in the populated areas. An easy and an inexpensive estimation can be performed through atmospheric dispersion modelling. This paper present a case study carry out at two pollution sources located near to an airport. Measurements at source and in the atmosphere were performed. The dispersion estimation was realized on specialized software using for input measured data for emission and meteorological data. The paper presents a short overview regarding adverse effects of different air pollutants (NOx, CO, SO2, THC, PM and O3) on human health, which have been well studied worldwide. The work performed in this article aims to quantify the contribution of various pollution sources (incinerator and thermal power station), to the local air pollution from an airport area. In order to evaluate when the functioning of the sources will be considered dangerous for populations we elaborate the worst scenario regarding the CO, NOx, SO2, which can be applied by the authorities from both pollution sources. At the end of the paper conclusions and future plans will be presented.

Cureño GI, Bravo AH, Sosa ER. 2012. The importance of the generation of emission factors for developing countries: Case of Mexico. Journal of Environmental Science and Engineering: A 1(4A): 495-502.

Abstract: Developing countries as Mexico lack their own emission factors for thermoelectric power plants, so they have the need to develop them, considering specific operation conditions for each plant. This study develops specific emission factors in Mexico for: sulfur dioxide (SO2), nitrogen oxides (NOx) and particles, for thermoelectric power plants that use fuel oil. This work was necessary due to the differences found

between the measured and the calculated emissions, using emission factors of different agencies, such as, US-EPA (Environmental Protection Agency of the United States), IPCC (Intergovernmental Panel on Climate Change), and UK-NAEI (National Atmospheric Emissions Inventory of the United Kingdom). The new emission factors were used to calculate the emissions of a thermoelectric power plant in Mexico. The comparisons between the measured and the calculated emissions (with the new emission factors) for SO2, particles and NOx were not significantly different ($p > 0.05$).

De S, Bajpai A, Mishra DD, Bharti J. 2010. Air quality assessment in Sarni, Dist. Betul (M.P.) with special reference to thermal power station (TPS) and mining activities. Pollution Research 29: 141-4.

Abstract: Urban air pollution is worsening due to upward trends in power consumption, industrialization, vehicle use and scores of other development activities taken up by human beings. There are five major harmful substances, i.e. carbon monoxide, hydrocarbons, particulates, sulphur dioxide and nitrogen compounds released into the atmosphere in sufficient quantities as a result of natural events or by human activities. The quality of air with respect to SPM, SO2 & NOx around thermal power station in Sarni, district-Betul, M. P. has been assessed. Air quality deterioration due to large-scale coal mining, transportation and small scale utilization in the coal belt area of M.P. near 'Sarni' has become matter of concern like any other industrial area in India. India is world's third largest coal-producing country. Hence, it is necessary to assess the air quality of the study area using air quality data. The air quality survey was carried out covering three seasons, i.e. summer, monsoon and post-monsoon during the year 2006. Results indicate that, ambient air quality levels are within permissible limits.

DeCarlo PF, Dunlea EJ, Kimmel JR, Aiken AC, Sueper D, Crounse J et al. 2008. Fast airborne aerosol size and chemistry measurements above Mexico City and Central Mexico during the MILAGRO campaign. Atmospheric Chemistry and Physics 8(14): 4027-48.

Abstract: The concentration, size, and composition of non-refractory submicron aerosol (NR-PM1) was measured over Mexico City and central Mexico with a High-Resolution Time-of-Flight Aerosol Mass Spectrometer (HR-ToF-AMS) onboard the NSF/NCAR C-130 aircraft as part of the MILAGRO field campaign. This was the first aircraft deployment of the HR-ToF-AMS. During the campaign the instrument performed very well, and provided 12 s data. The aerosol mass from the AMS correlates strongly with other aerosol measurements on board the aircraft. Organic aerosol (OA) species dominate the NR-PM1 mass. OA correlates strongly with CO and HCN indicating that pollution (mostly secondary OA, SOA) and biomass burning (BB) are the main OA sources. The OA to CO ratio indicates a typical value for aged air of around 80 mu g m(-3) (STP) ppm(-1). This is within the range observed in outflow from the Northeastern US, which could be due to a compensating effect between higher BB but lower biogenic VOC emissions during this study. The O/C atomic ratio for OA is calculated from the HR mass spectra and shows a clear increase with photochemical age, as SOA forms rapidly and quickly overwhelms primary urban OA, consistent with Volkamer et al. (2006) and Kleinman et al. (2008). The stability of the OA/CO while O/C increases with photochemical age implies a net loss of carbon from the OA. BB OA is marked by signals at m/z 60 and 73, and also by a signal enhancement at large m/z indicative of larger molecules or more resistance to fragmentation. The main inorganic components show different spatial patterns and size distributions. Sulfate is regional in nature with clear volcanic and petrochemical/power plant sources, while the urban area is not a major regional source for this species. Nitrate is enhanced significantly in the urban area and immediate outflow, and is strongly correlated with CO indicating a strong urban source. The importance of nitrate decreases with distance from the city likely due to evaporation. BB does not appear to be a strong source of nitrate despite its high emissions of nitrogen oxides, presumably due to low ammonia emissions. NR-chloride often correlates with HCN indicating a fire source, although other sources likely contribute as well. This is the first aircraft study of the regional evolution of aerosol chemistry from a tropical megacity.

Ghodke S, Kumar R, Singh N, Khandelwal H. 2012. Estimation of green house gas emission from Indian coal based thermal power plant. IOSR Journal of Engineering 2(4): 591-7.

Abstract: Measurements of CO2 (direct GHG) and CO, SO2, NO (indirect GHGs) were conducted on-line at some of the coal-based thermal power plant in India. The objective of the study having three major

objectives: to quantify the measured emissions in terms of emission coefficient per kg of coal and per kWh of electricity, to calculate the total possible emission from Indian thermal power plant, and subsequently to compare them with some previous studies. Instrument IMR 2800A Flue Gas Analyzer was used on-line to measure the emission rates of CO2, CO, SO2, and NO at 08 numbers of generating units of different ratings. Certain quality assurance (QA) and quality control (QC) techniques were also adopted to gather the data so as to avoid any ambiguity in subsequent data interpretation. For the betterment of data interpretation, the requisite statistical parameters (standard deviation and arithmetic mean) for the measured emissions have been also calculated. The emission coefficients determined for CO2, CO, SO2, and NO have been compared with their corresponding values as obtained in the studies conducted by other groups. The total emissions of CO2, CO, SO2, and NO calculated on the basis of the emission coefficients find have been found to be 511.944, 2.0576, 4.473, 1.241 Tg respectively.

Harrington W, Morgenstern R, Shih J, Bell ML. 2012. Did the Clean Air Act Amendments of 1990 really improve air quality? Air Quality, Atmosphere and Health 5(4): 353-67.

Abstract: The degree to which federal policies, such as the Clean Air Act (CAA), actually improve air quality is not fully understood. We investigate what portion of reductions in ambient fine particulate matter (PM2.5) that occurred 1999-2005 can be attributed to sulfur dioxide (SO2) and nitrogen oxide (NOx) emissions reductions from implementation of title IV, phase 2, of the 1990 CAA Amendments. A detailed statistical model links sources and receptors over time and space to estimate the relationship between changes in emissions and observed improvements in air quality. We employ relatively transparent statistical methods incorporating uncertainty bounds to complement point estimates of the complex physico-chemical fate and transport models commonly used to estimate source-receptor relationships associated with long-range emissions transport. Monitor-specific estimates of changes in PM2.5 from changes in emissions from individual power plants are highly significant and mostly of the expected relative magnitudes for distance and direction from sources; and the model performs well on out-of-sample forecasts. Although we observe substantial model uncertainty, using our preferred specification, we estimate that the title IV, phase II emissions reduction policy implemented 1999-2005 reduced PM2.5 in the eastern USA by an average of 1.07 μg/m3, roughly 8 % (standard deviation, 0.11 μg/m3) versus a counterfactual of no change in emission rates per unit of energy input. On a population-weighted basis, the comparable reduction in PM2.5 is 0.89 μg/m3, roughly 6 %. This model presents a practical tool that can be used for policy analysis of air quality.

Hayden KL, Sills DML, Brook JR, Li SM, Makar PA, Markovic MZ, et al. 2011. Aircraft study of the impact of lake-breeze circulations on trace gases and particles during BAQS-Met 2007. Atmospheric Chemistry and Physics 11: 10173-92.

Abstract: High time-resolved aircraft data, concurrent surface measurements and air quality model simulations were explored to diagnose the processes influencing aerosol chemistry under the influence of lake-breeze circulations in a polluted region of southwestern Ontario, Canada. The analysis was based upon horizontal aircraft transects conducted at multiple altitudes across an entire lake-breeze circulation. Air mass boundaries due to lake-breeze fronts were identified in the aircraft meteorological and chemical data, which were consistent with the frontal locations determined from surface analyses. Observations and modelling support the interpretation of a lake-breeze circulation where pollutants were lofted at a lake-breeze front, transported in the synoptic flow, caught in a downdraft over the lake, and then confined by onshore flow. The detailed analysis led to the development of conceptual models that summarize the complex 3-D circulation patterns and their interaction with the synoptic flow. The identified air mass boundaries, the interpretation of the lake-breeze circulation, and the air parcel circulation time in the lake-breeze circulation (3.0 to 5.0 h) enabled formation rates of organic aerosol (OA/ΔCO) and SO42− to be determined. The formation rate for OA (relative to excess CO in ppmv) was found to be 11.6–19.4 μg m−3 ppmv−1 h−1 and the SO42− formation rate was 5.0–8.8% h−1. The formation rates are enhanced relative to regional background rates implying that lake-breeze circulations are an important dynamic in the formation of SO42− and secondary organic aerosol. The presence of cumulus clouds associated with the lake-breeze fronts suggests that these enhancements could be due to cloud processes. Additionally, the effective confinement of pollutants along the shoreline may have limited pollutant dilution leading to elevated oxidant concentrations.

Hays MD, Beck L, Barfield P, Willis RD, Landis MS, Stevens RK et al. 2009. Physical and chemical characterization of residual oil-fired power plant emissions. Energy and Fuels 23(5): 2544-51.

Abstract: Although the toxicity of oil combustion emissions is a significant public health concern, few studies characterize the emissions from plant-scale utility boilers firing residual oil. This study remedies that deficiency by diluting, sampling, and monitoring stack emissions from a 432 gigajoules (GJ) front-fired fossil fuel steam generator burning residual oil. Over a 3-day test period, continuous CO2, SO2, and NOx emissions monitoring confirms a steady fuel feed rate, high combustion efficiency (3.4 kg of CO2/kg of fuel oil burned), and evidence of a nocturnal soot-blowing event. The utility boiler emits fine aerosol (PM 2.5) at a rate of 53 ± 2 μg/kJ (2 g/kg of oil burned). Vesicular coarse particles composed of C and S and spherical Al silicates with V and Ni inclusions are identified in a cyclone rinse using scanning electron microscopy and backscatter analysis. Ion chromatography results establish that the fine aerosol is predominantly sulfate (44% ± 0.2%, w/w) which is likely coordinated to transition metals. From thermal optical transmittance measurements, less than 1% (w/w) of the fine aerosol is surmised to be carbonaceous. Low emissions of particle-phase carbon and contaminants interfered with the gas chromatography - mass spectrometry (GC-MS) analysis of polcyclic aromatic hydrocarbons and certain other semivolatile organic compounds. However, trace levels of branched-, cyclic-, and w-alkanes and organic acids are observed in the particle emissions. Sterane and hopane molecules are below the picogram level GC-MS detection limits. Future research determining the individual organic species in the particles emitted from this source will require real-time single particle measurements. Finally, application of EPA methods TO-11 and TO-15 shows that the total volatile nonmethane organic gas emissions from the plant-scale boiler vary between 6 and 28 mg/kg of fuel oil burned; greater than 50% of this mass is ascribed to oxygenated matter.

He H, Stehr JW, Hains JC, Krask DJ, Doddridge BG, Vinnikov KY et al. 2013. Trends in emissions and concentrations of air pollutants in the lower troposphere in the Baltimore/Washington airshed from 1997 to 2011. Atmospheric Chemistry and Physics 13: 7859-74.

Abstract: Trends in the composition of the lower atmosphere (0–1500 m altitude) and surface air quality over the Baltimore/Washington area and surrounding states were investigated for the period from 1997 to 2011. We examined emissions of ozone precursors from monitors and inventories as well as ambient ground-level and aircraft measurements to characterize trends in air pollution. The US EPA Continuous Emissions Monitoring System (CEMS) program reported substantial decreases in emission of summertime nitrogen oxides (NOx) from power plants, up to ~80% in the mid-Atlantic States. These large reductions in emission of NOx are reflected in a sharp decrease of ground-level concentrations of NOx starting around 2003. The decreasing trend of tropospheric column CO observed by aircraft is ~0.8 Dobson unit (DU) per year, corresponding to ~35 ppbv yr−1 in the lower troposphere (the surface to 1500 m above ground level). Satellite observations of long-term, near-surface CO show a ~40% decrease over western Maryland between 2000 and 2011; the same magnitude is indicated by aircraft measurements above these regions upwind of the Baltimore/Washington airshed. With decreasing emissions of ozone precursors, the ground-level ozone in the Baltimore/ Washington area shows a 0.6 ppbv yr−1 decrease in the past 15 yr. Since photochemical production of ozone is substantially influenced by ambient temperature, we introduce the climate penalty factor (CPF) into the trend analysis of long-term aircraft measurements. After compensating for inter-annual variations in temperature, historical aircraft measurements indicate that the daily net production of tropospheric ozone over the Baltimore/Washington area decreased from ~20 ppbv day−1 in the late 1990s to ~7 ppbv day−1 in the early 2010s during ozone season. A decrease in the long-term column ozone is observed as ~0.2 DU yr−1 in the lowest 1500 m, corresponding to an improvement of ~1.3 ppbv yr−1. Our aircraft measurements were conducted on days when severe ozone pollution was forecasted, and these results represent the decreasing trend in high ozone events over the past 15 yr. Back trajectory cluster analysis demonstrates that emissions of air pollutants from Ohio and Pennsylvania through Maryland influence the column abundances of downwind ozone in the lower atmosphere. The trends in air pollutants reveal the success of regulations implemented over the past decades and the importance of region-wide emission controls in the eastern United States.

Huang K, Zhuang G, Lin Y, Wang Q, Fu JS, Zhang R et al. 2012. Impact of anthropogenic emission on air quality over a megacity – revealed from an intensive atmospheric campaign during the Chinese Spring Festival. Atmospheric Chemistry and Physics 12: 11631-45.

Abstract: The Chinese Spring Festival is one of the most important traditional festivals in China. The peak transport in the Spring Festival season (spring travel rush) provides a unique opportunity for investigating the impact of human activity on air quality in the Chinese megacities. Emission sources are varied and fluctuate greatly before, during and after the Festival. Increased vehicular emissions during the "spring travel rush" before the 2009 Festival resulted in high level pollutants of NOx (270 μg m−3), CO (2572 μg m−3), black carbon (BC) (8.5 μg m−3) and extremely low single scattering albedo of 0.76 in Shanghai, indicating strong, fresh combustion. Organics contributed most to PM2.5, followed by NO3−, NH4+, and SO42−. During the Chinese Lunar New Year's Eve and Day, widespread usage of fireworks caused heavy pollution of extremely high aerosol concentration, scattering coefficient, SO2, and NOx. Due to the "spring travel rush" after the festival, anthropogenic emissions gradually climbed and mirrored corresponding increases in the aerosol components and gaseous pollutants. Secondary inorganic aerosol (SO42−, NO3−, and NH4+) accounted for a dominant fraction of 74% in PM2.5 due to an increase in human activity. There was a greater demand for energy as vast numbers of people using public transportation or driving their own vehicles returned home after the Festival. Factories and constructions sites were operating again.
The potential source contribution function (PSCF) analysis illustrated the possible source areas for air pollutants of Shanghai. The effects of regional and long-range transport were both revealed. Five major sources, i.e. natural sources, vehicular emissions, burning of fireworks, industrial and metallurgical emissions, and coal burning were identified using the principle component analysis. The average visibility during the whole study period was less than 6 km. It had been estimated that 50% of the total light extinction was due to the high water vapor in the atmosphere. This study demonstrates that organic aerosol was the largest contributor to aerosol extinction at 47%, followed by sulfate ammonium, nitrate ammonium, and EC at 22%, 14%, and 12%, respectively. Our results indicated the dominant role of traffic-related aerosol species (i.e. organic aerosol, nitrate and EC) on the formation of air pollution, and suggested the importance of controlling vehicle numbers and emissions in mega-cities of China as its population and economy continue to grow.

Jaffe DA, Reidmiller DR. 2009. Now you see it, now you don't: Impact of temporary closures of a coal-fired power plant on air quality in the Columbia River Gorge National Scenic Area. Atmospheric Chemistry and Physics 9: 7997-8005.

Abstract: The goal of this study is to identify major point sources that contribute to elevated particulate matter in the Columbia River Gorge, USA and to quantify their contribution. To answer this question we analyzed 14 years of aerosol data spanning 1993-2006 from the IMPROVE site at Wishram, Washington (45.66 degrees N, 121.00 degrees W; 178 ma.s.l.) in the Columbia River Gorge (CRG) National Scenic Area of the Pacific Northwest of the USA. Two types of analyses were conducted. First, we examined the transport for days with the highest fine mass (PM2.5) concentrations using HYSPLIT backtrajectories. We found that the highest PM2.5 concentrations occurred during autumn and were associated with easterly flow, down the CRG. Such flow transports emissions from a large coal power plant in Boardman, Oregon and a large agricultural facility into the CRG. This transport was found on 20 out of the 50 worst PM2.5 days and resulted in an average daily concentration of 20.1 μg/m3, compared with an average of 18.8 μg/m3 for the 50 highest days and 5.9 μg/m3 for all days. These air masses contain not only high PM2.5 concentrations, but also elevated levels of aerosol NO3-. In the second analysis, we examined PM2.5 concentrations in the CRG during periods when the Boardman power plant was shut down due to repairs and compared these values with concentrations when the facility was operating at near full capacity. We also examined this relationship on the days when backtrajectories suggested the greatest influence from the power plant on air quality in the CRG. From this analysis, we found significantly higher PM2.5 concentrations when the power plant was operating at or near full capacity. We use these data to calculate that the contribution to PM2.5 mass in the CRG from the Boardman power plant was 0.90 μg/m3 averaged over the entire year, 3.94 μg/m3 if only the month of November is considered and 7.40 μg/m3 if only November days when the airflow is "down-gorge" (from east to west). This represents 14, 46 and 56% of the PM2.5 mass in the CRG for the full year, November only and November days with "down-gorge" transport, respectively.

Kim SW, McKeen SA, Frost GJ, Lee SH, Trainer M, Richter A et al. 2011. Evaluations of NOx and highly reactive VOC emission inventories in Texas and their implications for ozone plume simulations during the Texas Air Quality Study 2006. Atmospheric Chemistry and Physics 11: 11361-86.

Abstract: Satellite and aircraft observations made during the 2006 Texas Air Quality Study (TexAQS) detected strong urban, industrial and power plant plumes in Texas. We simulated these plumes using the Weather Research and Forecasting-Chemistry (WRF-Chem) model with input from the US EPA's 2005 National Emission Inventory (NEI-2005), in order to evaluate emissions of nitrogen oxides (NOx = NO + NO2) and volatile organic compounds (VOCs) in the cities of Houston and Dallas-Fort Worth. We compared the model results with satellite retrievals of tropospheric nitrogen dioxide (NO2) columns and airborne in-situ observations of several trace gases including NOx and a number of VOCs. The model and satellite NO2 columns agree well for regions with large power plants and for urban areas that are dominated by mobile sources, such as Dallas. However, in Houston, where significant mobile, industrial, and in-port marine vessel sources contribute to NOx emissions, the model NO2 columns are approximately 50%–70% higher than the satellite columns. Similar conclusions are drawn from comparisons of the model results with the TexAQS 2006 aircraft observations in Dallas and Houston. For Dallas plumes, the model-simulated NO2 showed good agreement with the aircraft observations. In contrast, the model-simulated NO2 is ~60% higher than the aircraft observations in the Houston plumes. Further analysis indicates that the NEI-2005 NOx emissions over the Houston Ship Channel area are overestimated while the urban Houston NOx emissions are reasonably represented. The comparisons of model and aircraft observations confirm that highly reactive VOC emissions originating from industrial sources in Houston are underestimated in NEI-2005. The update of VOC emissions based on Solar Occultation Flux measurements during the field campaign leads to improved model simulations of ethylene, propylene, and formaldehyde. Reducing NOx emissions in the Houston Ship Channel and increasing highly reactive VOC emissions from the point sources in Houston improve the model's capability of simulating ozone (O3) plumes observed by the NOAA WP-3D aircraft, although the deficiencies in the model O3 simulations indicate that many challenges remain for a full understanding of the O3 formation mechanisms in Houston.

Li W, Zhou S, Wang X, Xu Z, Yuan C, Yu Y et al. 2011. Integrated evaluation of aerosols from regional brown hazes over northern China in winter: Concentrations, sources, transformation, and mixing states. Journal of Geophysical Research-Atmospheres 116, D9.

Abstract: To evaluate the wintertime regional brown haze in northern China, trace gases and aerosols were measured at an urban site between 9 and 20 November 2009. Ion chromatography and transmission electron microscopy (TEM) were used to investigate soluble ions in PM2.5 and the mixing state of individual particles. The contrasts between clear and hazy days were examined in detail. Concentrations of the primary gases including NO (55.62 ppbv), NO2 (54.86 ppbv), SO2 (83.03 ppbv), and CO (2.07 ppmv) on hazy days were 2 to 6 times higher than those on clear days. In contrast, concentrations of O-3 remained low (5.71 ppbv) on hazy days. Mass concentrations of PM2.5 (135.90 mu g m(-3)) and BC (7.85 mu g m(-3)) were 3 times higher on hazy days than on clear days. Based on the estimations from TEM analysis, fractions of both ammoniated sulfate (AS)-soot (20%) and AS-soot/organic matter/fly ash (20%) were larger on hazy days than on clear days (13% and 12%), implying that coagulation is an important mixing process in the polluted air. The SO2 emissions from coal combustion for power plants, industrial activities, and household heating led to high concentrations. Also, high concentrations of secondary sulfates significantly formed in the haze. Therefore, high concentrations of acidic gases contributed to the increased mass and number of secondary aerosols. Our study indicates that metal-catalyzed oxidation in the aqueous phase is a major pathway of sulfate formation. The mixtures of aerosol particles, together with MODIS images, suggest that the hazes covered not only the industrial cities, but extended into the neighboring rural regions.

Lin Y, Huang K, Zhuang G, Fu JS, Xu C, Shen J et al. 2013. Air Quality over the Yangtze River Delta during the 2010 Shanghai Expo. Aerosol and Air Quality Research 13(6): 1655-66.

Abstract: An air quality monitoring network consisting of 53 stations at 9 cities over the Yangtze River Delta (YRD) simultaneously measured gaseous and particulate pollutants (SO2, NO2, CO, O3, PM2.5 and PM10) during the six-month Shanghai World Expo in 2010. The regional distribution of air pollutants showed that Shanghai was a low-SO2-PM10 zone over the YRD during the Expo, owing to the effective controls that were applied to power plants, industrial activities and construction works. However, Shanghai also became a high-NOx-CO-O3 zone in the YRD, partly due to the large number of vehicles in Shanghai, and also the expected increase in transportation emissions due to the tremendous number of visitors during the Expo. Monthly variations in the major pollutants generally presented similar patterns, with lower values in the middle of the Expo, i.e., from July to September, and higher values in May, June and October. The magnitudes of pollutant precursor (SO2 and NO2) concentrations and meteorological conditions (e.g., wind speed, directional wind from X vector, and mixing layer height) were investigated, and found to play important roles in the monthly variations. Spatial correlations of air pollutants between Shanghai and the other 8 cities revealed the impact of regional transport on air quality in Shanghai, and vice versa. Intense air pollution episodes in Shanghai were mainly related to the regional/long-range transport from inland polluted regions. The high frequency of marine winds during the Expo had a positive effect on the air quality of coastal cities, while it had a negative effect on some inland cities in the YRD.

Lioy PJ, Fan Z, Zhang J, Georgopoulos P, Wang SW, Ohman-Strickland P et al. 2011. Personal and ambient exposures to air toxics in Camden, New Jersey. Research Report Health Effects Institute 160: 3,127; discussion 129-51.

Abstract: Personal exposures and ambient concentrations of air toxics were characterized in a pollution "hot spot" and an urban reference site, both in Camden, New Jersey. The hot spot was the city's Waterfront South neighborhood; the reference site was a neighborhood, about 1 km to the east, around the intersection of Copewood and Davis streets. Using personal exposure measurements, residential ambient air measurements, statistical analyses, and exposure modeling, we examined the impact of local industrial and mobile pollution sources, particularly diesel trucks, on personal exposures and ambient concentrations in the two neighborhoods. Presented in the report are details of our study design, sample and data collection methods, data- and model-analysis approaches, and results and key findings of the study. In summary, 107 participants were recruited from nonsmoking households, including 54 from Waterfront South and 53 from the Copewood-Davis area. Personal air samples were collected for 24 hr and measured for 32 target compounds--11 volatile organic compounds (VOCs*), four aldehydes, 16 polycyclic aromatic hydrocarbons (PAHs), and particulate matter (PM) with an aerodynamic diameter 0.6) was found between benzene and MTBE in both locations. These results suggest that automobile exhausts were the main contributors to benzene and MTBE air pollution in both neighborhoods. Formaldehyde and acetaldehyde concentrations were found to be high in both neighborhoods. Mean (+/- SD) concentrations of formaldehyde were 20.2 +/- 19.5 μg/m3 in Waterfront South and 24.8 +/- 20.8 μg/m3 in Copewood-Davis. A similar trend was observed for the two compounds during the saturation-sampling campaigns. The results indicate that mobile sources (i.e., diesel trucks) had a large impact on formaldehyde and acetaldehyde concentrations in both neighborhoods and that both are aldehyde hot spots. The study also showed that PM2.5, aldehydes, BTEX, and MTBE concentrations in both Waterfront South and Copewood-Davis were higher than ambient background concentrations in New Jersey and than national average concentrations, indicating that both neighborhoods are in fact hot spots for these pollutants. Higher concentrations were observed on weekdays than on weekend days for several compounds, including toluene, ethylbenzene, and xylenes (known collectively as TEX) as well as PAHs and PM2.5. These observations showed the impact on ambient air pollution of higher traffic volumes and more active industrial and commercial operations in the study areas on weekdays. Seasonal variations differed by species. Concentrations of TEX, for example, were found to be higher in winter than in summer in both locations, possibly because of higher emission rates from automobiles and reduced photochemical reactivity in winter. In contrast, concentrations of MTBE were found to be significantly higher in summer than in winter in both locations, possibly because of higher evaporation rates from gasoline in summer. Similarly, concentrations of heavier PAHs, such as benzo[a]pyrene, were found to be higher in winter in both locations, possibly because of higher emission rates from mobile sources, the use of home

heating, and the reduced photochemical reactivity of benzo[a]pyrene in winter. In contrast, concentrations of lighter PAHs were found to be higher in summer in both locations, possibly because of volatilization of these compounds from various surfaces in summer. In addition, higher concentrations of formaldehyde were observed in summer than in winter, possibly because of significant contributions from photochemical reactions to formaldehyde air pollution in summer. Personal concentrations of toluene (25.4 +/- 13.5 μg/m3) and acrolein (1.78 +/- 3.7 μg/m3) in Waterfront South were found to be higher than those in the Copewood-Davis neighborhood (13.1 +/- 15.3 μg/m3 for toluene and 1.27 +/- 2.36 μg/m3 for acrolein). However, personal concentrations for most of the other compounds measured in Waterfront South were found to be similar to or lower than those than in Copewood-Davis. (For example, mean +/- SD concentrations were 4.58 +/- 17.3 μg/m3 for benzene, 4.06 +/- 5.32 μg/m3 for MTBE, 16.8 +/- 15.5 μg/m3 for formaldehyde, and 0.40 +/- 0.94 ng/m3 for benzo[a]pyrene in Waterfront South and 9.19 +/- 34.0 μg/m3 for benzene, 6.22 +/- 19.0 μg/m3 for MTBE, 16.0 +/- 16.7 μg/m3 for formaldehyde, and 0.42 +/- 1.08 ng/m3 for benzo[a]pyrene in Copewood-Davis.) This was probably because many of the target compounds had both outdoor and indoor sources. The higher personal concentrations of these compounds in Copewood-Davis might have resulted in part from higher exposure to environmental tobacco smoke (ETS) of subjects from Copewood-Davis. The Spearman correlation coefficient (R) was found to be high for pollutants with significant outdoor sources. The R's for MTBE and carbon tetrachloride, for example, were > 0.65 in both Waterfront South and Copewood-Davis. The R's were moderate or low (0.3-0.6) for compounds with both outdoor and indoor sources, such as BTEX and formaldehyde. A weaker association (R < 0.5) was found for compounds with significant indoor sources, such as BTEX, formaldehyde, PAHs, and PM2.5. The correlations between personal and ambient concentrations of MTBE and BTEX were found to be stronger in Waterfront South than in Copewood-Davis, reflecting the significant impact of local air pollution sources on personal exposure to these pollutants in Waterfront South. Emission-based ambient concentrations of benzene, toluene, and formaldehyde and contributions of ambient exposure to personal concentrations of these three compounds were modeled using atmospheric dispersion modeling and Individual Based Exposure Modeling (IBEM) software, respectively, which were coupled for analysis in the Modeling Environment for Total Risk (MENTOR) system. The compounds were associated with the three types of dominant sources in the two neighborhoods: industrial sources (toluene), exhaust from gasoline-powered motor vehicles (benzene), and exhaust from diesel-powered motor vehicles (formaldehyde). Subsequently, both the calculated and measured ambient concentrations of each of the three compounds were separately combined with the time diaries and activity questionnaires completed by the subjects as inputs to IBEM-MENTOR for estimating personal exposures from ambient sources. Modeled ambient concentrations of benzene and toluene were generally in agreement with the measured ambient concentrations within a factor of two, but the values were underestimated at the high-end percentiles. The major local (neighborhood) contributors to ambient benzene concentrations were from mobile sources in the study areas; both mobile and stationary (point and area) sources contributed to the ambient toluene concentrations. This finding can be used as guidance for developing better emission inventories to characterize, through modeling, the ambient concentrations of air toxics in the study areas.

Luria M, Valente RJ, Bairai S, Parkhurst WJ, Tanner RL. 2008. Airborne study of ozone formation over Dallas, Texas. Atmospheric Environment 42(29): 6951-8.

Abstract: Twelve research fights were performed during August 2005 over the Dallas (Texas) metropolitan area. The primary objective was to estimate the relative contribution of primary emissions from large point sources, i.e., major power plants, compared with mobile sources in terms of O3 production. The distinction between the source types was derived from concurrent measurements of SO2 (tracer for point sources) and CO (tracer for mobile sources) relative to levels of O3 and NOx (the O3 precursor). The flights also examined the vertical structure of the atmosphere and its effect on the dispersion/dilution of the trace gases. During the first half of the study the O3 levels in the Dallas area were relatively low and only during the second half were significantly elevated O3 levels observed. For the latter period the relationship between maximum O3 levels, the air mass chemical age and the O3 yield are evaluated. The results also revealed that mobile sources are the main contributors to the elevated O3 levels in the Dallas area.

Morgenstern RD, Harrington W, Shih JS, Bell ML, HEI Health Review Committee. 2012. Accountability analysis of title IV phase 2 of the 1990 Clean Air Act Amendments. Research Report Health Effects Institute 168: 5-35.

Abstract: In this study, we sought to assess what portion, if any, of the reductions in ambient concentrations of particulate matter (PM*) < or = 2.5 μm in aerodynamic diameter (PM2.5) that occurred in the United States between the years 1999 and 2006 can be attributed to reductions in emissions of sulfur dioxide (SO2) and nitrogen oxides (NOx) resulting from implementation of Phase 2 of Title IV of the 1990 Clean Air Act Amendments. To this end, a detailed statistical model linking sources and monitors over time and space was used to estimate associations between the observed emissions reductions and improvements in air quality. Overall, it turned out to be quite feasible to use relatively transparent statistical methods to assess these outcomes of the Phase 2 program, which was designed to reduce long-range transport of emissions. Associations between changes in emissions from individual power plants and monitor-specific estimates of changes in concentrations of PM2.5, our indicator pollutant, were highly significant and were mostly of the expected relative magnitudes with respect to distances and directions from sources. Originally estimated on monthly data for a set of 193 monitors between 1999 and 2005, our preferred model performed equally well using data for the same 193 monitors for 2006 as well as for an additional 217 monitors not in the original set in 2006. Although substantial model uncertainty was observed, we were able to estimate that the Title IV Phase 2 emissions reduction program implemented between 1999 and 2005 reduced PM2.5 concentrations in the eastern United States by an average of 1.07 μg/m3 (standard deviation [SD] = 0.11 μg/m3) compared with a counterfactual case defined as there having been no change in emission rates per unit of energy input (1 million British thermal units [BTUs]). On a population-weighted basis, the comparable reduction in PM2.5 was 0.89 μg/m3. Compared with the air quality fate and transport models used by the U.S. Environmental Protection Agency (EPA) to estimate air quality improvements associated with the Clean Air Interstate Rule (CAIR) for 2010 and 2015, when baseline PM2.5 concentrations were expected to be about one-third lower, our statistical model yielded roughly similar results per ton of SO2 reduced, well within the estimated confidence intervals of the models. We have proposed a number of steps to advance air quality outcomes research using statistical methods. Specifically, we have emphasized the value of updating our analysis with post-2005 data to try to corroborate our findings. We have also recommended extending the work on air quality outcomes to include changes in health outcomes that might be associated with the implementation of Title IV Phase 2.

Nazari S, Shahhoseini O, Sohrabi-Kashani A, Davari S, Paydar R, Delavar-Moghadam Z. 2010. Experimental determination and analysis of CO2, SO2 and NOx emission factors in Iran's thermal power plants. Energy 35(7): 2992-8.

Abstract: Emission factors of CO2, SO2 and NOx emitted from Iran's thermal power plants are fully covered in this paper. To start with, emission factors of flue gases were calculated for fifty thermal power plants with the total installed capacity of 34,863 MW over the period 2007–2008 with regard to the power plants' operation characteristics including generation capacity, fuel type and amount and the corresponding alterations, stack specifications, analysis of flue gases and physical details of combustion gases in terms of g kWh-1. This factor was calculated as 620, 2.57 and 2.31 g kWh-1 for CO2, SO2 and NOx respectively. Regarding these results, total emissions of CO2, SO2 and NOx were found to be 125.34, 0.552 and 0.465 Tg in turn. To achieve an accurate comparison, these values were compared with their alternatives in North American countries. According to this comparison, emission factor of flue gases emitted from Iran's thermal power plants will experience an intensive decline if renewable, hydroelectric and nuclear types of energy are more used, power plants' efficiency is increased and continuous emission monitoring systems and power plant pollution reduction systems are utilized.

Nethaji Mariappan VE, Mohana P, Murrugesan CA. 2013. Spatio-temporal assessment of air pollution from thermal stations and vehicular pollution from urban places in Tamil Nadu. International Journal of ChemTech Research 5(1): 172-9.

Abstract: India has evolved as self reliance country at all forefronts. Demand for energy is on rise due to the robust development of sectors like Automobile, Chemical, Information Technology and ITES in most part of

the metropolitan states in India. There is a great deficit on energy particularly with supply chain management in Tamil Nadu. Government is exploring new ways of harnessing clean and green energy to meet out the demand. Source of energy is derived from thermal, hydro, wind, solar etc., So far and so forth, maximum energy is harnessed from thermal using coal as the raw material. Type and quality of coal determines the energy conversion ratio and the pollution emission of SO2, NOx and RSPM etc.. This study attempts to spatially and temporally explore the pollution concentration and assess with respect to Air Quality Index (AQI) of the available data on thermal power stations in Tamil Nadu. A comparison between the vehicular pollution concentrations and thermal pollution concentration has entailed us that SO2 and NOX emission was higher from vehicles and SPM was higher from thermal stations and that lead us to take precautionary measures in managing the environmental pollution. Thus this study gives an insight on the rise in pollution concentration and its effect on human health.

Neuman JA, Nowak JB, Zheng W, Flocke F, Ryerson TB, Trainer M, et al. 2009. Relationship between photochemical ozone production and NOx oxidation in Houston, Texas. Journal of Geophysical Research 114, D00F08.

Abstract: An instrumented aircraft was used to study anthropogenic emissions and subsequent ozone and reactive nitrogen photochemistry in the continental boundary layer downwind of Houston, Texas. Measurements of ozone, carbon monoxide, NOx, and NOx oxidation products were conducted from the NOAA WP-3 aircraft during the 2006 Texas Air Quality Study under a variety of meteorological conditions. Sixty-five crosswind transects of plumes from Houston urban and industrial areas performed on 10 daytime flights from 13 September to 6 October 2006 are examined. Coincident measurements of NOx and its oxidation products show that NOx was oxidized predominately to nitric acid and peroxy acyl nitrates on time scales of a few hours. The observed relationships between O3 and NOx oxidation products are affected by both photochemistry and mixing of different air masses. On four flights, background pollutant mixing ratios were constant and CO to NOy enhancement ratios in downwind plume transects remained at the emission ratio. The enhancement ratio of O3 to NOx oxidation products was also nearly constant and could be used to derive ozone production efficiency (OPE) in plumes downwind from the Houston area. On the other flights, variable mixing of regionally polluted background air with plumes caused CO to NOy and O3 to NOy − NOx enhancement ratios to increase as plumes were transported. In such cases, enhancement ratios do not solely reflect plume processing, and OPE could not be determined. The OPE averages 5.9 ± 1.2 in coalesced plumes from urban and petrochemical industrial sources in Houston, with higher values in isolated plumes downwind from petrochemical facilities located along the Houston ship channel.

Peischl J, Ryerson TB, Holloway JS, Parrish DD, Trainer M, Frost GJ et al. 2010. A top-down analysis of emissions from selected Texas power plants during TexAQS 2000 and 2006. Journal of Geophysical Research-Atmospheres 115: D16303.

Abstract: Airborne measurements were taken downwind of eleven Texas power generation facilities in 2000 and 2006 as part of the two Texas Air Quality Study (TexAQS) campaigns. From these measurements, we determine emission ratios of NOx (= NO + NO2), SO2, and CO to coemitted CO2 for each facility. These measurements provide an independent external assessment of reported emission ratios from continuous emission monitoring systems (CEMS). During the TexAQS study years, we find the SO2/CO2 and NOx/CO2 emission ratios derived from measurements aboard the aircraft agree quantitatively with inventory values from CEMS, with standard deviations of less than ±14%. We document significant decreases in atmospheric mixing ratios of NOx as a result of emission reductions due to controls implemented at the W. A. Parish plant after TexAQS 2000. For several of the facilities, CO emissions appear relatively constant in time. Derived CO/CO2 emission ratios agree substantially better with Texas Commission on Environmental Quality inventories in 2006 than in 2000, which we attribute to better inventory data from three facilities that installed CO CEMS between the two study years and not because of any significant change in CO emissions. Other plants appear to have varying CO emissions over time, complicating comparison to annual inventory values. Finally, we use two independent NO2 measurements, along with measurements of O3, NO3, and N2O5, to quantify the fraction of NOx directly emitted as NO2 from the Oklaunion Power Plant, providing the first quantitative estimate of NO2 emissions from a power generation facility using ambient data.

Perrino C, Catrambone M, Esposito G, Lahav D, Mamane Y. 2009. Characterisation of gaseous and particulate atmospheric pollutants in the East Mediterranean by diffusion denuder sampling lines. Environmental Monitoring and Assessment 152(1-4): 231-44.

Abstract: A field study aimed to characterize atmospheric pollutants in the gaseous and the particulate phases was conducted during the fall-winter of 2004 and the summer of 2005 in the Ashdod area, Israel. The site is influenced by both anthropogenic sources (power plants, refineries, chemical and metal industries, a cargo port, road traffic) and natural sources (sea-spray and desert dust). The use of diffusion lines--a series of annular diffusion denuders for sampling gaseous compounds followed by a cyclone and a filter pack for determining PM2.5 composition--allowed a good daily characterization of the main inorganic compounds in both the gaseous (HCl, HNO3, SO2, NH3) and the particulate phase (Cl-, NO3-, SO42-, NH4+, and base cations). During the summer campaign two other activities were added: an intensive 3-h sampling period and the determination of PM2.5 bulk composition. The results were interpreted on the basis of meteorological condition, especially the mixing properties of the lower atmosphere as determined by monitoring the natural radioactivity due to Radon progeny, a good proxy of the atmospheric ability to dilute pollutants. Several pollution episodes were identified and the predominance of different sources was highlighted (sea-spray, desert dust, secondary photochemical pollutants). During the summer period a considerable increase of nitric acid and particulate sulphate was observed. Secondary inorganic pollutants (nitrate, sulphate and ammonium) constituted, on the average, 57% of the fine particle fraction, organic compounds 20%, primary anthropogenic compounds 14%, natural components (sea-spray and crustal elements) 9%. The advantages of the diffusion lines in determining gaseous and particulate N- and S- inorganic compounds are discussed.

Pudasainee D, Kim JH, Lee SH, Park JM, Jang HN, Song GJ et al. 2010. Hazardous air pollutants emission from coal and oil-fired power plants. Asia-Pacific Journal of Chemical Engineering 5: 299-303.

Abstract: Hazardous air pollutants (HAPs) emission characteristics from coal (anthracite, bituminous) and oil-fired power plants were studied in order to control pollutants by formulating US maximum achievable control technology (MACT)-like regulation in Korea. Sampling and analysis were carried out according to either Korean standard test method or US EPA method. Relatively lower levels of NOx and SOx were emitted from plants burning bituminous than the anthracite coal. Less dust was emitted from oil-fired power plants. Mercury, lead, and chromium were dominant in coal-fired power plants, following which, nickel and chromium were emitted from oil-fired power plants. The major volatile organic compounds (VOCs) emitted from coal-fired plants were 1,2-dichloroethane, benzene, carbon tetrachloride, chloroform, trichloro-ethylene. The emission of mercury and other heavy metals in flue gas was attributed to fuel types, operating conditions, residence time in the control devices and air pollution control devices configuration. After emission tests in the field and on analysis of the continuous emission monitoring data collected from facilities under operation and consideration of other various factors, management guidelines will be suggested with special reference to US MACT-like regulation.

Pudasainee D, Seo YC, Kim JH, Jang HN. 2013. Fate and behavior of selected heavy metals with mercury mass distribution in a fluidized bed sewage sludge incinerator. Journal of Material Cycles and Waste Management 15: 202-9.

Abstract: In this paper, emission and distribution behavior of six heavy metals (As, Cd, Cr, Ni, Pb, and Hg), particulate matter and mass distribution of mercury within the different streams of a fluidized bed sewage sludge incinerator are presented. At the inlet of air pollution control devices (APCDs); Cd, Cr, Ni and Pb were mainly enriched in coarse particles; comparatively As content was higher in fine particles (Ni > Pb > As > Cd. Mercury was almost always distributed in flue gas. Metals, other than mercury, were efficiently removed in APCDs and their concentrations in bottom ash, with fly ash being higher, whereas for that in wastewater, then waste sand was lesser. Overall mercury removal efficiency of APCDs was 98.6 %. More than 83.3 % of mercury was speciated into oxidized form at the inlet of APCDs, attributed by higher chlorine content in sludge. Mercury was mainly distributed in wastewater (78.4 %), wastewater from a spray dry reactor (16.8 %),

fly ash in a hopper (3.4 %) and flue gas (1.4 %). This result is one of the first for data to be obtained; more experiments are required to control emission from such sources.

Schade GW, Khan S, Park C, Boedeker I. 2011. Rural southeast Texas air quality measurements during the 2006 Texas Air Quality Study. Journal of the Air and Waste Management Association 61: 1070–1081.

Abstract: The authors conducted air quality measurements of the criteria pollutants carbon monoxide, nitrogen oxides, and ozone together with meteorological measurements at a park site southeast of College Station, TX, during the 2006 Texas Air Quality Study II (TexAQS). Ozone, a primary focus of the measurements, was above 80 ppb during 3 days and above 75 ppb during additional 8 days in summer 2006, suggestive of possible violations of the ozone National Ambient Air Quality Standard (NAAQS) in this area. In concordance with other air quality measurements during the TexAQS II, elevated ozone mixing ratios coincided with northerly flows during days after cold front passages. Ozone background during these days was as high as 80 ppb, whereas southerly air flows generally provided for an ozone background lower than 40 ppb. Back trajectory analysis shows that local ozone mixing ratios can also be strongly affected by the Houston urban pollution plume, leading to late afternoon ozone increases of as high as 50 ppb above background under favorable transport conditions. The trajectory analysis also shows that ozone background increases steadily the longer a southern air mass resides over Texas after entering from the Gulf of Mexico. In light of these and other TexAQS findings, it appears that ozone air quality is affected throughout east Texas by both long-range and regional ozone transport, and that improvements therefore will require at least a regionally oriented instead of the current locally oriented ozone precursor reduction policies.

Sjostedt SJ, Slowik JG, Brook JR, Chang RYW, Mihele C, Stroud CA, et al. 2011. Diurnally resolved particulate and VOC measurements at a rural site: indication of significant biogenic secondary organic aerosol formation. Atmospheric Chemistry and Physics 11: 5745-60.

Abstract: We report simultaneous measurements of volatile organic compound (VOC) mixing ratios including C6 to C8 aromatics, isoprene, monoterpenes, acetone and organic aerosol mass loadings at a rural location in southwestern Ontario, Canada by Proton-Transfer-Reaction Mass Spectrometry (PTR-MS) and Aerosol Mass Spectrometry (AMS), respectively. During the three-week-long Border Air Quality and Meteorology Study in June–July 2007, air was sampled from a range of sources, including aged air from the polluted US Midwest, direct outflow from Detroit 50 km away, and clean air with higher biogenic input. After normalization to the diurnal profile of CO, a long-lived tracer, diurnal analyses show clear photochemical loss of reactive aromatics and production of oxygenated VOCs and secondary organic aerosol (SOA) during the daytime. Biogenic VOC mixing ratios increase during the daytime in accord with their light- and temperature-dependent sources. Long-lived species, such as hydrocarbon-like organic aerosol and benzene show little to no photochemical reactivity on this timescale. From the normalized diurnal profiles of VOCs, an estimate of OH concentrations during the daytime, measured O3 concentrations, and laboratory SOA yields, we calculate integrated local organic aerosol production amounts associated with each measured SOA precursor. Under the assumption that biogenic precursors are uniformly distributed across the southwestern Ontario location, we conclude that such precursors contribute significantly to the total amount of SOA formation, even during the period of Detroit outflow. The importance of aromatic precursors is more difficult to assess given that their sources are likely to be localized and thus of variable impact at the sampling location.

Slowik JG, Brook J, Chang RYW, Evans GJ, Hayden K, Jeong CH, et al. 2011. Photochemical processing of organic aerosol at nearby continental sites: contrast between urban plumes and regional aerosol. Atmospheric Chemistry and Physics 11: 2991-3006.

Abstract: As part of the BAQS-Met 2007 field campaign, Aerodyne time-of-flight aerosol mass spectrometers (ToF-AMS) were deployed at two sites in southwestern Ontario from 17 June to 11 July 2007. One instrument was located at Harrow, ON, a rural, agriculture-dominated area approximately 40 km southeast of the Detroit/Windsor/Windsor urban area and 5 km north of Lake Erie. The second instrument was located at Bear Creek, ON, a rural site approximately 70 km northeast of the Harrow site and 50 km east of Detroit/Windsor. Positive matrix factorization analysis of the combined organic mass spectral dataset

yields factors related to secondary organic aerosol (SOA), direct emissions, and a factor tentatively attributed to the reactive uptake of isoprene and/or condensation of its early generation reaction products. This is the first application of PMF to simultaneous AMS measurements at different sites, an approach which allows for self-consistent, direct comparison of the datasets. Case studies are utilized to investigate processing of SOA from (1) fresh emissions from Detroit/Windsor and (2) regional aerosol during periods of inter-site flow. A strong correlation is observed between SOA/excess CO and photochemical age as represented by the NOx/NOy ratio for Detroit/Windsor outflow. Although this correlation is not evident for more aged air, measurements at the two sites during inter-site transport nevertheless show evidence of continued atmospheric processing by SOA production. However, the rate of SOA production decreases with airmass age from an initial value of ~10.1 μg m−3 ppmv CO−1 h−1 for the first ~10 h of plume processing to near-zero in an aged airmass (i.e. after several days). The initial SOA production rate is comparable to the observed rate in Mexico City over similar timescales.

Sun Y, Zhou X, Wai K, Yuan Q, Xu Z, Zhou S et al. 2013. Simultaneous measurement of particulate and gaseous pollutants in an urban city in North China Plain during the heating period: Implication of source contribution. Atmospheric Research 134: 24-34.

Abstract: A comprehensive measurement program was undertaken in winter 2009 in a large urban city (Ji'ian) in North China Plain (NCP). The average concentrations of NO, NO2, NOx, NOy, SO2, O-3, CO, PM2.5 and BC during the program were 63.9 +/- 65.1 ppb, 45.2 +/- 16.9 ppb, 106.6 +/- 77.8 ppb, 120.7 +/- 77.4 ppb, 54.3 +/- 25.8 ppb, 63 +/- 6.0 ppb, 21383 +/- 1512.8 ppb, 1713 83.9 μg/m3 and 9.8 +/- 6.9 μg/m3 respectively. Two severe haze episodes were observed. All species, except O3, had elevated concentrations on the episodes compared with those on non-hazy days due to accumulation of pollutants. Diurnal variations of species concentrations and correlation analysis suggested that emissions from vehicles and coal combustion (from power plants, industry and domestic heating) are the main sources. Air mass on Episode 1 was predominately influenced by coal combustion, while pollution was characterized by the vehicular emissions on Episode 2. In contrast, on non-hazy days, pollutants were mainly from the mixing of local coal-fired and vehicular exhaust emissions. These distinct characteristics were further supported by higher ratios of CO to NOy and SO2 to NOy on Episode 1(25.46 ppb/ppb and 0.51 ppb/ppb) compared to Episode 2 (15.55 ppb/ppb and 036 ppb/ppb) and non-hazy days (18.15 ppb/ppb and 0.45 ppb/ppb). Multiple linear regression analysis was applied to the concentrations of NOy, SO2 and CO in the observation and empirical equations were obtained for the NOy concentration. Based on the equations, the relative contributions from mobile (i.e. vehicular exhaust) and point sources (i.e. coal combustion) to NOy were estimated to be 68.2% and 38.6%, respectively, demonstrating that even in the demanding period of domestic heating in NCP, vehicular emissions in a large urban city contribute more to NOy than coal combustion emissions. This also implies that vehicular emissions, featured with high NOx, become a dominant source of pollution, highlighting the recent finding of long-term increase of NO2 in the NCP region by satellite observation (Richter et al., 2005).

Upadhyay M, Damma SR. 2013. Analysis of air pollutants in surrounding of Korba district. International Journal of Agriculture Innovations and Research 2: 55-7.

Abstract: An investigation was undertaken to study the pollution levels in the villages in Korba district. The Presence of number of power plants & various industries in Korba district gave a support for the existence of Environmental problem in this area. Many industrial emissions from existing Thermal power plants, coal & Bauxite mines were being continuously released in to the atmosphere. This paper presents ambient air quality of villages in Korba district. Four different villages (Pathadi, Saragbundiya, Sandel and Kuddal) were selected for the study and compared. The parameters studied were Particulate matter (PM 10, PM 2.5), Sulphur Dioxide, Nitrogen Oxides and Ammonia. The results were compared with National Ambient air Quality Standards-NAAQS-2009, (Environment (Protection) seventh amendment rules - 2009), A Gazette notification released by Ministry of Environment and Forests, Government of India. From overall analysis, it was observed that the concentration of all the above parameters is within the prescribed limit of Central Pollution control Board.

Walvekar PP, Gurjar BR. 2013. Formulation, application and evaluation of a stack emission model for coal-based power stations. International Journal of Environmental Science and Technology 10: 1235-44.

Abstract: Estimation of coal power plant emissions is a vital step to visualise emission trends with respect to specific policy implementations and technological interventions so that their effectiveness in terms of emission reductions and ambient air quality improvement can be quantitatively assessed. However, research work concerning stack emission estimations specifically for coal power plants in India is limited. To bridge the present gap, we present a plant-specific multi-year and multi-parameter Coal Power Stack Emission Model. This model has been developed to explore current and historical annual stack emissions from a coal-based thermal power plant taking into account essential variables such as coal characteristics, process attributes and control equipment aspects, which can significantly influence the stack emissions. This study concentrates on development of Coal Power Stack Emission model and its application for the estimation of plant and year-specific emission factors and stack emissions for a coal-based power plant at Badarpur, New Delhi, for the period of 2000-2008. The validation of Coal Power Stack Emission model has also been successfully carried out by comparing the trends of percentage change in annual emission estimates and observed ambient air concentrations of total suspended particles, PM10 and sulphur dioxide at two nearby air quality monitoring stations, namely Siri Fort and Nizamuddin.

Wang Y, Hopke PK, Chalupa DC, Utell MJ. 2011a. Effect of the shutdown of a coal-fired power plant on urban ultrafine particles and other pollutants. Aerosol Science and Technology 45: 1245–1249.

Abstract: Ultrafine particle (UFP) monitoring over the size range of 10-500 nm has been ongoing in Rochester, New York, since November 2001. A nearby large coal-fired power plant (CFPP) was shut down in the spring of 2008 for conversion to natural gas combustion. This shutdown resulted in a reduction in observed concentrations of UFP number and other pollutants. In this study, positive matrix factorization (PMF) model and conditional probability function (CPF) were used to elicit the CFPP source information based on 2005-2010 hourly concentration data of particles and gaseous species and meteorological variables. Five factors were identified, i.e., nucleation, regional transport, traffic, CFPP, and O-3-rich secondary aerosol that influenced the measured pollution levels. The average 10-50 nm, 50-100 nm, and 100-500 nm particle number concentrations decreased 49.8%, 51.9%, and 52.9% from 2007 to 2008, respectively. The annual average SO2, CO, and PM2.5 concentrations also decreased by 64.1%, 39.6%, and 45.6% from 2007 to 2008, respectively. The largest reductions of 10-50 nm particles, CO, and SO2 concentrations between 2007 and 2009 were observed with northerly winds. These changes were clearly attributed to the shutdown of the large CFPP in the study area.

Wang Y, Hopke PK, Chalupa DC, Utell MJ. 2011b. Long-term study of urban ultrafine particles and other pollutants. Atmospheric Environment 45: 7672-7680.

Abstract: Continuous measurements of number size distributions of ultrafine particles (UFPs) and other pollutants (PM2.5, SO2, CO and O3) have been performed in Rochester, New York since late November 2001. The 2002-2009 average number concentrations of particles in three size ranges (10-50 nm, 50-100 nm and 100-500 nm) were 4730 cm(-3), 1838 cm(-3), and 1073 cm(-3), respectively. The lowest annual average number concentrations of particles in 10-50 nm and 50-100 nm were observed during 2008-2009. The lowest monthly average number concentration of 10-50 nm particles was observed in July and the highest in February. The daily patterns of 10-50 nm particles had two peaks at early morning (7-8 AM) and early afternoon (2 PM). There was a distinct declining trend in the peak number concentrations from 2002-2005 to 2008-2009. Large reductions in SO2 concentrations associated with northerly winds between 2007 and 2009 were observed. The most significant annual decrease in the frequency of morning particle nucleation was observed from 2005 to 2007. The monthly variation in the morning nucleation events showed a close correlation with number concentrations of 10-50 nm particles ($r = 0.89$). The frequency of the local SO2-related nucleation events was much higher before 2006. All of these results suggest significant impacts of highway traffic and industrial sources. The decrease in particle number concentrations and particle nucleation events likely resulted from a combination of the U.S. EPA 2007 Heavy-Duty Highway Rule implemented on

October 1, 2006, the closure of a large coal-fired power plant in May 2008, and the reduction of Eastman Kodak emissions.

Yuval, Broday DM. 2009. Assessing the long term impact of power plant emissions on regional air pollution using extensive monitoring data. Journal of Environmental Monitoring 11(2): 425-33.

Abstract: In spite of the recent increasing interest in energy production from renewable sources, polluting hydrocarbon-fueled power plants will continue to provide most of the electricity to the world's population in the coming decades. This work studies the long term impact on the regional ambient air which can be attributable to three plants with different power outputs, fuel types, and stack heights. The study is carried out in an area with relatively flat topography and typical coastal meteorology. A dense air pollution monitoring network, operating for many years, makes this area a real life laboratory for studying the pollution routes, the impact of the sources at different directions and distances, and the effects of transition to cleaner fuel. The direct impact of each of the two large power plants on the ambient SO2 levels could be clearly detected in most of the monitoring stations at distances up to 40 km away. Interestingly, a relatively large impact can also be attributed to the indirect effect of emissions that are recirculated back to the region with the land breeze. The transition from using fuel oil to natural gas in one of the large power plants resulted in a dramatic reduction in the mean SO2 levels in all of the monitoring stations. The contribution of the industrial emissions to the ambient NO2 levels seems to be very modest relative to that from traffic. An analysis of the NO, NO2 and O3 records suggests that the highest mean NO2 concentrations, and a large proportion of the total NO2 encountered in the study area, are probably due to recirculated NOx emitted by traffic in a densely populated region north of it.

Zaveri RA, Berkowitz CM, Brechtel FJ, Gilles MK, Hubbe JM, Jayne JT et al. 2010. Nighttime chemical evolution of aerosol and trace gases in a power plant plume: Implications for secondary organic nitrate and organosulfate aerosol formation, NO3 radical chemistry, and N2O5 heterogeneous hydrolysis. Journal of Geophysical Research-Atmospheres 115: D12304.

Abstract: Nighttime chemical evolution of aerosol and trace gases in a coal-fired power plant plume was monitored with the Department of Energy Grumman Gulfstream-1 aircraft during the 2002 New England Air Quality Study field campaign. Quasi-Lagrangian sampling in the plume at increasing downwind distances and processing times was guided by a constant-volume balloon that was released near the power plant at sunset. While no evidence of fly ash particles was found, concentrations of particulate organics, sulfate, and nitrate were higher in the plume than in the background air. The enhanced sulfate concentrations were attributed to direct emissions of gaseous H2SO4, some of which had formed new particles as evidenced by enhanced concentrations of nucleation-mode particles in the plume. The aerosol species were internally mixed and the particles were acidic, suggesting that particulate nitrate was in the form of organic nitrate. The enhanced particulate organic and nitrate masses in the plume were inferred as secondary organic aerosol, which was possibly formed from NO3 radical-initiated oxidation of isoprene and other trace organic gases in the presence of acidic sulfate particles. Microspectroscopic analysis of particle samples suggested that some sulfate was in the form of organosulfates. Microspectroscopy also revealed the presence of sp(2) hybridized C = C bonds, which decreased with increasing processing time in the plume, possibly because of heterogeneous chemistry on particulate organics. Constrained plume modeling analysis of the aircraft and tetroon observations showed that heterogeneous hydrolysis of N2O5 was negligibly slow. These results have significant implications for several issues related to the impacts of power plant emissions on air quality and climate.

Zhao Y, Wang S, Nielsen CP, Li X, Hao J. 2010. Establishment of a database of emission factors for atmospheric pollutants from Chinese coal-fired power plants. Atmospheric Environment 44: 1515-23.

Abstract: Field measurements and data investigations were conducted for developing an emission factor database for inventories of atmospheric pollutants from Chinese coal-fired power plants. Gaseous pollutants and particulate matter (PM) of different size fractions were measured using a gas analyzer and an electric low-pressure impactor (ELPI), respectively, for ten units in eight coal-fired power plants across the country. Combining results of field tests and literature surveys, emission factors with 95% confidence intervals (CIs)

were calculated by boiler type, fuel quality, and emission control devices using bootstrap and Monte Carlo simulations. The emission factor of uncontrolled SO2 from pulverized combustion (PC) boilers burning bituminous or anthracite coal was estimated to be 18.0S kg t(-1) (i.e., 18.0 x the percentage sulfur content of coal, S) with a 95% CI of 17.25-18.5S. NOX emission factors for pulverized-coal boilers ranged from 4.0 to 11.2 kg t(-1), with uncertainties of 14-45% for different unit types. The emission factors of uncontrolled PM2.5, PM10, and total PM emitted by PC boilers were estimated to be 0.4A (where A is the percentage ash content of coal), 1.5A and 6.9A kg t(-1), respectively, with 95% CIs of 03A-0.5A, 1.1A-1.9A and 5.8A-7.9A. The analogous PM values for emissions with electrostatic precipitator (ESP) controls were 0.032A (95% CI: 0.021A-0.046A), 0.065A (0.039A-0.092A) and 0.094A (0.0656A-0.132A) kg t(-1), and 0.0147A (0.0092-0.0225A), 0.0210A (0.0129A-0.0317A), and 0.0231A (0.0142A-0.0348A) for those with both ESP and wet flue-gas desulfurization (wet-FGD). SO2 and NOX emission factors for Chinese power plants were smaller than those of U.S. EPA AP-42 database, due mainly to lower heating values of coals in China. PM emission factors for units with ESP, however, were generally larger than AP-42 values, because of poorer removal efficiencies of Chinese dust collectors. For units with advanced emission control technologies, more field measurements are needed to reduce emission factor uncertainties.

Zoras S, Triantafyllou AG, Evagelopoulos V. 2008. Aspects of year-long differential optical absorption spectroscopy and ground station measurements in an urban street canyon near industrial pollution sources. Atmospheric Environment 42: 4293-303.

Abstract: The annual performance of a differential optical absorption spectroscopy (DOAS) system in combination with a ground monitoring station was assessed in an urban street canyon of a medium-sized city, Greece. The urban environment is surrounded by complex terrain and located in proximity to coal-fired power plants. One-year hourly concentrations of ozone, nitrogen dioxide (NO2), and sulphur dioxide (SO2) that have been measured by DOAS were correlated against data from a conventional ground station. Concentrations of volatile organic compounds (benzene, toluene, and p,m-xylene) have also been presented and their photochernical role was related to their degree of reactivity. Experimental data of photochemical pollutants were significantly correlated against meteorology during a 7-day period. The parallel monitoring at ground and DOAS path levels has contributed in the verification of distant pollutants' transfer from the industry. The importance of wind speed in the photochemical production of ozone by was also stipulated the distinction of urban and rural conditions.

Grey literature

AECOM Inc. 2010. Report on the Third Operational Phase Air Media Sampling Program – Winter 2008. Final Report. Prepared for Montgomery County Department of Public Works and Transportation, Rockville, MD. Available at http://www.montgomerycountymd.gov/sws/resources/files/rrf/Third-Op-Phase.pdf.

Abstract: No abstract available.

Excerpt from Executive Summary:
[The Montgomery County, Maryland Solid Waste Resource Recovery Facility (RRF), near Dickerson, Maryland became operational in the spring of 1995. During the planning process for this facility, citizens in the area expressed concerns regarding the potential human health effects associated with exposure to emissions from this facility. In response to this concern, the County initiated a multi-media monitoring program in the vicinity of the facility to monitor the concentrations of various organic (e.g., dioxins/furans) and inorganic (e.g., metals) constituents in abiotic and biotic environmental media. The sampling program includes air-monitoring and non-air media monitoring components. This report describes the results of the winter 2008 air sampling program and discusses the results in comparison to results obtained in the 1994-95 (pre-operational phase program), 1996-97 (first operational phase) and 2002-03 (second operational phase) programs. The third operational phase monitoring occurred during January 10, 2008 through February 16, 2008, approximately 12 years after the RRF became operational. The air samples collected during the program were analyzed for polychlorinated dioxins and furans (PCDDs/PCDFs) and selected metals (arsenic,

beryllium, cadmium, chromium, lead, mercury, and nickel). These data were evaluated to determine whether evidence exists that facility operations made a detectable difference in the levels of any of these chemicals in the vicinity of the RRF.]

Alberta Environment. 2011. A Report on Air Quality Monitoring Conducted in the Three Creeks Area (Phase II). Available at http://esrd.alberta.ca/air/reports-data/documents/8359.pdf.

Abstract: In early 2010, a number of odour complaints from the Three Creeks area were called into the Energy Resources Conservation Board and Alberta Environment. After the initial complaints, Alberta Environment staff responded with visits to the affected sites and noted various levels of "hydrocarbon" type odours. Within the Three Creeks area and to the east, a number of industrial facilities were identified as possible contributors to the odour complaints. This report summarizes monitoring data collected between April and December, 2010 (Phase II).

In order to assess the ambient conditions in the area and to assist in determining the potential sources of the odours, Alberta Environment and local industry undertook a number of monitoring initiatives. A temporary continuous monitoring station was placed near the residence of one the community members who had detected the odours. At this station sulphur dioxide (SO2), total reduced sulphurs (TRS), total hydrocarbons (THC) and associated meteorological conditions are monitored continuously. Also at this station, air samples are collected periodically and analyzed for individual volatile organic compounds (VOCs). This station has been in operation since April 2010 (to present day) and the data has indicated periods of elevated hydrocarbon concentrations. In Alberta, background THC concentrations are 2 parts per million (ppm) or less. THC concentrations greater than 10 ppm have been measured in Alberta heavy industrial areas (such as the industrial areas east of Edmonton). At the temporary monitoring station, over fifty percent of THC concentrations measured were less than 2.0 ppm and approximately forty percent of THC concentrations measured were between 2.0 ppm and 2.5 ppm. Meteorological data indicates that THC concentrations greater than 2.4 ppm were observed when prevailing winds were from the east, east of northeast and east of southeast. The elevated THC concentrations were measured primarily during the night. The maximum observed THC concentration for this period was 6.6 ppm.

To further investigate the spatial extent of elevated hydrocarbon concentrations in the Three Creeks area, Alberta Environment deployed the Alberta Environment Mobile Air Monitoring Laboratory (MAML). The MAML is equipped with various ambient air monitoring instruments and is used to perform short-term ambient air quality surveys. The air quality at six sites was monitored with the MAML over a period of four evenings in October 2010. Data collected by the MAML was supplemented with canister air samples, which were later analyzed for VOCs. The one-hour average total VOC concentration, excluding methane, for these samples ranged from 2 to 84 parts per billion (ppb).

In order to investigate the VOC composition of air samples during perceived odour events, grab samples were collected at local residences. In addition, the residents in the Three Creeks area were encouraged to contact Alberta Environment if they wished to be provided canisters to collect air samples themselves. Alberta Environment provided canisters to residents for sampling and kept track of sample canisters. The total VOC concentrations, excluding methane, from grab samples collected at local residences ranged from 3 to 453 ppb.

To characterize ambient Polycyclic Aromatic Hydrocarbons (PAH) in the Three Creeks area, a three week survey was conducted. PAHs were sampled at six sites in the Three Creeks area. The lowest total PAH concentration was 3.4856 nanograms per cubic metre (ng/m3) on November 10 and the highest total PAH concentration was 41.5565 ng/m3 on November 22.

This interim report has identified the presence of a variety of hydrocarbons in the Three Creeks area. At times, these hydrocarbons were detected in elevated concentrations. No Alberta Ambient Air Quality Objectives were exceeded for any of the samples that had the appropriate sampling intervals.

Alberta Environment. 2010. Air Quality Monitoring: In the Grande Cache Area, September 2008. Available at http://environment.gov.ab.ca/info/library/8279.pdf.

Abstract: Alberta Environment, in conjunction with Energy Resources Conservation Board undertook a mobile air monitoring project in the Grande Cache area in September of 2008. The survey focused on measurement of particulate matter in the area of the operations of Grande Cache Coal and Milner Power.

Elevated concentrations of particulate matter were observed near mine haul roads. Particulate matter at these sites were characterized to be larger in size (greater than 2.5 μm) and likely due to road dust and haul vehicle emissions. In addition to particulate matter, sulphur dioxide and oxides of nitrogen concentrations were also noteworthy. Although ambient air quality objectives were not exceeded, elevated sulphur dioxide and oxides of nitrogen were noted concurrently at a number of sites. These observations occurred when the sites were downwind from the coal fired power plant. The results indicate that:
-Road dust and mine haul vehicles are a source of particulate matter especially near haul roads; and
-With the correct meteorological conditions, emissions from nearby power plant may impact ambient concentrations in the area. The measured concentrations during this study were well below the ambient air quality objectives.

Bulow C. 2008. Small decentralised thermal power stations for Refuse-Derived Fuel (RDF). In: 4th International Conference on Waste Management and the Environment, 63-7.

Abstract: We discuss a solution to bringing down energy costs and to making a contribution to climate protection. Small decentralised thermal power stations for RDF with a thermal capacity of 35 MW have some advantages in comparison to large plants. The required amount of RDF (approx. 70,000 t/a) is mostly locally available, which reduces the transport costs considerably. The produced electrical energy (up to 8 MW) and the waste heat from the thermal power station can be used in an industrial plant. An industrial plant and a refuse company founded a joint venture and built a thermal power station for RDF in Bremen. They replaced the old coal fired power station with a RDF-plant. Increasing energy costs are replaced by revenue for RDF. The industrial plant is now using the "cheap" energy from the RDF. The refuse company has a reliable customer and stable prices for its waste for long years: a typical win-win situation. After a 3-year operating time the experiences of the RDF thermal power station are positive without exception. The specified emissions are far below the limits. Furthermore, due to the fact that RDF contains a high proportion of biomass (approx. 45%) by changing the fuel from coal to RDF, a contribution to climate protection can be made. If the same amount of biogene content would be land filled, a large amount of methane, which is one of the more dangerous greenhouse gases, would be produced. The RDF thermal power station is built up modularly. The individual components are standardized so that the plant can be built fast and cost-effectively. The specific investment costs per ton of RDF are comparable to large plants (>100 MW). Due to the handling of RDF in a closed hall, there is no smell outside the plant. The RDF is burnt at over 870 degrees degrees Celsius to eliminate all pollutants completely. The steam is led through a back-pressure turbine and then used in the industrial plant. The modern flue gas treatment plant shows the expected consumption of additives. Since the initiation, the emission limits are constantly considerably below the requested limits of the EU-DIRECTIVE 2000/76/EC.

Catalin NG, Ionel I, Calinoiu D, Vetres I. 2010. Air pollution monitoring in a town nearly power plant. In: Advances in Biology, Bioengineering and Environment, International Conference, 181-4.

Abstract: Compared to other fossil fuels, coal reserves are the largest ones and are more evenly distributed worldwide. The burning of fossil fuels produces around 21.3 billion tonnes (21.3 gigatones) of carbon dioxide (CO2) per year, but also produces nitrogen oxides and sulphur dioxide emissions, which contribute to smog and acid rain and the formation of fine particulate matter. This paper presents a case study of pollution with of SO2, CO, NO, NO2, O3 and particulate matter in the proximity of Rovinari fossil-fuel power plant and its diurnal variations. Measurements were made simultaneously with different equipments in various meteorological conditions. Ash concentration at ground but also the size distribution has be found to depend strongly not only on the wind direction and intensity, but also on the time of the day.

Environmental Integrity Project. 2012. Air Quality Profile of Curtis Bay, Brooklyn and Hawkins Point, Maryland. Washington, DC. Available at http://www.environmentalintegrity.org/news_reports/documents/FINALBAYBROOKREPORT_003.pdf.

Abstract: *No abstract available.*

Excerpt from Executive Summary:
[The South Baltimore neighborhoods of Curtis Bay, Brooklyn and Hawkins Point (referred to in this report as the Baybrook Area or Baybrook) have a long history as the focal point of industrialization in Baltimore City. This includes two events in which residents were relocated from the most industrial part of this area because of health concerns. The Baybrook community presently has high mortality (death) rates from heart disease, chronic lower respiratory disease and lung cancer, which are diseases that have been associated with air pollution exposure. Furthermore, 2010 census statistics show approximately 20% of families living below the poverty line in Baybrook, raising environmental justice concerns. The Environmental Integrity Project (EIP) is issuing this report in order to provide more information to the community and to decision-makers about air pollution and health in Baybrook. However, there is still a great deal of information that is not known, particularly about the cumulative impacts on residents' health of the multiple source of pollution to which they are exposed. In conducting the research for this report, EIP reviewed air quality information from a number of different sources, including data recorded by ambient (outside) air monitors and models and databases developed by the United States Environmental Protection Agency (EPA).]

Kim JW, Kim YM, Jin SH. 2010. Chapter 5: The State of Air Pollution in North Korea in Comparison with South Korea In: Cancilla R, Gargano M (Eds), Global Environmental Policies: Impact, Management and Effects (pp 111-136). Nova Science Publishers, Inc.

Abstract: This study assessed the state of air pollution in North Korea mainly based on the measurement data for Pyongyang, the capital city, Geumho, a rural area in the East Coast, and Wonsan, an industrial city. The environmental data of North Korea have rarely been disclosed. Most of the reports on the North Korean environment have been based on wild assumptions and rumors, the reliability of them not confirmed: they usually describe it as very polluted. But, the measured data of SO2, NOx, TSP, CO and O3 showed that the air quality of the Geumho was very clean year round, even lower than those in rural areas in South Korea. It seemed that the air in this rural area was not much affected by air pollution from industries or urban cities near by. The level of SO2 in Pyongyang turned out to be similar to that in Seoul, well below the national environmental standard. The level of NOx in Pyongyang, both ambient and personal exposure level, was much lower than that in Seoul. The total emission of three major air pollutants (SO2, NOx, and TSP) in North Korea was estimated at about 1/6 of that in South Korea, judging from the energy consumption in 2003. The major emission source of SO2 and NOx in North Korea was coal burning in industrial sector, compared to transportation in South Korea. The emission in Pyongyang accounts for 14% of that in North Korea, and the thermal power plants 45% of that in Pyongyang. The SO2 emission estimated for Pyongyang was a little higher than that in most of the major cities in South Korea except Ulsan, a petrochemical industrial city, but the NOx emission was much lower than that in any major cities in South Korea. North Korea adopted strict air quality standards and emission regulations in accordance with Environmental Protection Law, but it could not be confirmed if the laws had been complied at all. There were some positive efforts observed to reduce the air pollution in North Korea. The major transportation means in Pyongyang were walking, subway, tram cars and trolley buses. Walking could be a major transportation means possibly due to the urban planning which minimized the transportation and the lack of energy. Automobiles were rare in Pyongyang. The high stacks of power plants also seemed helpful in reducing the ground-level air pollution.

New Hampshire Department of Environmental Services. 2009. Public Health Assessment: Ambient Air Quality in Claremont, Sullivan County, New Hampshire. EPA Facility ID: NH5986485322. Available at http://www.atsdr.cdc.gov/HAC/pha/AmbientAirQualityinClaremont/AmbientAirQualityinClaremont12-16-2009.pdf.

Abstract: *No abstract available.*

Excerpt from Report:
[During public hearings related to air permits for a local stationary source, some residents of Claremont, New Hampshire expressed concerns about air pollution emissions from the Wheelabrator, Claremont waste-to-energy facility. As a result, DES requested EHP to examine air quality and certain health effects that might be associated with air emissions from nearby point sources including the Wheelabrator, Claremont facility.
The overall conclusion of this report is that ambient air in the Claremont area does not present a health hazard to the general population. During the study periods, the ambient air monitors in the Claremont area confirmed compliance with all National Ambient Air Quality Standards, including those for the four criteria pollutants examined in this report: sulfur dioxide (SO2), fine particulate matter (PM2.5), ozone (O3), and nitrogen dioxide (NO2). Based on monitored levels, there are infrequent days when air pollution levels (i.e., O3 and PM2.5) in the Claremont area may result in adverse health effects among people with certain heart or lung diseases during outdoor exertion. Atmospheric analyses have determined that O3 air pollution events originate from regional and distant stationary and mobile sources and are transported long distances, primarily by winds that originate from a southerly direction in summer months. Claremont specifically experiences elevated O3 levels most often when winds blowing from the south bring air pollution originating from the New York City metropolitan region into the area. PM2.5 events usually share the same origin and transport characteristics as ozone events. The ozone and PM2.5 levels measured at other state locations are generally similar or higher than in Claremont. The Claremont location also experiences fewer air quality action day events than other monitored locations.]

Nielsen M, Nielsen OK, Thomsen M. 2010. Emissions from decentralised CHP plants 2007 - Energinet.dk Environmental project no. 07/1882. Project Report 5 – Emission factors and emission inventory for decentralised CHP production. Technical Report No. 786, National Environmental Research Institute, Aarhus University. 113 pp. Available at http://www2.dmu.dk/Pub/FR786.pdf.

Abstract: Updated emission factors for decentralised combined heat and power (CHP) plants with a capacity < 25MW_e have been estimated based on project emission measurements as well as emission measurements performed in recent years that were collected. The emission factors valid for 2006/2007 have been estimated for the plant technologies: Municipal solid waste (MSW) incineration plants, plants combusting straw or wood, natural gas fuelled reciprocating engines, biogas fuelled engines, natural gas fuelled gas turbines, gas oil fuelled reciprocating engines, gas oil fuelled gas turbines, steam turbines combusting residual oil and reciprocating engines combusting biomass producer gas based on wood. The emission factors for MSW incineration plants are much lower than the emission factors that were estimated for year 2000. The considerable reduction in the emission factors is a result of lower emission limit values in Danish legislation since 2006 that has lead to installation of new and improved flue gas cleaning systems in most MSW incineration plants. For CHP plants combusting wood or straw no major technical improvements have been implemented. The emission factors for natural gas fuelled reciprocating engines have been reduced since year 2000 as a result of technical improvements that have been carried out due to lower emission limit values in Danish legislation. The NOx emission factor for natural gas fuelled gas turbines has decreased 62 % since year 2000. This is a result of installation of low-NOx burners in almost all gas turbines that has been necessary to meet new emission limits in Danish legislation. The emission measurements programme included screening of the emissions of HCB, PCB, PCDD/-F and PBDD/-F. Compared to the Danish national emission decentralized CHP plants are major emission sources for CH4, NOx, SO2, heavy metals and HCB.

Schiopu C, Popa RG, Mitran RV, Gheorghe G. 2013. Monitoring of gases immission and particles in suspension in the Rovinari area. In: International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 715-20.

Abstract: The paper presents measurements and interpretations of some indicators: particulate matter, sulfur dioxide, nitrogen dioxide and carbon monoxide in the city area Rovinari. Measurements were performed during 2012 year by the automatic station for the monitoring of air quality. This automatic station being in to function at the end of the year 2011. The main sources of air pollution in the Rovinari area are represented by the Rovinari thermal power plant and its coal deposits, coal deposit of Rosia quarries and Beterega slag and ash deposit. Interpretation of the results was performed in according with the maximum limits permissible of concentrations of ambient air quality established in Law no 104/2011. The interpretation of the results found that only sulfur dioxide and particulate matter limit values have been exceeded allowable established by the Law no 104/1011 (Air Quality Act).

Sheffield Energy Recovery Facility. 2011. Annual Performance Report 2011. Sheffield Energy Recovery Facility (Municipal Solid Waste Incineration), PPC Permit BM 4082. Available at http://www.ukwin.org.uk/files/pdf/sheffield2011.pdf.

Abstract: *No abstract available.*

Excerpt from Report:
[All emissions to air from the 76m high chimney are controlled to meet the emission limits included in the PPC Permit. The flue gases released into the atmosphere are continuously monitored for particulate matter, hydrogen chloride, oxides of nitrogen, carbon monoxide, sulphur dioxide, total volatile organic compounds and ammonia. The monitoring equipment was in service during 2011 for whole of the plant operating time. This equipment is stringently monitored with routine calibration checks and is standardised to BSEN14181. Additionally, a full range of standby equipment is permanently in service should an unexpected failure occur. Bi-annual check monitoring of these emissions is carried out by approved contractors using independent extractive reference methods. Emissions of metals, dioxins and other substances are also monitored as detailed overleaf.]

Vakkilainen EK, Hamaguchi M, Laux DC. 2010. Grouping statistically emissions from a recovery boiler. XXI Encontro Nacional da TECNICELPA/VI CIADICYP 2010 (International Chemical Recovery Conference). pp 12.

Abstract: The aim of this study is to examine the emissions from a recovery boiler. In this study, the data used is emission from the stack of a large pulp mill in western Finland from years 2007–2008. It was recorded as hourly averages. The scope of the study was to analyze of the emission data by looking at different the load and other operating factors of the recovery boiler and to study how recovery boiler load and black liquor dry solids affect emissions. It can be concluded that if we regulate emissions based on "time over limit" then the actual average emission is strongly affected by the time period we look at. It should be noted that emissions are strongly related the load of the recovery boiler. It is apparent that the NOx emission value increases at the highest loads. CO and TRS emissions seem to increase when load is below 70% of MCR load. For this boiler the emissions are rather stable if the boiler load is higher than the 70% of MCR load.

3.5.3 Multiple pollutants - modeled emissions (emission inventories)

White literature

Baggio P, Baratieri M, Gasparella A, Longo GA. 2008. Energy and environmental analysis of an innovative system based on municipal solid waste (MSW) pyrolysis and combined cycle. Applied Thermal Engineering 28(2-3): 136-44.

Abstract: This paper presents the energy and the environmental impact analysis of an innovative system based on the pyrolysis of MSW which produces solid (char), liquid (tar) and gas (syngas) fuels used in a combined cycle for electric power generation. The syngas, after filtration and compression, feeds two gas

turbines. In turn, the exhaust from the gas turbines, after post-combustion with char and tar, drives a steam turbine power plant. Before being discharged, the flue gas is processed in a selective catalytic reduction (SCR) unit to reduce CO, VOC and NOx content and is filtered to remove particulate matter. This innovative approach to energy recovery from MSW combines high energy efficiency with a low level of polluting emissions. The estimated global efficiency of the plant, referred to the LHV of the MSW, is around 28-30%, a much higher value than ordinarily obtained in traditional waste incineration plants. The environmental analysis includes a study of the polluting emissions and the simulation of their concentration in the area surrounding the plant: the emissions of the plant have a negligible influence on the original polluting levels of the settlement area.

Baldasano JM, Güereca LP, López E, Gassó S, Jimenez-Guerrero P. 2008. Development of a high-resolution (1 km x 1 km, 1 h) emission model for Spain: The High-Elective Resolution Modelling Emission System (HERMES). Atmospheric Environment 42: 7215-33.

Abstract: This work presents the results of the development and application of the High-Elective Resolution Modelling Emission System (HERMES). HERMES generates the emissions for Spain needed for the application of high-resolution chemistry transport models, taking the year 2004 as reference with a temporal resolution of 1 h and a spatial resolution of 1 km^2 considering both anthropogenic (power generation, industrial activities, on-road traffic, ports, airports, solvent use, domestic and commercial fossil fuel use) and biogenic sources (vegetation), using a bottom-up approach, up-to-date information and state-of-the-art methodologies for emission estimation. HERMES is capable of calculating emissions by sector-specific sources or by individual installations and stacks. The annual addition of hourly sectorial emissions leads to an estimation of total annual emissions as follows: NOx, 795 kt; NMVOCs, 1025 kt; CO, 1236 kt; SO2, 1142 kt and TSP, 180 kt; which are distributed principally in the greater areas of the main cities, highways and large point sources. NOx, SO2 and PM2.5 highly correlate with the power generation by coal use, achieving higher emission levels during summertime due to the increase of electricity demand by cooling systems. NMVOCs show high correlation with temperature and solar radiation (mainly as a consequence of the important weight of biogenic emissions) causing the maximum emissions during the daylight hours of summer months. CO emissions are mostly influenced by the on-road traffic; consequently the higher emissions are attained in summer because of the increase of daily average traffic during holidays. The most significant total emission sources are on-road traffic (38%), combustion in power generation plants (33%), biogenic sources (12%) and combustion in manufacturing industries (9%). The inventory generated with HERMES emission model has been successfully integrated within the Spanish Ministry of the Environment's air quality forecasting system (Caliope project), being the emission core for the validation and assessment of air quality simulations in Spain.

Chemel C, Sokhi RS, Dore AJ, Sutton P, Vincent KJ, Griffiths SJ et al. 2011. Predictions of U.K. regulated power station contributions to regional air pollution and deposition: a model comparison exercise. Journal of the Air and Waste Management Association 61(11): 1236-45.

Abstract: Contributions of the emissions from a U.K. regulated fossil-fuel power station to regional air pollution and deposition are estimated using four air quality modeling systems for the year 2003. The modeling systems vary in complexity and emphasis in the way they treat atmospheric and chemical processes, and include the Community Multiscale Air Quality (CMAQ) modeling system in its versions 4.6 and 4.7, a nested modeling system that combines long- and short-range impacts (referred to as TRACK-ADMS [Trajectory Model with Atmospheric Chemical Kinetics-Atmospheric Dispersion Modelling System]), and the Fine Resolution Atmospheric Multi-pollutant Exchange (FRAME) model. An evaluation of the baseline calculations against U.K. monitoring network data is performed. The CMAQ modeling system version 4.6 data set is selected as the reference data set for the model footprint comparison. The annual mean air concentration and total deposition footprints are summarized for each modeling system. The footprints of the power station emissions can account for a significant fraction of the local impacts for some species (e.g., more than 50% for SO2 air concentration and non-sea-salt sulfur deposition close to the source) for 2003. The spatial correlation and the coefficient of variation of the root mean square error (CVRMSE) are calculated between each model footprint and that calculated by the CMAQ modeling system version 4.6. The correlation coefficient quantifies model agreement in terms of spatial patterns, and the CVRMSE measures the magnitude of the difference between model footprints. Possible reasons for the differences between

model results are discussed. Finally, implications and recommendations for the regulatory assessment of the impact of major industrial sources using regional air quality modeling systems are discussed in the light of results from this case study.

Dong X, Gao Y, Fu JS, Li J, Huang K, Zhuang G et al. 2013. Probe into gaseous pollution and assessment of air quality benefit under sector dependent emission control strategies over megacities in Yangtze River Delta, China. Atmospheric Environment 79: 841-52.

Abstract: On February 29th 2012, China published its new National Ambient Air Quality Standard (CH-NAAQS) aiming at revising the standards and measurements for both gaseous pollutants including ozone (O3), nitrogen dioxide (NO2), and sulfur dioxide (SO2), and also particle pollutants including PM10 and PM2.5. In order to understand the air pollution status regarding this new standard, the integrated MM5/CMAQ modeling system was applied over Yangtze River Delta (YRD) within this study to examine the criteria gaseous pollutants listed in the new CH-NAAQS. Sensitivity simulations were also conducted to assess the responses of gaseous pollutants under 8 different sector-dependent emission reduction scenarios in order to evaluate the potential control strategies. 2006 was selected as the simulation year in order to review the air quality condition at the beginning of China's 11th Five-Year-Plan (FYP, from 2006 to 2010), and also compared with air quality status in 2010 as the end of 11th FYP to probe into the effectiveness of the national emission control efforts. Base case simulation showed distinct seasonal variation for gaseous pollutants: SO2, and NO2 were found to have higher surface concentrations in winter while O3 was found to have higher concentrations in spring and summer than other seasons. According to the analyses focused on 3 megacities within YRD, Shanghai, Nanjing, and Hangzhou, we found different air quality conditions among the cities: NO2 was the primary pollutant that having the largest number of days exceeding the CH-NAAQS daily standard (80 μg m−3) in Shanghai (59 days) and Nanjing (27 days); SO2 was the primary pollutant with maximum number of days exceeding daily air quality standard (150 μg m−3) in Hangzhou (28 days), while O3 exceeding the daily maximum 8-h standard (160 μg m−3) for relatively fewer days in all the three cities (9 days in Shanghai, 14 days in Nanjing, and 11 days in Hangzhou). Simulation results from predefined potential applicable emission control scenarios suggested significant air quality improvements from emission reduction: 90% of SO2 emission removed from power plant in YRD would be able to reduce more than 85% of SO2 pollution, 85% NOx emission reduction from power plant would reduce more than 60% of NO2 pollution, in terms of reducing the number of days exceeding daily air quality standard. NOx emission reduction from transportation and industry were also found to effectively reduce NO2 pollution but less efficient than emission control from power plants. We also found that multi-pollutants emission control including both NOx and VOC would be a better strategy than independent NOx control over YRD which is China's 12th Five-Year-Plan (from 2011 to 2015), because O3 pollution would be increased as a side effect of NOx control and counteract NO2 pollution reduction benefit.

Farooqui ZM, John K, Biswas J, Sule N. 2013. Modeling analysis of the impact of anthropogenic emission sources on ozone concentration over selected urban areas in Texas. Atmospheric Pollution Research 4(1): 33-42.

Abstract: Due to several regional–scale high ozone episodes that impacted the urban areas in south and central Texas over the past decade, the Texas Commission on Environmental Quality (TCEQ) has designated several urban regions as near non–attainment areas. A regional photochemical modeling experiment was set up to simulate a high ozone episode of September 11–14, 2002 in order to evaluate the impact of various anthropogenic emissions sources on ozone concentrations. The base case simulation showed reasonable model performance by capturing the peaks and the diurnal variability of observed ozone concentrations within the modeling domain. A comprehensive impact assessment of anthropogenic emissions from various source categories to the 8–hour ozone concentration was evaluated for each of the urban areas within the study region. Through a source apportionment analysis of emissions influencing the 8–hour ozone concentrations, NOx and VOC limited areas were identified. The model results showed that the net effect of all anthropogenic emissions was approximately 8.4 ppb in Victoria, 8.8 ppb in Corpus Christi, and 31.2 and 34.1 ppb in Austin and San Antonio, respectively. Impact of major emissions source categories differed regionally with ozone concentrations in Austin and San Antonio mainly influenced by mobile sources, while Corpus Christi and Victoria were largely impacted by long–range transport of ozone. On a local scale, Corpus

Christi was also impacted by non–road sources, while Victoria was influenced by point sources. Ozone sensitivity analysis showed higher sensitivity towards VOC within the urban cores of Austin, San Antonio, and Corpus Christi, while the overall modeling regions showed higher NOx sensitivity. This would indicate that both NOx and VOC emissions reduction plans need to be developed and implemented for the mitigation of regional and urban ozone. The results also revealed that biogenic emissions played an important role in the urban regions of south and central Texas.

Fu X, Wang S, Zhao B, Xing J, Cheng Z, Liu H et al. 2013. Emission inventory of primary pollutants and chemical speciation in 2010 for the Yangtze River Delta region, China. Atmospheric Environment 70: 39-50.

Abstract: We developed a high-resolution emission inventory of primary air pollutants for Yangtze River Delta (YRD) region, which included Shanghai plus 24 cities in the provinces of Jiangsu and Zhejiang. The emissions of SO2, NOX, PM10, PM2.5, NMVOCs and NH3 in the year of 2010 were estimated as 2147 kt, 2776 kt, 1006 kt, 643 kt, 3822 kt and 1439 kt, respectively. Power plants are the largest emission sources for SO2 and NOX, which contributes 44.1% and 37.3% of total SO2 and NOX emissions. Emissions from industrial process accounted for 26.9%, 28.9% and 33.7% of the total PM10, PM2.5 and NMVOCs respectively. Besides, 37.3% of NMVOCs emissions were contributed by solvent use. Livestock and fertilizer application contribute over 90% of NH3 emissions. High emission densities are visible in Shanghai and the area around Tai Lake. This emission inventory includes the speciation of PM2.5 for the YRD region for the first time, which is important to source apportionment and secondary-pollution analysis. In 2010, emissions of three major PM2.5 species, namely OC, EC and sulfate, are 136.9 kt, 75.0 kt and 76.2 kt, respectively. Aromatics and alkanes are the main NMVOC species, accounting for 30.4% and 20.3% of total VOCs. Non-road transportation and biomass burning were main uncertain sources because of a lack of proper activity and emission factor data. Compared with other pollutants, NMVOCs and NH3 have higher uncertainty. From 2000 to 2010, emissions of all pollutants have changed significantly, suggesting that the newly updated and high-resolution emission inventory will be useful for the identification of air pollution sources in YRD.

Hasan MH, Muzammil WK, Mahlia TMI, Jannifar A, Hasanuddin I. 2012. A review on the pattern of electricity generation and emission in Indonesia from 1987 to 2009. Renewable and Sustainable Energy Reviews 16(5): 3206-19.

Abstract: The level of energy demand plays a fundamental role in today's society. It is a vital input in supporting the physical and social development of a country, as well as national economic growth. Looking at the energy demand scenario in present time, the global energy consumption is likely to grow faster than the population growth across the world. Like any other energy sectors, electricity demand has significantly increased in Indonesia over the past years. Currently, there are six types of power plants in the country. The main sources of electrical energy are generated using the gas turbines, steam turbines, combined cycles, geothermal, diesel engine and hydro-powers. Most of Indonesia's power plants are using fossil fuel for electricity generation. Substantial growth in domestic energy demand, however, would be a major challenge for Indonesia's energy supply sector in the future. Over the past decade, thermal power plants generated about 86.69% of electricity and about 13.31% was generated by renewable energy such as hydro-power and geothermal in 2009. The purpose of this study is to chronicle and show a clear view of 23 years trend of Indonesia's electricity generation industry. Furthermore, the capacity of power generation installed and electricity generation from 1987 to 2009 has been gathered for this study. The total pollutant emissions and emission per unit electricity generation for each type of power plants have been also calculated using emission factors. Also, the pattern of electricity generation and emission has been presented. The results show that the implementation and contribution of combined cycle power plants should be increased together with renewable energy and natural gas which are recommended to reduce greenhouse gas emission.

Hinneburg D, Renner E, Wolke R. 2009. Formation of secondary inorganic aerosols by power plant emissions exhausted through cooling towers in Saxony. Environmental Science and Pollution Research International 16(1): 25-35.

Abstract: BACKGROUND, AIM, AND SCOPE: The fraction of ambient PM10 that is due to the formation of secondary inorganic particulate sulfate and nitrate from the emissions of two large, brown-coal-fired power stations in Saxony (East Germany) is examined. The power stations are equipped with natural-draft cooling towers. The flue gases are directly piped into the cooling towers, thereby receiving an additionally intensified uplift. The exhausted gas-steam mixture contains the gases CO, CO2, NO, NO2, and SO2, the directly emitted primary particles, and additionally, an excess of 'free' sulfate ions in water solution, which, after the desulfurization steps, remain non-neutralized by cations. The precursor gases NO2 and SO2 are capable of forming nitric and sulfuric acid by several pathways. The acids can be neutralized by ammonia and generate secondary particulate matter by heterogeneous condensation on preexisting particles. MATERIALS AND METHODS: The simulations are performed by a nested and multi-scale application of the online-coupled model system LM-MUSCAT. The Local Model (LM; recently renamed as COSMO) of the German Weather Service performs the meteorological processes, while the Multi-scale Atmospheric Transport Model (MUSCAT) includes the transport, the gas phase chemistry, as well as the aerosol chemistry (thermodynamic ammonium-sulfate-nitrate-water system). The highest horizontal resolution in the inner region of Saxony is 0.7 km. One summer and one winter episode, each realizing 5 weeks of the year 2002, are simulated twice, with the cooling tower emissions switched on and off, respectively. This procedure serves to identify the direct and indirect influences of the single plumes on the formation and distribution of the secondary inorganic aerosols. RESULTS AND CONCLUSIONS: Surface traces of the individual tower plumes can be located and distinguished, especially in the well-mixed boundary layer in daytime. At night, the plumes are decoupled from the surface. In no case does the resulting contribution of the cooling tower emissions to PM10 significantly exceed 15 μg m-3 at the surface. These extreme values are obtained in narrow plumes on intensive summer conditions, whereas different situations with lower turbulence (night, winter) remain below this value. About 90% of the PM10 concentrations in the plumes are secondarily formed sulfate, mainly ammonium sulfate, and about 10% originate from the primarily emitted particles. Under the assumptions made, ammonium nitrate plays a rather marginal role. RECOMMENDATIONS AND PERSPECTIVES: The analyzed results depend on the specific emission data of power plants with flue gas emissions piped through the cooling towers. The emitted fraction of 'free' sulfate ions remaining in excess after the desulfurization steps plays an important role at the formation of secondary aerosols and therefore has to be measured carefully.

Huang C, Chen CH, Li L, Cheng Z, Wang HL, Huang HY et al. 2011. Emission inventory of anthropogenic air pollutants and VOC species in the Yangtze River Delta region, China. Atmospheric Chemistry and Physics 11: 4105-20.

Abstract: The purpose of this study is to develop an emission inventory for major anthropogenic air pollutants and VOC species in the Yangtze River Delta (YRD) region for the year 2007. A "bottom-up" methodology was adopted to compile the inventory based on major emission sources in the sixteen cities of this region. Results show that the emissions of SO2, NOx, CO, PM10, PM2.5, VOCs, and NH3 in the YRD region for the year 2007 are 2392 kt, 2293 kt, 6697 kt, 3116 kt, 1511 kt, 2767 kt, and 459 kt, respectively. Ethylene, mp-xylene, o-xylene, toluene, 1,2,4-trimethylbenzene, 2,4-dimethylpentane, ethyl benzene, propylene, 1-pentene, and isoprene are the key species contributing 77 % to the total ozone formation potential (OFP). The spatial distribution of the emissions shows the emissions and OFPs are mainly concentrated in the urban and industrial areas along the Yangtze River and around Hangzhou Bay. The industrial sources, including power plants other fuel combustion facilities, and non-combustion processes contribute about 97 %, 86 %, 89 %, 91 %, and 69 % of the total SO2, NOx, PM10, PM2.5, and VOC emissions. Vehicles take up 12.3 % and 12.4 % of the NOx and VOC emissions, respectively. Regarding OFPs, the chemical industry, domestic use of paint & printing, and gasoline vehicles contribute 38 %, 24 %, and 12 % to the ozone formation in the YRD region.

Huang K, Fu JS, Gao Y, Dong X, Zhuang G, Lin Y. 2014. Role of sectoral and multi-pollutant emission control strategies in improving atmospheric visibility in the Yangtze River Delta, China. Environmental Pollution 184: 426-34.

Abstract: The Community Multi-scale Air Quality modeling system is used to investigate the response of atmospheric visibility to the emission reduction from different sectors (i.e. industries, traffic and power plants) in the Yangtze River Delta, China. Visibility improvement from exclusive reduction of NOx or VOC emission was most inefficient. Sulfate and organic aerosol would rebound if NOx emission was exclusively reduced from any emission sector. The most efficient way to improve the atmospheric visibility was proven to be the multi-pollutant control strategies. Simultaneous emission reductions (20-50%) on NOx, VOC and PM from the industrial and mobile sectors could result in 0.3-1.0 km visibility improvement. And the emission controls on both NOx (85%) and SO2 (90%) from power plants gained the largest visibility improvement of up to 4.0 km among all the scenarios. The seasonal visibility improvement subject to emission controls was higher in summer while lower in the other seasons.

Kansal A, Khare M, Sharma CS. 2011. Air quality modelling study to analyse the impact of the World Bank emission guidelines for thermal power plants in Delhi. Atmospheric Pollution Research 2(1): 99-105.

Abstract: Recent strategies for air pollution control in Delhi have largely neglected the emission reduction measures from thermal power plants (TPPs), which are the second most polluting sources. The present study investigates how the ambient air quality of Delhi would improve if the World Bank emission guidelines (WBEG) for the TPPs were to be implemented. To accomplish this, a comprehensive inventory of point, area, and line sources was conducted in the selected study area, primarily aiming to estimate the sectoral emission contributions to ambient air quality. The Industrial Source Complex Short-Term Model, Version 3 (ISCST3) was used to predict the ambient concentrations of total suspended particulates (TSP), sulphur dioxide (SO2), and nitrogen dioxide (NO2) at seven monitoring sites (receptor locations) operated by the Central Pollution Control Board (CPCB) for the period from July 2004 to June 2005. The ISCST3 model predictions for TSP and NO2 were satisfactory at all receptor locations. However, for SO2, the model predictions were satisfactory at only two receptor locations. The vehicles contributed 58% of the total ambient air pollution, followed by TPPs contributing 30%. The study estimates that adoption of WBEG may reduce the ambient air pollution due to TPPs emissions by 56% to 82%, bringing it within the National Ambient Air Quality Standards (NAAQS) set for industrial areas in India, except at one location where TPP's contribution to ambient air pollution is negligible compared to vehicular emissions.

Kuo JH, Lin CL, Chen JC, Tseng HH, Wey MY. 2011. Emission of carbon dioxide in municipal solid waste incineration in Taiwan: A comparison with thermal power plants. International Journal of Greenhouse Gas Control 5(4): 889-98.

Abstract: Taiwan is currently confronted by problems on dense population and limited space. In this regard, incineration as a widely used waste treatment technology functions as an alternative to landfill treatment. This study emphasizes the comparison of emission characteristics of pollutants such as NOx, SOx, particulates, and global warming gas (CO2) between incinerators and thermal power plants in Taiwan. From the data and construction information presented here, four types of incinerators as defined by different air pollution control devices (APCDs) are discussed. Taiwan's MSW incineration is considered an available and successful technology for renewable energy exploitation as compared to that of other countries. Thus, a comparison of the pollutant control and emission characteristics of MSW incineration showed that its pollutants are much lower than those from thermal power plants. The pollutants emission level (PEL) of different pollutants shows that the particulates, NOx, and SOx in thermal power plants are about 31, 16, and 267 times more than those in incinerators. Estimation CO2 emission level (CEL) values indicate that the CO2 generated from thermal power plants is lower than those emitted from MSW incineration processes. The reasons for this are the different carbon content, heat energy transfer rate, and heating value between MSW and thermal power stocks.

Kurokawa J, Ohara T, Morikawa T, Hanayama S, Janssens-Maenhout G, Fukui T et al. 2013. Emissions of air pollutants and greenhouse gases over Asian regions during 2000–2008: Regional Emission inventory in ASia (REAS) version 2. Atmospheric Chemistry and Physics 13: 11019-58.

Abstract: We have updated the Regional Emission inventory in ASia (REAS) as version 2.1. REAS 2.1 includes most major air pollutants and greenhouse gases from each year during 2000 and 2008 and following areas of Asia: East, Southeast, South, and Central Asia and the Asian part of Russia. Emissions are estimated for each country and region using updated activity data and parameters. Monthly gridded data with a 0.25° × 0.25° resolution are also provided. Asian emissions for each species in 2008 are as follows (with their growth rate from 2000 to 2008): 56.9 Tg (+34%) for SO2, 53.9 Tg (+54%) for NOx, 359.5 Tg (+34%) for CO, 68.5 Tg (+46%) for non-methane volatile organic compounds, 32.8 Tg (+17%) for NH3, 36.4 Tg (+45%) for PM10, 24.7 Tg (+42%) for PM2.5, 3.03 Tg (+35%) for black carbon, 7.72 Tg (+21%) for organic carbon, 182.2 Tg (+32%) for CH4, 5.80 Tg (+18%) for N2O, and 16.0 Pg (+57%) for CO2. By country, China and India were respectively the largest and second largest contributors to Asian emissions. Both countries also had higher growth rates in emissions than others because of their continuous increases in energy consumption, industrial activities, and infrastructure development. In China, emission mitigation measures have been implemented gradually. Emissions of SO2 in China increased from 2000 to 2006 and then began to decrease as flue-gas desulphurization was installed to large power plants. On the other hand, emissions of air pollutants in total East Asia except for China decreased from 2000 to 2008 owing to lower economic growth rates and more effective emission regulations in Japan, South Korea, and Taiwan. Emissions from other regions generally increased from 2000 to 2008, although their relative shares of total Asian emissions are smaller than those of China and India. Tables of annual emissions by country and region broken down by sub-sector and fuel type, and monthly gridded emission data with a resolution of 0.25° × 0.25° for the major sectors are available from the following URL: http://www.nies.go.jp/REAS/.

Li L, Chen CH, Fu JS, Huang C, Streets DG, Huang HY et al. 2011. Air quality and emissions in the Yangtze River Delta, China. Atmospheric Chemistry and Physics 11: 1621-39.

Abstract: Regional trans-boundary air pollution has become an important issue in the field of air pollution modeling. This paper presents the results of the implementation of the MM5-CMAQ modeling system in the Yangtze River Delta (YRD) for the months of January and July of 2004. The meteorological parameters are obtained by using the MM5 model. A new regional emission inventory with spatial and temporal allocations based on local statistical data has been developed to provide input emissions data to the MM5-CMAQ modeling system. The pollutant concentrations obtained from the MM5-CMAQ modeling system have been compared with observational data from the national air pollution monitoring network. It is found that air quality in winter in the YRD is generally worse than in summer, due mainly to unfavorable meteorological dispersion conditions. In winter, the pollution transport from Northern China to the YRD reinforces the pollution caused by large local emissions. The monthly average concentration of SO2 in the YRD is 0.026 ± 0.011 mg m−3 in January and 0.017 ± 0.009 mg m−3 in July. Monthly average concentrations of NO2 in the YRD in January and July are 0.021 ± 0.009 mg m−3, and 0.014 ± 0.008 mg m−3, respectively. The monthly average concentration of PM10 in the YRD is 0.080 ± 0.028 mg m−3 in January and 0.025 ± 0.015 mg m−3 in July. Visibility is also a problem, with average deciview values of 26.4 ± 2.95 dcv in winter and 17.6 ± 3.3 dcv in summer. The ozone concentration in the downtown area of a city like Zhoushan can be very high, with the highest simulated value reaching 0.24 mg m−3. In January, the monthly average concentration of O3 in the YRD is 0.052 ± 0.011 mg m−3, and 0.054 ± 0.008 mg m−3 in July. Our results show that ozone and haze have become extremely important issues in the regional air quality. Thus, regional air pollution control is urgently needed to improve air quality in the YRD.

Lonsdale CR, Stevens RG, Brock CA, Makar PA, Knipping EM, Pierce JR. 2012. The effect of coal-fired power-plant SO2 and NOx control technologies on aerosol nucleation in the source plumes. Atmospheric Chemistry and Physics 12(23): 11519-31.

Abstract: Nucleation in coal-fired power-plant plumes can greatly contribute to particle number concentrations near source regions. The changing emissions rates of SO2 and NOx due to pollution-control technologies over recent decades may have had a significant effect on aerosol formation and growth in the plumes with ultimate implications for climate and human health. We use the System for Atmospheric Modeling (SAM) large-eddy simulation model with the TwO-Moment Aerosol Sectional (TOMAS) microphysics algorithm to model the nucleation in plumes of coal-fired plants. We test a range of cases with

varying emissions to simulate the implementation of emissions-control technologies between 1997 and 2010. We start by simulating the W. A. Parish power plant (near Houston, TX) during this time period, when NOx emissions were reduced by ~90% and SO2 emissions decreased by ~30%. Increases in plume OH (due to the reduced NOx) produced enhanced SO2 oxidation and an order-of-magnitude increase in particle nucleation in the plume despite the reduction in SO2 emissions. These results suggest that NOx emissions could strongly regulate particle nucleation and growth in power-plant plumes. Next, we test a range of cases with varying emissions to simulate the implementation of SO2 and NOx emissions-control technologies. Particle formation generally increases with SO2 emission, while NOx shows two different regimes: increasing particle formation with increasing NOx under low-NOx emissions and decreasing particle formation with increasing NOx under high-NOx emissions. Next, we compare model results with airborne measurements made in the W. A. Parish power-plant plume in 2000 and 2006, confirming the importance of NOx emissions on new particle formation and highlighting the substantial effect of background aerosol loadings on this process (the more polluted background of the 2006 case caused more than an order-of-magnitude reduction in particle formation in the plume compared to the cleaner test day in 2000). Finally, we calculate particle-formation statistics of 330 coal-fired power plants in the US in 1997 and 2010, and the model results show a median decrease of 19% in particle formation rates from 1997 to 2010 (whereas the W. A. Parish case study showed an increase). Thus, the US power plants, on average, show a different result than was found for the W. A. Parish plant specifically, and it shows that the strong NOx controls (90% reduction) implemented at the W. A. Parish plant (with relatively weak SO2 emissions reductions, 30%) are not representative of most power plants in the US during the past 15 yr. These results suggest that there may be important climate implications of power-plant controls due to changes in plume chemistry and microphysics, but the magnitude and sign of the aerosol changes depend greatly on the relative reductions in NOx and SO2 emissions in each plant. More extensive plume measurements for a range of emissions of SO2 and NOx and in varying background aerosol conditions are needed, however, to better quantify these effects.

Lu Q, Zheng J, Ye S, Shen X, Yuan Z, Yin S. 2013. Emission trends and source characteristics of SO2, NOx, PM10 and VOCs in the Pearl River Delta region from 2000 to 2009. Atmospheric Environment 76: 11-20.

Abstract: Emission trends and variations in source contributions of SO2, NOx, PM10 and VOCs in the Pearl River Delta (PRD) region from 2000 to 2009 were characterized by using a dynamic methodology, taking into account the economic development, technology penetration, and emission control. The results indicated that SO2 emissions increased rapidly during 2000–2005 but decreased significantly afterward. NOx emissions went up consistently during 2000–2009 except for a break point in 2008. PM10 emissions increased by 76% during 2000–2007 but started to decrease slightly in the following years. VOCs emissions presented continuous increase during the study period. Power plants and industrial sources were consistently the largest SO2 and PM10 emission contributors. The on-road mobile source was the largest emission contributor for VOCs and NOx emissions with decreasing contributions. The NOx contribution from power plants and industrial sources kept increasing. Worthy of mention is that the non-road mobile source is becoming an important SO2 and NOx contributor in this region. Comparisons with satellite data, ground observations and national trends indicated that emission trends developed in this study were reasonable. Implications for future air pollution control policies were discussed.

Lu Z, Zhang Q, Streets DG. 2011. Sulfur dioxide and primary carbonaceous aerosol emissions in China and India, 1996-2010. Atmospheric Chemistry and Physics 11: 9839-64.

Abstract: China and India are the two largest anthropogenic aerosol generating countries in the world. In this study, we develop a new inventory of sulfur dioxide (SO2) and primary carbonaceous aerosol (i.e., black and organic carbon, BC and OC) emissions from these two countries for the period 1996-2010, using a technology-based methodology. Emissions from major anthropogenic sources and open biomass burning are included, and time-dependent trends in activity rates and emission factors are incorporated in the calculation. Year-specific monthly temporal distributions for major sectors and gridded emissions at a resolution of 0.1 degrees x 0.1 degrees distributed by multiple year-by-year spatial proxies are also developed. In China, the interaction between economic development and environmental protection causes large temporal variations in the emission trends. From 1996 to 2000, emissions of all three species showed a decreasing trend (by 9%-

17%) due to a slowdown in economic growth, a decline in coal use in non-power sectors, and the implementation of air pollution control measures. With the economic boom after 2000, emissions from China changed dramatically. BC and OC emissions increased by 46% and 33% to 1.85 Tg and 4.03 Tg in 2010. SO2 emissions first increased by 61% to 34.0 Tg in 2006, and then decreased by 9.2% to 30.8 Tg in 2010 due to the wide application of flue-gas desulfurization (FGD) equipment in power plants. Driven by the remarkable energy consumption growth and relatively lax emission controls, emissions from India increased by 70%, 41%, and 35% to 8.81 Tg, 1.02 Tg, and 2.74 Tg in 2010 for SO2, BC, and OC, respectively. Monte Carlo simulations are used to quantify the emission uncertainties. The average 95% confidence intervals (CIs) of SO2, BC, and OC emissions are estimated to be -16%-17%, -43%-93%, and -43%-80% for China, and -15%-16%, -41%-87%, and -44%-92% for India, respectively. Sulfur content, fuel use, and sulfur retention of hard coal and the actual FGD removal efficiency are the main contributors to the uncertainties of SO2 emissions. Biofuel combustion related parameters (i.e., technology divisions, fuel use, and emission factor determinants) are the largest source of OC uncertainties, whereas BC emissions are also sensitive to the parameters of coal combustion in the residential and industrial sectors and the coke-making process. Comparing our results with satellite observations, we find that the trends of estimated emissions in both China and India are in good agreement with the trends of aerosol optical depth (AOD) and SO2 retrievals obtained from different satellites.

Ma Z, Xue B, Geng Y, Ren W, Fujita T, Zhang Z et al. 2013. Co-benefits analysis on climate change and environmental effects of wind-power: A case study from Xinjiang, China. Renewable Energy 57: 35-42.

Abstract: The combustion of fossil fuel contributes to not only global warming but also the emissions of air pollutants. In China, the rapid growth of energy consumption leads to a large quantity of greenhouse gas (GHG) and air pollutant emissions. Although many measures have been proposed by the local governments to mitigate the GHG emissions and improve air quality, limited economic resources slow the efforts of the local government to implement measures to control both types of emissions. The co-benefits approach can use resources efficiently to solve multiple environmental problems. In this study, we first calculated the CO2 and air pollutants (SO2, NOx and PM2.5) emissions in Xinjiang Uygur Autonomous Region. Then, the co-benefits of wind power, including mitigation of CO2 and air pollutants (SO2, NOx and PM2.5) emissions and water savings, were assessed and quantified in the Xinjiang Uygur Autonomous Region. The results demonstrate that, during the 11th five-year period (2006-2010), emissions mitigation by wind power accounted for 4.88% (1065 x 10^4 t) of CO2, 4.31% (4.38 x 10^4 t) of SO2, 8.23% (3.41 x 10^4 t) of NOx and 4.23% (0.32 x 10^4 t) of PM2.5 emission by the thermal power sector. The total economic co-benefits of wind power accounted for 0.46% (1.38 billion 2009US$) of the GDP of Xinjiang during 2006-2010.

Majumdar D, Gajghate DG. 2011. Sectoral CO2, CH4, N2O and SO2 emissions from fossil fuel consumption in Nagpur City of Central India. Atmospheric Environment 45: 4170-9.

Abstract: Emission inventory of CO2, CH4, N2O and SO2 has been prepared for Nagpur city in Central India for the year 2004. Data on fossil fuel (coal, light diesel oil, high speed diesel, petrol/gasoline, low sulphur heavy stock, furnace oil and kerosene) consumption in thermal power, industrial, transport and domestic sectors were collected. Thermal power sector had the maximum coal consumption followed by the industrial and domestic sectors, whereas kerosene, liquefied petroleum gas (LPG), diesel and gasoline were used only in any single sector. Total annual CO2, CH4, N2O and SO2 emissions from these fuels in Nagpur city for the year 2004 was found to be 14792418 MT (14.8 Tg), 4649 (4.6 Tg), 1529 (1.5 Tg) and 69093 (6.9 Tg), respectively, in which thermal power and domestic sector had the maximum share. Coal was found to be the major contributor to Green House Gas (GHG) and SO2 emissions in all the sectors barring transport and domestic sectors. Carbon dioxide was the predominant GHG emitted by the selected sectors in terms of absolute emissions and also global warming contribution (GWC), though the share in the latter was lesser in magnitude due to higher global warming potential (GWP) of CH4 and N2O than CO2. Thermal power sector had a share of 51% in total CO2 emissions from all the sectors, followed by domestic, industrial and transport sectors having 27, 12 and 10% contributions, respectively. Share of thermal power sector in total

SO2 emissions was 61%, followed by 24% from industrial, 10% from domestic and 5% from transport sector.

Martinez A, Deshpande B. 2009. Analysis of point source emissions in the Texas-Mexico border region. International Journal of Environment and Pollution 38: 361-70.

Abstract: Pollutant emissions in the Texas-Mexico border were investigated using an emission database that covers 25 Texas counties and the states of Coahuila, Chihuahua, Nuevo Leon and Tamaulipas in Mexico. Major emissions are from energy generation, mainly from two coal-fired facilities in Coahuila, which also generate most of carbon dioxide. Texas exhibits a larger concentration of sources; around Laredo and the Lower Rio Grande Valley and a sugarcane mill is a significant contributor to particles emissions. In Mexico the minerals and metals industries are the second major contributors to emissions, especially particles. Fossil fuel production is the main source of VOCs.

Mazandarani A, Mahlia TMI, Chong WT, Moghavvemi M. 2010. A review on the pattern of electricity generation and emission in Iran from 1967 to 2008. Renewable and Sustainable Energy Reviews 14: 1814-29.

Abstract: The electricity consumption growth in Iran requires a rapid development of power plant construction. Like many other countries, most of the power plants in Iran are using fossil fuel. In the past decade, thermal power plants generated about 94% of electricity and about 6% was generated by renewable sources such as hydro-power. This study is to show a clear view of 42 years an evolutionary trend of Iran's electricity generation industry. The capacity of power generation installed and electricity generation from the years 1967 to 2008 has been gathered. The total pollutant emissions and emission per unit electricity generation for each type of power plants have also been calculated using emission factors and the pattern of electricity generation and emission has been presented. The results shown that encouraging of using renewable energy sources and increasing the contribution of the combined cycle as a best type of thermal power plants and use more natural gas is recommended to reduce emission.

Mazandarani A, Mahlia TMI, Chong WT, Moghavvemi M. 2011. Fuel consumption and emission prediction by Iranian power plants until 2025. Renewable and Sustainable Energy Reviews 15(3): 1575-92.

Abstract: Electricity consumption has grown eleven-times within the last 30 years in Iran, which has resulted in about 118 Mtons in CO2 emission in 2009. Economic growth in Iran depends on electricity; therefore, the trend of electricity generation should keep going in the future to guarantee this growth. In view of this need, the country has to build many new power plants. If most of them are thermal types, the CO2 and other air pollutant emissions will increase and cause harmful environmental effects. In this paper, Iranian future power plant composition is investigated to predict the fuel consumption and emissions until 2025, which is the end of the country's 20-year vision plan (2006–2025). Government is planning to change the structure of power industries to a more variety and fewer shares of fossil fuel bases. The results showed that in this new composition, consumption of natural gas will increase by 47% and diesel by 50% by 2025. Coal consumption in power plants will reach to 10,826 ktons in the same time span. Whereas if the old composition continues in the future, fuel consumption will increase by 130%, 106% and 69% for natural gas, diesel and fuel oil respectively. It is also found that by 2025, CO2 emission will increase another 2.1 times for the old and 1.6 times for the new power plant composition which government is planning to do.

Odman MT, Hu Y, Russell AG, Hanedar A, Boylan JW, Brewer PF. 2009. Quantifying the sources of ozone, fine particulate matter, and regional haze in the Southeastern United States. Journal of Environmental Management 90(10):3155-68.

Abstract: A detailed sensitivity analysis was conducted to quantify the contributions of various emission sources to ozone (O3), fine particulate matter (PM2.5), and regional haze in the Southeastern United States. O3 and particulate matter (PM) levels were estimated using the Community Multiscale Air Quality (CMAQ) modeling system and light extinction values were calculated from modeled PM concentrations. First, the base case was established using the emission projections for the year 2009. Then, in each model run, SO2, primary

carbon (PC), NH3, NOx or VOC emissions from a particular source category in a certain geographic area were reduced by 30% and the responses were determined by calculating the difference between the results of the reduced emission case and the base case. The sensitivity of summertime O3 to VOC emissions is small in the Southeast and ground-level NOx controls are generally more beneficial than elevated NOx controls (per unit mass of emissions reduced). SO2 emission reduction is the most beneficial control strategy in reducing summertime PM2.5 levels and improving visibility in the Southeast and electric generating utilities are the single largest source of SO2. Controlling PC emissions can be very effective locally, especially in winter. Reducing NH3 emissions is an effective strategy to reduce wintertime ammonium nitrate (NO3NH4) levels and improve visibility; NOx emissions reductions are not as effective. The results presented here will help the development of specific emission control strategies for future attainment of the National Ambient Air Quality Standards in the region.

Pacsi AP, Alhajeri NS, Zavala-Araiza D, Webster MD, Allen DT. 2013. Regional air quality impacts of increased natural gas production and use in Texas. Environmental Science and Technology 47(7): 3521-7.

Abstract: Natural gas use in electricity generation in Texas was estimated, for gas prices ranging from $1.89 to $7.74 per MMBTU, using an optimal power flow model. Hourly estimates of electricity generation, for individual electricity generation units, from the model were used to estimate spatially resolved hourly emissions from electricity generation. Emissions from natural gas production activities in the Barnett Shale region were also estimated, with emissions scaled up or down to match demand in electricity generation as natural gas prices changed. As natural gas use increased, emissions decreased from electricity generation and increased from natural gas production. Overall, NOx and SO2 emissions decreased, while VOC emissions increased as natural gas use increased. To assess the effects of these changes in emissions on ozone and particulate matter concentrations, spatially and temporally resolved emissions were used in a month-long photochemical modeling episode. Over the month-long photochemical modeling episode, decreases in natural gas prices typical of those experienced from 2006 to 2012 led to net regional decreases in ozone (0.2-0.7 ppb) and fine particulate matter (PM) (0.1-0.7 μg/m3). Changes in PM were predominantly due to changes in regional PM sulfate formation. Changes in regional PM and ozone formation are primarily due to decreases in emissions from electricity generation. Increases in emissions from increased natural gas production were offset by decreasing emissions from electricity generation for all the scenarios considered.

Pham TB, Manomaiphiboon K, Vongmahadlek C. 2008. Development of an inventory and temporal allocation profiles of emissions from power plants and industrial facilities in Thailand. Science of the Total Environment 397(1-3): 103-18.

Abstract: An emission inventory (EI) of power plants and industrial (i.e., non-power plant) facilities in Thailand was developed. Emissions considered are those from fuel consumption (i.e., combustion) for power plants and those from both fuel consumption and industrial processes (i.e., non-combustion) for industrial facilities. For power plants, total annual emissions due to fuel consumption are 107.9 x 10^3 ton NOx (as NO2), 146.2 x 10^3 ton SO2, 6.1 x 10^3 ton NMVOC (non-methane volatile organic compounds), 47.0 x 10^3 ton CO, 1.8 x 10^3 ton NH3, 1.5 x 10^3 ton OC (organic carbon), and 1.5 x 10^3 ton BC (black carbon). For industrial facilities, total annual emissions due to fuel consumption are 111.4 x 10^3 ton NOx (as NO2), 476.9 x 10^3 ton SO2, 33.4 x 10^3 ton NMVOC, 193.1 x 10^3 ton CO, 1.6 x 10^3 ton NH3, 8.5 x 10^3 ton OC, and 8.0 x 10^3 ton BC. Among various industrial types, Food and Beverage, Chemical, and Non-Metal industries are dominant emitters. Total annual emissions due to industrial processes are 79.2 x 10^3 ton SO2, 76.0 x 10^3 ton NMVOC, and 4.8 x 10^3 ton CO. The Central and Eastern regions combined contribute considerably to total emissions for most emission species. Emission estimates found here show fair agreement with those in some selected past studies. A crude estimation of potential fugitive NMVOC emissions specifically from petroleum industry was also made, and the estimates found could be considered significant (nearly half of NMVOC emissions from industrial processes). Several temporal allocation profiles of emissions were also developed and suggested for power plants and industrial facilities, including monthly, daily, and hourly profiles.

Vardar N, Yumurtaci Z. 2010. Emissions estimation for lignite-fired power plants in Turkey. Energy Policy 38: 243-52.

Abstract: The major gaseous emissions (e.g. sulfur dioxides, nitrogen oxides, carbon dioxide, and carbon monoxide), some various organic emissions (e.g. benzene, toluene and xylenes) and some trace metals (e.g. arsenic, cobalt, chromium, manganese and nickel) generated from lignite-fired power plants in Turkey are estimated. The estimations are made separately for each one of the thirteen plants that produced electricity in 2007, because the lignite-fired thermal plants in Turkey are installed near the regions where the lignite is mined, and characteristics and composition of lignite used in each power plant are quite different from a region to another. Emission factors methodology is used for the estimations. The emission factors obtained from well-known literature are then modified depending on local moisture content of lignite. Emission rates and specific emissions (per MWh) of the pollutants from the plants having no electrostatic precipitators and flue -gas desulfurization systems are found to be higher than emissions from the plants having electrostatic precipitators and flue -gas desulfurization systems. Finally a projection for the future emissions due to lignite-based power plants is given. Predicted demand for the increasing generation capacity based on the lignite-fired thermal power plant, from 2008 to 2017 is around 30%.

Vongmahadlek C, Pham TB, Satayopas B, Thongboonchoo N. 2009. A compilation and development of spatial and temporal profiles of high-resolution emissions inventory over Thailand. Journal of the Air and Waste Management Association 59(7): 845-56.

Abstract: Thailand, located in Southeast Asia, has both anthropogenic and natural emission sources. It is important to develop an emission information system to provide fundamental data to support emission control strategies and air quality studies. In this research, emissions were compiled for the year 2005. Emission sources cover key anthropogenic and natural emission sources. The methodology to calculate emissions is based on the bottom-up approach using local specific data. For gaseous species, annual emission estimation is found as follows: 9465.9 Gg of carbon monoxide, 2583.1 Gg of nonmethane volatile organic compounds, 886.0 Gg of sulfur dioxide, 790.3 Gg of oxides of nitrogen, and 439.2 Gg of ammonia. For aerosol species, annual emission estimations are 1277.4 Gg of particulate matter smaller than or equal to 10 p.m in aerodynamic diameter, 325.5 Gg of organic carbon, and 136.4 Gg of black carbon. The intercomparison with literature shows an acceptable agreement of annual estimation. Emissions are projected until the year 2027 based on a Business-as-Usual scenario from governmental trends. Spatial allocations with 1- by 1-km resolution and temporal (i.e., monthly, weekly, and diurnal) allocation profiles are also developed to investigate the variation of emissions.

Wagstrom KM, Pandis SN, Yarwood G, Wilson GM, Morris RE. 2008. Development and application of a computationally efficient particulate matter apportionment algorithm in a three-dimensional chemical transport model. Atmospheric Environment 42(22): 5650-9.

Abstract: An on-line and an off-line version of a computationally efficient particulate matter source apportionment algorithm have been developed and compared using the three-dimensional chemical transport model PMCAMx. Both versions of the algorithm use source specific-species that track the contributions of source locations of source classes. The two versions showed a good agreement with each other and with more accurate, computationally demanding methods. The off-line algorithm (Particulate Source Apportionment Technology, PSAT) is simpler to implement, has a lower computational cost and is suitable for a range of source apportionment studies. As a first application, PSAT was used to investigate the contribution of power plant SO2 emissions to particulate sulfate concentrations in the Eastern United States. The impact of the transport of SO2 emissions from the Chicago, IL area and the impact of these emissions on particulate sulfate concentration in surrounding areas were also studied as a second application. The implementation of PSAT for the SO2/particulate sulfate system only resulted in a 1% increase in computation time over the base simulation. The algorithm provides a computationally efficient platform for the study of pollutant transport and source contributions on regional scales.

Wilson JH,Jr, Mullen MA, Bollman AD, Thesing KB, Salhotra M, Divita F,Jr et al. 2008. Emission

projections for the U.S. Environmental Protection Agency Section 812 second prospective Clean Air Act cost/benefit analysis. Journal of the Air and Waste Management Association 58(5): 657-72.

Abstract: Section 812 of the Clean Air Act Amendments (CAAA) of 1990 requires the U.S. Environmental Protection Agency (EPA) to perform periodic, comprehensive analyses of the total costs and total benefits of programs implemented pursuant to the CAAA. The first prospective analysis was completed in 1999. The second prospective analysis was initiated during 2005. The first step in the second prospective analysis was the development of base and projection year emission estimates that will be used to generate benefit estimates of CAAA programs. This paper describes the analysis, methods, and results of the recently completed emission projections. There are several unique features of this analysis. One is the use of consistent economic assumptions from the Department of Energy's Annual Energy Outlook 2005 (AEO 2005) projections as the basis for estimating 2010 and 2020 emissions for all sectors. Another is the analysis of the different emissions paths for both with and without CAAA scenarios. Other features of this analysis include being the first EPA analysis that uses the 2002 National Emission Inventory files as the basis for making 48-state emission projections, incorporating control factor files from the Regional Planning Organizations (RPOs) that had completed emission projections at the time the analysis was performed, and modeling the emission benefits of the expected adoption of measures to meet the 8-hr ozone National Ambient Air Quality Standards (NAAQS), the Clean Air Visibility Rule, and the PM2.5 NAAQS. This analysis shows that the 1990 CAAA have produced significant reductions in criteria pollutant emissions since 1990 and that these emission reductions are expected to continue through 2020. CAAA provisions have reduced volatile organic compound (VOC) emissions by approximately 7 million t/yr by 2000, and are estimated to produce associated VOC emission reductions of 16.7 million t by 2020. Total oxides of nitrogen (NO(x)) emission reductions attributable to the CAAA are 5, 12, and 17 million t in 2000, 2010, and 2020, respectively. Sulfur dioxide (SO2) emission benefits during the study period are dominated by electricity-generating unit (EGU) SO2 emission reductions. These EGU emission benefits go from 7.5 million t reduced in 2000 to 15 million t reduced in 2020.

Woo JH, He S, Tagaris E, Liao K-, Manomaiphiboon K, Amar P et al. 2008. Development of North American emission inventories for air quality modeling under climate change. Journal of the Air and Waste Management Association 58(11): 1483-94.

Abstract: An assessment of how future climate change will impact regional air quality requires projecting emissions many decades into the future in a consistent manner. An approach that integrates the impact of both the current regulations and the longer-term national and global trends is developed to construct an emissions inventory (EI) for North America for the mid-century in support of a regional modeling study of ozone and particulate matter (PM) less than or equal to 2.5 μm (PM2.5). Because the time horizon of such a distant projection is beyond that of EIs used in typical modeling studies, it is necessary to identify a practical approach that allows the emission projections to account for emission controls and climatic and energy-use changes. However, a technical challenge arises because this requires integration of various different types of information with which emissions from human activities are associated. Often, emission information in global models has less detail and uses coarser spatiotemporal resolution. The method developed here is based on data availability, spatiotemporal coverage and resolution, and future-scenario consistency (i.e., Inter-governmental Panel on Climate Change Special Report on Emissions Scenarios [IPCC SRES] A1B), and consists of two major steps: (1) near-future EI projection (to the year 2020), and (2) longer-term EI projection (to mid-century). The first step is based closely on the U.S. Environmental Protection Agency Clean Air Interstate Rule EI, the Environment Canada EI, as well estimates of Mexico's EI; whereas the second step follows approaches proposed by the EI from the Integrated Model to Assess the Global Environment (IMAGE), developed by Netherlands's National Institute for Public Health and the Environment (RIVM). For the United States, the year-2050 emissions for nitrogen oxides (NOx), sulfur dioxide (SO2), PM2.5, anthropogenic volatile organic compounds (VOCs), and ammonia are projected to change by -55, -55, -30, -40, and +20%, respectively, compared with 2001. NOx and SO2 emission changes are very similar in total amount but different in sectoral contribution. The projected emission trends for Canada and Mexico differ considerably. After taking into account the modeled climate changes, biogenic VOC emission increases from three countries overwhelm the decreases in anthropogenic VOC emissions, leading to a net small increase (~2%) in overall VOC emissions.

Xing J, Wang SX, Chatani S, Zhang CY, Wei W, Hao JM et al. 2011. Projections of air pollutant emissions and its impacts on regional air quality in China in 2020. Atmospheric Chemistry and Physics 11: 3119-36.

Abstract: Anthropogenic emissions of air pollutants in China influence not only local and regional environments but also the global atmospheric environment; therefore, it is important to understand how China's air pollutant emissions will change and how they will affect regional air quality in the future. Emission scenarios in 2020 were projected using forecasts of energy consumption and emission control strategies based on emissions in 2005, and on recent development plans for key industries in China. We developed four emission scenarios: REF[0] (current control legislations and implementation status), PC[0] (improvement of energy efficiencies and current environmental legislation), PC[1] (improvement of energy efficiencies and better implementation of environmental legislation), and PC[2] (improvement of energy efficiencies and strict environmental legislation). Under the REF[0] scenario, the emission of SO2, NOx, VOC and NH3 will increase by 17%, 50%, 49% and 18% in 2020, while PM10 emissions will be reduced by 10% over East China, compared to that in 2005. In PC[2], sustainable energy polices will reduce SO2, NOx and PM10 emissions by 4.1 Tg, 2.6 Tg and 1.8 Tg, respectively; better implementation of current control policies will reduce SO2, NOx and PM10 emission by 2.9 Tg, 1.8 Tg, and 1.4 Tg, respectively; strict emission standards will reduce SO2, NOx and PM10 emissions by 3.2 Tg, 3.9 Tg, and 1.7 Tg, respectively. Under the PC[2] scenario, SO2 and PM10 emissions will decrease by 18% and 38%, while NOx and VOC emissions will increase by 3% and 8%, compared to that in 2005. Future air quality in China was simulated using the Community Multi-scale Air Quality Model (CMAQ). Under REF[0] emissions, compared to 2005, the surface concentrations of SO2, NO2, hourly maximum ozone in summer, PM2.5, total sulfur and nitrogen depositions will increase by 28%, 41%, 8%, 8%, 19% and 25%, respectively, over east China. Under the PC[2] emission scenario, the surface concentrations of SO2, PM2.5, total sulfur depositions will decrease by 18%, 16% and 15%, respectively, and the surface concentrations of NO2, nitrate, hourly maximum ozone in summer, total nitrogen depositions will be kept as 2005 level, over east China. The individual impacts of SO2, NOx, NH3, NMVOC and primary PM emission changes on ozone and PM2.5 concentrations have been analyzed using sensitivity analysis. The results suggest that NOx emission control need to be enhanced during the summertime to obtain both ozone and PM2.5 reduction benefits. NH3 emission controls should also be considered in order to reduce both nitrate concentration and total nitrogen deposition in the future.

Zhang Q, Streets DG, Carmichael GR, He KB, Huo H, Kannari A et al. 2009. Asian emissions in 2006 for the NASA INTEX-B mission. Atmospheric Chemistry and Physics 9(14): 5131-53.

Abstract: A new inventory of air pollutant emissions in Asia in the year 2006 is developed to support the Intercontinental Chemical Transport Experiment-Phase B (INTEX-B) funded by the National Aeronautics and Space Administration (NASA). Emissions are estimated for all major anthropogenic sources, excluding biomass burning. We estimate total Asian anthropogenic emissions in the year 2006 as follows: 47.1 Tg SO2, 36.7 Tg NOx, 298.2 Tg CO, 54.6 Tg NMVOC, 29.2 Tg PM10, 22.2 Tg PM2.5, 2.97 Tg BC, and 6.57 Tg OC. We emphasize emissions from China because they dominate the Asia pollutant outflow to the Pacific and the increase of emissions from China since 2000 is of great concern. We have implemented a series of improved methodologies to gain a better understanding of emissions from China, including a detailed technology-based approach, a dynamic methodology representing rapid technology renewal, critical examination of energy statistics, and a new scheme of NMVOC speciation for model-ready emissions. We estimate China's anthropogenic emissions in the year 2006 to be as follows: 31.0 Tg SO2, 20.8 Tg NOx, 166.9 Tg CO, 23.2 Tg NMVOC, 18.2 Tg PM10, 13.3 Tg PM2.5, 1.8 Tg BC, and 3.2 Tg OC. We have also estimated 2001 emissions for China using the same methodology and found that all species show an increasing trend during 2001–2006: 36% increase for SO2, 55% for NOx, 18% for CO, 29% for VOC, 13% for PM10, and 14% for PM2.5, BC, and OC. Emissions are gridded at a resolution of 30 min×30 min and can be accessed at our web site (http://mic.greenresource.cn/intex-b2006).

Zhao Y, Wang S, Duan L, Lei Y, Cao P, Hao J. 2008. Primary air pollutant emissions of coal-fired power plants in China: Current status and future prediction. Atmospheric Environment 42(36): 8442-52.

Abstract: To explore the atmospheric emissions of coal-fired power sector in China, a unit-based method was developed based on detailed information of unit type, fuel quality, emission control technology, and geographical location. During 2000-2005, the period when power sector developed fastest in the past 20 years, SO2, NOx and PM emissions of coal-fired power plants increased by 1.5, 1.7 and 1.2 times, respectively. The SO2, emission of coal-fired power sector was estimated to be 16 097 kt in 2005, and would decrease to 11 801 kt in 2010, attributed mainly to the wide application of the flue gas desulfurization (FGD) technology. The NOx emission, however, would increase from 6965 kt in 2005 to 9680 kt in 2010, since few NOx control measures would be taken during the five years. The TSP, PM10, and PM2.5 emissions in 2005 were estimated to be 2774, 1842 and 994 kt, and the values would be 2540, 1824 and 1090 kt in 2010 respectively. The wet FGD would play an important role on dust emission removal. Through faithful implementation of closing small units and emission control policies in the acid rain and sulfur dioxide control zones, approximately 33%, 6% and 25% of SO2, NOx, and TSP emissions respectively could be further reduced in 2010. Emissions in 2015 and 2020 of coal-fired power plants were predicted applying scenario analysis. For SO2 and TSP, optimistic situation can be achieved through reasonable control policies; in contrast, NOx would probably be a more serious issue in future.

Zheng J, Zhang L, Che W, Zheng Z, Yin S. 2009. A highly resolved temporal and spatial air pollutant emission inventory for the Pearl River Delta region, China and its uncertainty assessment. Atmospheric Environment 43(32): 5112-22.

Abstract: A highly resolved temporal and spatial Pearl River Delta (PRD) regional emission inventory for the year 2006 was developed with the use of best available domestic emission factors and activity data. The inventory covers major emission sources in the region and a bottom–up approach was adopted to compile the inventory for those sources where possible. The results show that the estimates for SO2, NOx, CO, PM10, PM2.5 and VOC emissions in the PRD region for the year 2006 are 711.4 kt, 891.9 kt, 3840.6 kt, 418.4 kt, 204.6 kt, and 1180.1 kt, respectively. About 91.4% of SO2 emissions were from power plant and industrial sources, and 87.2% of NOx emissions were from power plant and mobile sources. The industrial, mobile and power plant sources are major contributors to PM10 and PM2.5 emissions, accounting for 97.7% of the total PM10 and 97.2% of PM2.5 emissions, respectively. Mobile, biogenic and VOC product-related sources are responsible for 90.5% of the total VOC emissions. The emissions are spatially allocated onto grid cells with a resolution of 3 km × 3 km, showing that anthropogenic air pollutant emissions are mainly distributed over PRD central-southern city cluster areas. The preliminary temporal profiles were established for the power plant, industrial and on-road mobile sources. There is relatively low uncertainty in SO2 emission estimates with a range of -16% to +21% from power plant sources, medium to high uncertainty for the NOx emissions, and high uncertainties in the VOC, PM2.5, PM10 and CO emissions.

Grey literature

Adina T, Florin PM, Dragos P, Andrei R. 2011. Modelling dispersion of pollutants from the atmosphere from thermal Rovinari. In: Recent Researches in Manufacturing Engineering, 3rd WSEAS International Conference on Manufacturing Engineering, Quality and Production Systems, 35-9.

Abstract: The purpose of this paper is to conduct an assessment of the potential for undesirable effects on the environment and human health and objective analysis on the pollution of SO2, NO2, CO, particulate Rovinari area. Mathematical modeling of the concentration fields was performed for the main pollutants emitted from sources related to the objective using Austal View program. Were considered, the pollutants were associated values for the protection of sensitive receptors likely to be affected (people of the neighborhood). Graphic representation of mathematical modeling results of the dispersion of pollutants was georeferenced topographical maps.

Bulucea CA, Jeles A, Mastorakis NE, Bulucea CA, Brindusa C. 2011. Assessing the environmental pollutant vector of combustion gases emission from coal-fired power plants. In: Recent Researches in Geography, Geology, Energy, Environment and Biomedicine, 35-42.

Abstract: Within the present industrial metabolism, electric and thermal energy production is one of the main consumers of fossil fuels. Coal is a natural resource and fossil fuel used in the coal-fired power plants in Romania. Unfortunately, beyond the environmental depletion, the problems caused by the environmental releases in operation of these power plants are also related to human health impact. This paper highlights some of these problems, analyzing the pollutant vector of combustion emissions and the specific physical parameters associated to a coal-fired power plant in Romania. The environmental pollutants belonging to combustion gases vector, as sulfur dioxide SO2, nitrogen oxides NOx, particulate matter PM, and carbon dioxide CO2 have been analyzed for the Energetic Power Plant of Turceni - Romania. Mathematical models of environmental pollutant vector, estimating the emission factors specific to fossil fuel combustion process have been applied for the thermo-electrical blocks on 330 MW of Turceni power plant. For each combustion gases component of pollutant vector, the results with regard to emission factor and pollutant concentration are presented in this study. Also, the Projection in the Mirror of the combustion gases pollutant vector had allowed an evaluation of mass concentration of the ash in the combustion gases quill. In this case study for the thermoelectric blocks of 330 MW of Turceni power plant, the projection in mirror is developed for distances of 300 meters, and for modelling the ascendant smoke quill according to this projection in mirror, it has been adopted the FDP pattern - probability density function, elaborated by Weil. Accordingly, the nomograms of ash-particulate matter pollutant have been simulated.

Alberta Environment. 2008a. Alberta Air Emissions Trends and Projections. Edmonton, AB. Available at http://environment.gov.ab.ca/info/library/7964.pdf.

Abstract: *No abstract available.*

Excerpt from Introduction:
[This paper was prepared for the CASA Clean Air Strategy Project Team to provide a summary of air emissions trends and projections for Alberta. Emissions by industry sector and predicted regional distribution of emissions are also presented. In addition emissions information relevant to CASA project teams has been included. Data and figures from various external sources were used and are identified throughout the report.]

Alberta Environment. 2008b. Technical and Regulatory Review and Benchmarking of Air Emissions from Alberta's Kraft Pulp Mills. Prepared by: Bruce Process Consulting Ltd. Available at http://environment.gov.ab.ca/info/library/8021.pdf.

Abstract: *No abstract available.*

Excerpt from Executive Summary:
[The Environmental Policy Branch of Alberta Environment (AB Environment) requires a study of emission limits and control technologies for pulp and paper mills and issued a request for proposal on 13 April 2007. The purpose of the study is to compare the Alberta regulations and actual mill emissions performance relative to international standards, with a view to furthering environmental performance.
The scope includes benchmarking the Alberta mills against other mills in selected jurisdictions, describing best available processes and emission control technologies with specific attention to odorous gas venting, reviewing air emission guidelines and standards in relevant jurisdictions, and identifying any "early wins" that would improve the environmental performance while providing economic benefits. The study is limited to the kraft pulp mills of Alberta. Initial investigation of permits showed that the main sources of emissions of concern such as particulate matter (PM), nitrogen oxides (NOx), sulphur gases (odour and SO2) were the four kraft pulp mills. The other mills comprising two mechanical pulp mills, and the sole newsprint mill would represent small sources in comparison. In addition, as these three mills are not required to submit emission data to AB Environment, no benchmarking data is available. AB Environment staff therefore agreed that study effort should concentrate on the Alberta kraft pulp mills. These are located at Boyle, Grand Prairie, Hinton and Peace River.]
[Turning to benchmarking actual emission performance, source emission sampling data submitted to Alberta Environment for 2005 was assembled for the four Alberta kraft mills, as was data for a number of selected Canadian and US kraft pulp mills. While Finland and Sweden publish emission data, they do so only on a mill

wide basis and so, without data on individual sources, they could not be included.
The data within each group was ranked by magnitude and is presented in graphical form with the data for each Alberta mill labeled. A graphical presentation was selected to bring out any clear overall pattern, but none was apparent. The high degree of scatter reflects the wide range of technological age and degrees of modernization of these Canadian and US mills.]

Commission for Environmental Cooperation. 2011. North American Power Plant Air Emissions. Available at http://www.cec.org/storage/56/4876_powerplant_airemission_en.pdf.

Abstract: *No abstract available.*

Excerpt from Introduction:
[The fossil fuel electricity generation sector is an important component of North America's economy and provides an indispensable commodity. However, this sector is one of the major contributors to atmospheric pollutants in the region, including criteria air contaminants such as sulfur dioxide, nitrogen oxides, and particulate matter; and greenhouse gases such as carbon dioxide and methane. Depending on the fuel used, power plants can also release trace metals such as mercury. There is growing concern about the effects of these pollutants on our local and global environments.
Each of the three North American countries has a unique profile involving private and/or public ownership of electric utilities, combinations of electricity generation technologies, and differences in fuel availability and usage. Interdependencies also exist among and within the three countries, not only in terms of electricity imports and exports to meet energy demand, but also in terms of the production and management of power plant emissions.]
[The most recent year for which data from the three countries were available at the time of writing was 2005; therefore, all the information presented in this report is for 2005 unless otherwise specified. Only public information on facilities' installed capacity, electricity generation, technologies utilized, and fuels burned is presented; in the absence of available data and where possible, estimates are calculated based on surrogate public information. The scope and level of information of the present report have increased since the 2004 edition, due to the recent availability of public data for emissions of methane (CH4), nitrous oxide (N2O) and particulate matter (PM). These were unavailable for the previous report, which was limited to the analysis of data for emissions of sulfur dioxide (SO2), nitrogen oxides (NOX), mercury (Hg) and carbon dioxide (CO2). The present report also covers a larger number of facilities than were included in the 2004 report, thereby offering a more complete picture of the contribution of each country to power plant air emissions across North America. Emissions and operational information on the facilities included in this report can be accessed through the CEC website at www.cec.org/powerplants.
Through the presentation and analysis of the latest available data on the sources, types and amounts of pollutants generated in each of the three countries, this report can improve our understanding of North American power plant emissions and their associated environmental and human health impacts for the region, and support decision-making relative to reducing and preventing pollution from this sector.]

Electric Power Research Institute. 2009. Updated Hazardous Air Pollutants (HAPs) Emissions Estimates and Inhalation Human Health Risk Assessment for US Coal-Fired Electric Generating Units. Report 1017980, Palo Alto, California. Available at http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001017980.

Abstract: Since the mid-1990s, there has been no comprehensive evaluation of hazardous air pollutants (HAPs) emissions from U.S. coal-fired electric power plants and the risks associated with those emissions. With the exception of mercury, none of the HAPs-classified chemicals has been fundamentally reassessed for more than 15 years. The set of EPRI studies reported on here provides a fundamental reevaluation of potential HAPs emissions from coal-fired power plants based on current data concerning coals burned, controls installed, and new measurements taken in the intervening period. In addition, the human health risks due to inhalation of trace amounts of HAPs emitted from coal-fired power plants are assessed for each individual power plant facility as well as for facilities having stacks located within 50 km of one another. These risk assessments were carried out using current EPA-supported air quality models and archived databases on the location of residents in the vicinity of each power plant stack. This report presents an

updated assessment of HAPs emissions and the consequent human health risks by inhalation for all U.S. coal-fired electric generation units.

Environmental Integrity Project. 2013. The Toxic Ten: Top Power Plant Emissions of Mercury, Toxic Metals, and Acid Gases in 2011. Available at http://environmentalintegrity.org/news_reports/documents/Toxic10PowerPlantsreport-January32013.pdf.

Abstract: *No abstract available.*

Excerpt from Introduction:
[Coal-burning power plants release millions of pounds of toxic pollutants into the air every year, including mercury and other metals like arsenic and chromium, and acid gases like hydrogen chloride. The United States Environmental Protection Agency's Toxics Release Inventory (TRI) can be used to identify the largest sources of these dangerous pollutants based on annual reports the electric power industry submits to the Agency under federal Right to Know laws. Nationwide, equipment installed to reduce emissions of sulfur dioxide and particulate matter has also helped cut down on the release of mercury, toxic metals and acid gases from power plants over the last ten years. But that progress is uneven, and the dirtiest plants continue to churn out thousands of pounds of toxins that can be hazardous to human health even in small concentrations.]

Environmental Integrity Project. 2011. Waste-To-Energy: Dirtying Maryland's Air by Seeking a Quick Fix on Renewable Energy? Washington, DC. Available at http://www.environmentalintegrity.org/documents/FINALWTEINCINERATORREPORT-101111.pdf.

Abstract: *No abstract available.*

Excerpt from Executive Summary:
[Maryland has recently seen a surge in proposals to construct or expand Waste-to-Energy (WTE) incinerators which will result in more than doubling Maryland's capacity to incinerate trash for energy use. These facilities combust trash (i.e. municipal solid waste) to generate electricity and produce steam for heating buildings. Although industry reports show that no incinerators were constructed in the entire country between 1996 and 2007, Maryland currently has at least three projects – the new Energy Answers plant in Baltimore City, the proposed expansion of the Harford County Resource Recovery Facility, in Harford County, and the proposed Frederick County Incinerator in Frederick County – under development or already permitted for construction. In light of this recent trend, the Environmental Integrity Project researched the emissions from these facilities, the policies underlying this trend, the impact on renewable energy in Maryland, and steps Maryland can take to minimize emissions or reduce the need for new plants. Our results are summarized below:
-WTE incinerators in Maryland typically emit more pollutants per hour of energy produced than Maryland's largest coal-fired power plants. Emissions include pollutants like mercury and lead that disproportionately harm children, are harmful even in small doses and bioaccumulate over time.
-These facilities produce ash in the combustion process that can be highly toxic and must be carefully tested to determine its toxicity and appropriate management.]

Mittal ML, Sharma C, Singh R. 2012. Estimates of emissions from coal fired thermal power plants in India. In: 20th Emission Inventory Conference, Tampa, Florida.

Abstract: Coal is the primary fuel for electricity generation in India and its usage is continuously increasing to meet the energy demands of the country. This paper presents emissions of carbon dioxide (CO2), sulfur dioxide (SO2), and nitric oxide (NO) from thermal power plants in India for a period of nine years from 2001-02 to 2009-10. The emission estimates are based on a model in which the mass emission factors are theoretically calculated using the basic principles of combustion and operating conditions. Future emission

scenarios for the period up to 2020-21 are generated based on the estimates of the nine years from 2001-02 to 2009-10. Power plants in India use different qualities of coal, different combustion technologies and operating conditions. As a result, these plants have differences in achieved efficiencies (coal usage per unit of electricity). The estimates show region wise differences in total emissions as well as differences in emissions per unit of electricity. Computed estimates show the total CO2 emissions from thermal power plants have increased from 323474.85 Gg for the year 2001-02 to 498655.78 Gg in 2009-10. SO2 emissions increased from 2519.93 Gg in 2001-02 to 3840.44 Gg in 2009-10, while NO emissions increased from 1502.07 Gg to 2314.95 Gg during this period. The emissions per unit of electricity are estimated to be in the range of 0.91 to 0.95 kg/kWh for CO2, 6.94 to 7.20 g/kWh for SO2, and 4.22 to 4.38 g/kWh for NO during the period 2001-02 to 2009-10. The future emission scenario, based on the projected coal consumption in Indian thermal power plants by Planning Commission of India under 'Business-as Usual (BAU)' and 'Best case Scenario (BCS)' show the emission in the range of 714976 to 914680 Gg CO2, 4734 to 6051 Gg SO2 and 366 to 469 Gg NO in the year 2020-21. Increase in coal use efficiencies in electricity generation by thermal power plants can significantly reduce the emissions of greenhouse and polluting gases. This methodology provides a useful tool for inventory preparation in a sector where measured values for emissions factors are very sparse.

MJ Bradley & Associates. 2013. Benchmarking Air Emissions of the 100 Largest Electric Power Producers in the United States. Concord, MA. Available at http://www.nrdc.org/air/pollution/benchmarking/files/benchmarking-2013.pdf.

Abstract: *No abstract available.*

Excerpt from Introduction:
[This report examines and compares the stack air pollutant emissions of the 100 largest power producers in the United States based on their 2011 generation, plant ownership, and emissions data. Table 1 lists the 100 largest power producers featured in this report ranked by their total electricity generation from fossil fuel, nuclear, and renewable energy facilities. These producers include public and private entities (collectively referred to as "companies" or "producers" in this report) that own more than 2,600 power plants and account for 86 percent of reported electric generation and 88 percent of the industry's reported emissions. The report focuses on four power plant pollutants for which public emissions data are available: sulfur dioxide (SO2), oxides of nitrogen (NOx), mercury (Hg), and carbon dioxide (CO2). These pollutants are associated with significant environmental and public health problems, including acid deposition, global warming, fine particle air pollution, mercury deposition, nitrogen deposition, ozone smog, and regional haze. The report benchmarks, or ranks, each company's absolute emissions and its emission rate (determined by dividing emissions by electricity produced) for each pollutant against the emissions of the other companies.]

Natural Resources Defense Council. 2012. Toxic Power: How Power Plants Contaminate Our Air and States. Available at http://www.nrdc.org/air/files/toxic-power-presentation.pdf.

Abstract: *No abstract available.*

Excerpt from Introduction:
[The electric sector is the largest industrial (stack) source of toxic air pollution in the United States. In fact, in 2010 coal- and oil-fired power plants alone accounted for nearly 44 percent of all reported toxic pollution from industrial sources. Thanks to the U.S. Environmental Protection Agency (EPA), however, toxic pollution from power plants should decline dramatically over the next several years. The EPA recently finalized the Mercury and Air Toxics Standards (MATS) which requires significant reductions in mercury and air toxic emissions. Compared to 2010 levels, the standard will reduce mercury pollution from 34 tons to 7 tons, a 79% reduction, by 2015. Sulfur dioxide pollution will be reduced from 5,140,000 tons in 2010 to 1,900,000 tons in 2015, a 63% reduction. Another dangerous acid gas, hydrochloric acid, will be reduced from 106,000 tons in 2010 to 5,500 tons in 2015, a 95% reduction.]
[The Toxic Twenty states are the top states responsible for a disproportionate share of toxic emissions from the U.S. electric sector. In 2010, these Toxic Twenty states accounted for approximately: 92% of electric sector toxic air pollution; 72% of electric sector mercury emissions. For comparison, in 2010, these same states accounted for just: 62% of electricity generation; 54% of total U.S. population; 50% of total U.S.

economic output. Residents of the Toxic Twenty and surrounding states may be exposed to dangerous levels of toxic pollution and could face increased risk of certain health disorders.]

4. List of abstracts – non-priority substances

4.1 Particulate matter components (elements, metals, polycyclic aromatic hydrocarbons)

4.1.1 PM components - health effects

Hu SW, Chan YJ, Hsu HT, Wu KY, ChangChien GP, Shie RH, Chan CC. 2011. Urinary levels of 1-hydroxypyrene in children residing near a coal-fired power plant. Environmental Research 111(8): 1185-1191.

Funding Agency: Taiwan Chapter of Society for Risk Analysis	
Study Location: Taiwan	**Study Design:** Cross-sectional
Fuel Type: Coal	**Chemicals:** PAH

Abstract: Background: The effects of emissions from coal-fired power plants on children's exposure to polycyclic aromatic hydrocarbons (PAHs) are not well understood. Objectives: This study aimed to evaluate the sources and the urinary levels of 1-hydroxypyrene, a biomarker of exposure to PAHs, among children living in proximity to a coal-fired power plant. Methods: Study areas consisted of two high exposure and two low exposure communities, at different distances and directions from a large coal-fired power plant in central Taiwan. Study subjects included 369 children aged 1-13 years and randomly selected from each community. Each child's urinary 1-hydroxypyrene concentration was measured by a high-performance liquid chromatography-fluorescence detector method. Samples of ambient air were analyzed for PAHs using a gas chromatography-mass spectrometry method. Information on important factors was collected by an interview using a structured questionnaire. Multiple regression analysis was used to assess factors significantly associated with urinary 1-hydroxypyrene levels. Results: Levels of PAHs in ambient air in the high exposure communities were higher than those in the low exposure communities. Children living in high exposure communities had higher mean urinary 1-hydroxypyrene concentrations than those in low exposure communities (0.186 and 0.194 vs. 0.113 and 0.122 μmol/mol-creatinine, respectively). The difference in urinary 1-hydroxypyrene levels between the high exposure communities and one low exposure community remained significant after adjusting for age, gender, environmental tobacco smoke, dietary exposure, and traffic. Conclusions: Children living in communities downwind of and in proximity to the coal-fired power plant had significantly increased urinary 1-hydroxypyrene levels.

Strengths and Limitations:

Strengths: Objective outcome measure. Considered several potential confounders (eg. demographic factors, environmental tobacco smoke, diet, traffic, cooking/heating methods at home). Measured 16 different PAHs in ambient air samples.
Limitations: Weak exposure assessment (high exposure vs low exposure community). PAH levels only measured during two seasons. Contribution of power plant emissions to total PAH pollution not known. No discussion of blinding (for interviews or urine analysis).

Study Score and Ranking:

0.88; High

Perera F, Li TY, Lin C, Tang D. 2012. Effects of prenatal polycyclic aromatic hydrocarbon exposure and environmental tobacco smoke on child IQ in a Chinese cohort. Environmental Research 114: 40-6.

Funding Agency: V. Kann Rasmussen Foundation, Energy Foundation, Schmidt Family Foundation, Rockefeller Brothers Fund, Porpoise Fund

Study Location: China	**Study Design:** Prospective cohort
Fuel Type: Coal	**Chemicals:** PAH

Abstract: Objective: This study of a birth cohort in the city of Tongliang in Chongqing, China, evaluated the relationship between two prenatal exposures (polycyclic aromatic hydrocarbons (PAH) and environmental tobacco smoke (ETS)) and child intelligence quotient (IQ) as measured by the Wechsler Preschool and Primary Scale of Intelligence at age 5 years. A coal-fired power plant was the major source of ambient PAH in this city. We tested the hypothesis that, after adjusting for potential confounders, prenatal exposure to these pollutants would be associated with lower IQ scores at 5 years of age. Methods: Nonsmoking mothers and children were enrolled before delivery. PAH exposure was measured by DNA adducts in umbilical cord white blood cells using High-Performance Liquid Chromatography-Fluorescence. Estimated exposure to environmental tobacco smoke was based on personal interview. At age 5 years, scores for verbal, performance, and full scale IQ were obtained. Multiple regression was used to test the main effects of adducts and environmental tobacco smoke on IQ and to explore the interactions between these exposures on IQ. Results: after adjusting for potential confounders, neither DNA adducts nor exposure to environmental tobacco smoke had significant main effects on IQ. However, significant interactions between adducts and environmental tobacco smoke were observed on full scale ($p=0.025$) and verbal ($p=0.029$) IQ scores, indicating that the adverse effects of prenatal PAH exposure became greater as exposure to environmental tobacco smoke increased. The interaction on performance IQ score was not significant ($p=0.135$). Conclusion: These results suggest that exposure of pregnant women to emissions of PAHs from the coal-burning plant, in combination with prenatal exposure to environmental tobacco smoke, may have adversely affected cognitive function of children at age 5. The polluting coal-fired plant has since been closed by the government, with likely important benefits to child health and development.

Strengths and Limitations:

Strengths: Study well-defined and thorough. Use of cord blood DNA adducts as a biomarker of exposure. Use of standardized testing to examine neurodevelopmental outcomes (Child IQ). Controlled for potential confounders, including exposure to environmental tobacco smoke.
Limitations: Small sample size. No information on post-natal exposures.

Study Score and Ranking:

0.96; High

Perera F, Li TY, Zhou ZJ, Yuan T, Chen YH, Qu L et al. 2008. Benefits of reducing prenatal exposure to coal-burning pollutants to children's neurodevelopment in China. Environmental Health Perspectives 116(10): 1396-400.

Funding Agency: National Institute of Environmental Health Sciences, V. Kann Rasmussen Foundation, Energy Foundation, Schmidt Family Foundation, Rockefeller Brothers Fund, Porpoise Fund

Study Location: China	**Study Design:** Prospective cohort
Fuel Type: Coal	**Chemicals:** Hg, Pb, PAH

Abstract: Background: Coal burning provides 70% of the energy for China's industry and power, but releases large quantities of polycyclic aromatic hydrocarbons (PAHs) and other pollutants. PAHs are reproductive and developmental toxicants, mutagens, and carcinogens. Objective: We evaluated the benefit to neurobehavioral development from the closure of a coal-fired power plant that was the major local source of ambient PAHs. Methods: The research was conducted in Tongliang, Chongqing, China, where a coal-fired power plant operated seasonally before it was shut down in May 2004. Two identical prospective cohort studies enrolled nonsmoking women and their newborns in 2002 (before shutdown) and 2005 (after shutdown). Prenatal PAH exposure was measured by PAH-DNA adducts (benzo[a]pyrene-DNA) in umbilical cord blood. Child development was assessed by the Gesell Developmental Schedules at 2 years of age. Prenatal exposure to other neurotoxicants and potential confounders (including lead, mercury, and environmental tobacco smoke) was measured. We compared the cohorts regarding the association between PAH-DNA adduct levels and neurodevelopmental outcomes. Results: Significant associations previously seen in 2002 between elevated adducts and decreased motor area developmental quotient (DQ) ($p = 0.043$) and average DQ ($p = 0.047$) were not observed in the 2005 cohort ($p = 0.546$ and $p = 0.146$). However, the direction of the relationship did not change. Conclusion: The findings indicate that neurobehavioral development in Tongliang children benefited by elimination of PAH exposure from the coal-burning plant, consistent with the significant reduction in PAH-DNA adducts in cord blood of children in the 2005 cohort. The results have implications for children's environmental health in China and elsewhere.

Strengths and Limitations:

Strengths: Study well-defined and thorough. Use of cord blood DNA adducts as a biomarker of exposure. Use of standardized testing to examine neurodevelopmental outcomes. Controlled for potential confounders, including exposure to environmental tobacco smoke.
Limitations: Small sample size. No information on post-natal exposures.

Study Score and Ranking:

0.96; High

Tang D, Li TY, Chow JC, Kulkarni SU, Watson JG, Ho SS et al. 2014. Air pollution effects on fetal and child development: A cohort comparison in China. Environmental Pollution 185: 90-6.

Funding Agency: V. Kann Rasmussen Foundation, Energy Foundation, Schmidt Family Foundation, Rockefeller Brothers Fund, Porpoise Fund	
Study Location: China	**Study Design:** Prospective cohort
Fuel Type: Coal	**Chemicals:** PAH

Abstract: In Tongliang, China, a coal-fired power plant was the major pollution source until its shutdown in 2004. We enrolled two cohorts of nonsmoking women and their newborns before and after the shutdown to examine the relationship between prenatal exposure to polycyclic aromatic hydrocarbons (PAHs) and fetal and child growth and development. PAHs were used to measure exposure to air pollution generated by the power plant. Using PAH-DNA adduct levels as biomarkers for the biologically effective dose of PAH exposure, we examined whether PAH-DNA adduct levels were associated with birth outcome, growth rate, and neurodevelopment. Head circumference was greater in children of the second cohort, compared with the first ($p = 0.001$), consistent with significantly reduced levels of cord blood PAH-DNA adducts in cohort II ($p < 0.001$) and reduced levels of ambient PAHs ($p = 0.01$).

Strengths and Limitations:

Strengths: Study well-defined and thorough. Use of cord blood DNA adducts as a biomarker of exposure. Objective measure of health effect. Controlled for potential confounders, including exposure to environmental tobacco smoke.
Limitations: Small sample size. No information on post-natal exposures.

Study Score and Ranking:

0.96; High

Tang D, Li TY, Liu JJ, Zhou ZJ, Yuan T, Chen YH et al. 2008. Effects of prenatal exposure to coal-burning pollutants on children's development in China. Environmental Health Perspectives 116(5): 674-9.

Funding Agency: National Institute of Environmental Health Sciences, V. Kann Rasmussen Foundation, Energy Foundation, Schmidt Family Foundation, Rockefeller Brothers Fund, Porpoise Fund

Study Location: China	**Study Design:** Prospective cohort
Fuel Type: Coal	**Chemicals:** Hg, Pb, PAH

Abstract: Background: Environmental pollutants such as polycyclic aromatic hydrocarbons (PAHs), lead, and mercury are released by combustion of coal and other fossil fuels. Objectives: In the present study we evaluated the association between prenatal exposure to these pollutants and child development measured by the Gesell Developmental Schedules at 2 years of age. Methods: The study was conducted in Tongliang, Chongqing, China, where a seasonally operated coal-fired power plant was the major source of ambient PAHs and also contributed lead and mercury to the air. In a cohort of nonsmoking women and their newborns enrolled between March 2002 and June 2002, we measured levels of PAH–DNA adducts, lead, and mercury in umbilical cord blood. PAH–DNA adducts (specifically benzo[a]pyrene adducts) provided a biologically relevant measure of PAH exposure. We also obtained developmental quotients (DQs) in motor, adaptive, language, and social areas. Results: Decrements in one or more DQs were significantly associated with cord blood levels of PAH–DNA adducts and lead, but not mercury. Increased adduct levels were associated with decreased motor area DQ ($p = 0.043$), language area DQ ($p = 0.059$), and average DQ ($p = 0.047$) after adjusting for cord lead level, environmental tobacco smoke, sex, gestational age, and maternal education. In the same model, high cord blood lead level was significantly associated with decreased social area DQ ($p = 0.009$) and average DQ ($p = 0.038$). Conclusion: The findings indicate that exposure to pollutants from the power plant adversely affected the development of children living in Tongliang; these findings have implications for environmental health policy.

Strengths and Limitations:

Strengths: Study well-defined and thorough. Use of cord blood DNA adducts as a biomarker of exposure. Use of standardized testing to examine neurodevelopmental outcomes. Controlled for potential confounders, including exposure to environmental tobacco smoke.
Limitations: Small sample size. No information on post-natal exposures.

Study Score and Ranking:

0.96; High

Bencko V, Rames J, Fabiánová E, Pesek J, Jakubis M. 2009. Ecological and human health risk aspects of burning arsenic-rich coal. Environmental Geochemistry and Health 31(S1): 239-243.

Funding Agency: European Community (INCO COPERNICUS EXPASCAN), Ministry of Education of the Czech Republic

Study Location: Slovakia	**Study Design:** Prospective
Fuel Type: Coal	**Chemicals:** As

Abstract: The subject of the study was the ecological and human health consequences of environmental pollution from emissions arising from burning local coal with an arsenic content ranging from 900 to 1,500 g/tonne of dry substance. The first indication of environmental pollution by arsenic-containing emissions was the mass extinction of honeybee colonies. The neurotoxic and carcinogenic aspects of arsenic exposure were followed. On using a group diagnostics approach, significant hearing losses were detected in exposed children in both air and bone conduction audiometry at high frequency range (4,000 and 8,000 Hz, respectively). Exposure assessment of the local population of the Prievidza district, Central Slovakia, was based on biological monitoring. The criterion of higher exposure was arsenic content in hair exceeding concentrations of 3 μg/g of hair. In a 7.5-km radius of the exposed region, live about two-tenths of the district population who were considered as "exposed" and rest of the district served as the "reference" population. The subject of our analysis was a database of 1,503 non-melanoma skin cancer (NMSC) cases (756 in men and 747 in women) collected from 1977 to 1996 in the Prievidza district, Central Slovakia (population ~125,000). The age standardized incidence of NMSC (each confirmed by histological examination) in non-occupational settings ranged from 45.9 to 93.9 in men and from 34.6 to 81.4 in women. Analysis of our data demonstrates a positive correlation between human cumulative exposure to arsenic and incidence of NMSC.

Strengths and Limitations:

Strengths: Objective outcome measure. Utilized biological monitoring (As concentrations in hair and urine in a sample of children) to estimate area exposure levels. Area followed for a 20-year period.
Limitations: No assessment of individual exposure. No discussion of subject recruitment or blinding (for measurement of As in hair and urine). Route of exposure not considered (inhalation, oral, soil). Did not control for confounding factors (though smoking was briefly discussed).

Study Score and Ranking:

0.54; Moderate

Chiang WF, Yang HJ, Lung SCC, Huang S, Chiu CY, Liu IL, et al. 2008. A comparison of elementary schoolchildren's exposure to arsenic and lead. Journal of Environmental Science and Health C 26(3): 237-255.

Funding Agency: Not stated	
Study Location: Taiwan	**Study Design:** Prospective cross-sectional
Fuel Type: Coal	**Chemicals:** As, Pb

Abstract: One hundred fifty seven fifth-grade students (aged 10–12 years) from three elementary schools in three different towns in Taichung County, Taiwan were chosen as study subjects for the present arsenic and lead exposure study. The three towns—Longgang, Shalach, and Shuntain—are known to be highly, moderately, and lightly (control) polluted by As and Pb, respectively. Spot morning urine samples of students were collected and analyzed for arsenic and lead. The levels of As in the urine of Longgang schoolchildren showed the highest value among the three schools, while those of the control group (Shuntain) had the lowest values. In addition, the levels of Pb in the urine of the schoolchildren in Shuntain were significantly lower than those in Longgang and Shalach, while the levels of Pb in the urine of the schoolchildren in Longgang and Shalach showed no significant difference. Results of daily intake of metals from the different exposure pathways (i.e., ingestion from drinking water, household dust and food, and inhalation from airborne particles) showed that the Longgang area had the highest daily intake of As and Pb among the three areas, while the lowest daily intake of As and Pb occurred in the control area (Shuntain). A significant correlation between the doses of daily intake and urinary concentrations of As ($p = 0.002$) and Pb ($p = 0.020$) was observed. This correlation suggests that the increase of unit dose of the daily intake for As resulted in an increase of 0.953 μg g−1 creatinine of As, whereas the increase of unit dose of the daily intake for Pb led to an increase of 0.053 μg g−1 creatinine of Pb. These data indicate that the level of As in urine increased about 18 times higher than that of Pb for the same amount of increase in daily intake.

Strengths and Limitations:

Strengths: Objective outcome measure. Urine samples collected twice (winter, summer); 155/157 children provided samples in both seasons. Measured metals in classroom air on day prior to urine sample; also considered metals in drinking water, food, and dust. Controlled for some potential confounders (parent smoking status, parent occupation, and incense burning in the home).
Limitations: Small sample size. Multiple pollution sources in the county; contribution of power plant to total pollution not known. Not known if investigators blinded to exposure status (particularly for analysis of metals in urine).

Study Score and Ranking:

0.73; Moderate

Chojnacka K, Saeid A, Michalak I, Mikulewicz M. 2012. Effects of local industry on heavy metals content in human hair. Polish Journal of Environmental Studies 21(6): 1563-1570.

Funding Agency: National Center for Research and Development (Europe)	
Study Location: Poland	**Study Design:** Cross-sectional
Fuel Type: Not stated	**Chemicals:** As, Cd, Cr, Cu, Hg, Ni, Pb, Zn

Abstract: In the present work hair mineral analysis of 110 individuals was carried out to determine environmental exposure based on the distance from a subject's residence to a pollutant source. The subjects were asked to fill in a questionnaire concerning their place of living in the city of Wroclaw (lower Silesia, Poland), which was divided in 12 sectors. The content of minerals in hair was determined by ICP-OES and ICP-MS technique in a laboratory certified by the Polish Centre for Accreditation and ILAC-MRA (No. AB 696). The results were elaborated statistically. Each person served as the experimental unit. Post-hoc comparisons were made by Tukey's test and the Spjotvoll/Stolin test. Results were considered significantly different when $p<0.1$. The differences in the content of As were statistically significant between IV-V regions ($p=0.0182$), IV-VII ($p=0.0720$), and IV-XII ($p=0.0586$). In the case of Cd, statistically significant differences were found between II and XII region ($p=0.0377$). Hair has been found to be a valuable indicator of environmental pollution in Wroclaw. The highest content of Al was found in sector VII, As - IV, Cd - II, Hg - VIII, Ni - V, and Pb - IX. The explanation could be the vicinity to a heat and power generating plant and a non-ferrous metals plant or other industrial units, as well as interactions between elements in a human organism. Additionally, statistically significant differences between Ni content ($p=0.0591$) in hair of males and females were found. These results showed that hair mineral content reflected exposure to elements from the environment.

Strengths and Limitations:

Strengths: Objective outcome measure. Considered several different sources of environmental exposure. Measured 39 different elements in the hair samples.
Limitations: Small sample size. Weak exposure assessment (residence distance to pollution source). Subjects were student volunteers (not a random sample of population). No discussion of blinding. No individual data. Did not control for confounding factors.

Study Score and Ranking:

0.65; Moderate

Grant WB. 2009. Air pollution in relation to US cancer mortality rates: an ecological study; Likely role of carbonaceous aerosols and polycyclic aromatic hydrocarbons. 3rd International Symposium on Vitamin D Analogs in Cancer Prevention and Therapy. Anticancer Research 29(9): 3537-3545.

Funding Agency: European Sunlight Association, UV Foundation (USA), Vitamin D Society (Canada)	
Study Location: United States	**Study Design:** Ecological
Fuel Type: Coal	**Chemicals:** BC, PAH, Hydrogen ion (pH)

Abstract: Background: There are large geographical variations of cancer mortality rates in the United States. In a series of ecological studies in the U.S., a number of risk-modifying factors including alcohol, diet, ethnic background, poverty, smoking, solar ultraviolet-B (UVB), and urban/rural residence have been linked to many types of cancer. Air pollution also plays a role in cancer risk. Materials and Methods: Cancer mortality rates averaged by state for two periods, 1950-1969 and 1970-1994, were used in multiple-linear regression analyses with respect to many of the risk-modifying factors mentioned with the addition of an air pollution index in the form of a map of acid deposition in 1985. This index is correlated with emissions from coal-fired power plants. In addition, lung cancer mortality rates for five-year periods front 1970-74 to 1990-94 were used in multiple linear regression analyses including air pollution and cigarette smoking. Results: The air pollution index correlated with respiratory, digestive tract, urogenital, female, blood and skin cancer. Air pollution was estimated to account for 5% of male cancer deaths and 3% of female cancer deaths between 1970-1994. Solar UVB was inversely correlated with all these types of cancer except the respiratory, skin and cervical cancer. Cigarette smoking was directly linked to lung cancer but not to other types of cancer in this study. Conclusion: Combustion of coal, diesel fuel and wood is the likely source of air pollution that affects cancer risk on a large scale, through production of black carbon aerosols with adsorbed polycyclic aromatic hydrocarbons.

Strengths and Limitations:

Strengths: Considered population data over a 45-year period. Large dataset (all states). Objective measure of health outcome (cancer mortality data registry). Accounted for some potential confounding factors at the state-level (eg. state smoking prevalence, alcohol consumption, solar ultraviolet-B (vitamin D production)).
Limitations: Weak exposure assessment. No individual data (eg. smoking status, occupation). Did not provide state or overall sample sizes (only obtained cancer mortality rates from the database). Potential ecological bias. Conference proceeding.

Study Score and Ranking:

0.75; Moderate

Liang F, Zhang G, Tan M, Yan C, Li X, Li Y, Li Y, Zhang Y, Shan Z. 2010. Lead in children's blood is mainly caused by coal-fired ash after phasing out of leaded gasoline in Shanghai. Environmental Science and Technology 44(12): 4760-4765.

Funding Agency: Major project of National Nature Science Foundation of China, Major project of Knowledge Innovation Program of Chinese Academy of Sciences	
Study Location: China	**Study Design:** Cross-sectional
Fuel Type: Coal	**Chemicals:** Pb

Abstract: Lead (Pb) is a highly toxic element to the human body. After phasing out of leaded gasoline we find that the blood lead level of children strongly correlates with the lead concentration in atmospheric particles, and the latter correlates with the coal consumption instead of leaded gasoline. Combined with the $^{207}Pb/^{206}Pb$ ratio measurements, we find that the coal consumption fly ash is a dominate source of Pb exposure to children in Shanghai, rather than vehicle exhaust, metallurgic dust, paint dust, and drinking water. Those particles are absorbed to childrens blood via breathing and digesting their deposition on ground by hand-to-mouth activities. Probably the same situation occurs in other large cities of developing countries where the structure of energy supply is mainly based on coal-combustion.

Strengths and Limitations:

Strengths: TSP samples were collected at 19 sites in Shanghai every day for 15 years. Objective outcome measure. Used Pb isotope ratio measurements to identify coal consumption fly ash as a dominate source of Pb exposure in children. Also considered Pb exposures from soil, paint, and drinking water.
Limitations: No discussion of blinding. No individual data. Did not account for personal confounding factors.

Study Score and Ranking:

0.69; Moderate

Yuan TH, Pien WH, Chan CC. 2013. Urinary heavy metal levels of residents in the vicinity of a petrochemical complex in Taiwan. Proceedings of the 16th International Conference on Heavy Metals in the Environment. E3S Web of Conferences 1: 21001.

Funding Agency: Environmental Protection Bureau (Taiwan)	
Study Location: Taiwan	**Study Design:** Cross-sectional
Fuel Type: Coal	**Chemicals:** Metals

Abstract: A petrochemical complex located in central Taiwan is a major emission source of air pollutants locally. Among these air pollutants, it is concern that the health effects of exposure to heavy metal because of its toxicity and persistency. Therefore, we conducted a biological monitoring study to investigate the effect of heavy metal pollutants on inhabitants around this petrochemical complex. According to the distance and the wind direction from the petrochemical complex, the study area was divided into high exposure (HE) and low exposure (LE) areas, and a total of 673 study subjects who aged above 35 years old living in HE and LE areas were recruited to be collected urine sample and personal information by health screen and questionnaire administration. The concentrations of ten kinds of urinary heavy metals were analyzed by inductively coupled plasma mass spectrometry. After adjusting for age, gender, socioeconomic status, smoking, dietary habits and other potential confounders, the multiple linear regression models showed that the urinary levels of vanadium, manganese, arsenic and strontium of inhabitants in HE area were significantly higher than those of inhabitants in LE area. This study indicated the potential effects of emitted metal pollutants from a petrochemical complex on the residents nearby.

Strengths and Limitations:

Strengths: Large sample size. Objective outcome measure. Controlled for several potential confounders (eg. education levels, nut intake, living close to road, drinking water source, seafood consumption).
Limitations: Weak exposure assessment (reside near petrochemical complex). Participation rates not provided. No ambient pollutant monitoring. Not known if investigators blinded to exposure status (for analysis of metals in urine). Conference proceeding.

Study Score and Ranking:

0.73; Moderate

Zeneli L, Daci NM, Daci-Ajvazi MN, Paçarizi H. 2008. Effects of pollution on lead and cadmium concentration and correlation with biochemical parameters in blood of human population nearby Kosovo thermo power plants. American Journal of Biochemistry and Biotechnology 4(3): 273-276.

Funding Agency: Not stated	
Study Location: Kosovo	**Study Design:** Cross-sectional
Fuel Type: Coal (lignite)	**Chemicals:** Cd, Pb

Abstract: This study describes an investigation of lead and cadmium pollution of Kosovo environment as a result of outflow from the coal processing industry. In a comparative study of lead and cadmium concentration in blood of human population of two different environments in Kosovo, one nearby Kosovo Thermo Power Plants, (Obiliq) a highly polluted environment and the other that is considered as relatively clean rural environment (Dragash). Analysis has shown that emission of particulate in fly ash from Thermo Power Plants during 2005 has exceeded EU standards by 400-500% and that lead concentration was 18mg kg-1 and cadmium concentration was <0.5 mg kg-1 of ash. A series of determinations of lead and cadmium concentrations in blood of population that lives in this environment, have shown direct effects in biochemical parameters CRE (Creatinin), DB (Direct Bilirubine), TB (Total Bilirubine), AST (Aspartat Aminotransferaza), CK (Creatin Kinaza) and CHE (Cholenisteraza) in human organism. The results that were achieved in this study showed a significant difference in average lead and cadmium concentration in the blood of the investigated group of peoples that lives in the area near by the Power Plants, from a control group that lives in a rural unpolluted environment. Lead and cadmium has been analyzed in 50 samples taken from persons from industrial zone and 25 samples in controlled group. The level of lead concentration was 23.0-112.1 μg L-1 in geometric average 46.05 μg L-1, cadmium concentration was 0.44-6.02 μg L-1 in geometric average of 1.56μg L-1. Controlled group from the rural relatively clean environment showed lead concentration of 6.7-33.8 μg L-1 in geometric avarage 17.76 μg L-1 and cadmium concentration of 0.21-1.8 μg L-1 or in geometric average of 0.73 μg L-1. In conclusion in exposed subjects, pollution from coal burning in Power Plant is very important factor for level of lead and cadmium concentration in blood of tested population.

Strengths and Limitations:

Strengths: Objective outcome measure.
Limitations: Small sample size. Weak exposure assessment. Coal mines were also located in exposed area. Not known if investigators blinded to exposure status (particularly for blood analysis). No discussion of subject recruitment. No individual data. Did not control for confounding factors.

Study Score and Ranking:

0.23; Low

Zeneli L, Daci N, Paçarizi H, Daci-Ajvazi MN. 2011. Impact of environmental pollution on human health of the population which lives nearby Kosovo thermopower plants. Indoor and Built Environment 20(4): 479-482.

Funding Agency: Not stated	
Study Location: Kosovo	**Study Design:** Cross-sectional
Fuel Type: Coal (lignite)	**Chemicals:** Cd, Pb

Abstract: This study describes an investigation of effects of environmental pollution as a result of outflow from the coal processing industry. Coal is one the largest deposits of fossil inorganic material where metal accumulations have been observed. The trace elements in coal that could have an undesirable environmental impact include: Hg, Pb, Be, Se, As, Cd, Cu, Ni, Zn, Cr, Ge, Mn, V and Co. Dust consisting of fly ash and bottom ash is one the main components of the environmental pollution that is released from the industrial area of thermopower plants of "Kosova". Analysis of the emission of the fly ash from thermopower plants of "Kosovo" during 2005 showed that contamination had exceeded EU standards by 400-500%. In a comparative study of biochemical parameters in blood of human population of two different environments in Kosovo, one done near by the Kosovo thermopower plants in Obilic, a highly polluted environment investigated group and the other that is considered as a relatively clean rural environment in Dragash, control group. Based on the results achieved in this study, it can be concluded that the pollution emitted from Kosovo thermopower plants by releasing fly ash and bottom ash to the environment has a direct effect on human health of the population living in the industrial area of Obilic.

Strengths and Limitations:

Strengths: Objective outcome measure.
Limitations: Small sample size. Weak exposure assessment. Coal mines were also located in exposed area. Not known if investigators blinded to exposure status (particularly for blood analysis). No discussion of subject recruitment. No individual data. Did not control for confounding factors.

Study Score and Ranking:

0.27; Low

Zeneli L, Paçarizi H, Daci NM, Daci-Ajvazi M, Prenaj A. 2009. The effects of air pollution and smoking on cadmium concentration in human blood and correlation with biochemical parameters. American Journal of Biochemistry and Biotechnology 5(2): 59-62.

Funding Agency: Not stated	
Study Location: Kosovo	**Study Design:** Cross-sectional
Fuel Type: Coal (lignite)	**Chemicals:** Cd

Abstract: Problem statement: The study described the research of the effects that the environment pollution and smoking have in cadmium concentration in human blood, as well as in the correlation between cadmium and the biochemical parameters. Approach: In a comparative study of cadmium concentration in blood of human population of two different environments in Kosovo, one nearby Kosovo Thermo Power Plants (Obiliq), a highly polluted environments (Investigated Group) and the other that was considered as relatively clean rural environment Dragash (control group). Results: The results showed that there exists a significant difference in the average concentration of cadmium in human blood between the Investigated Group (IG) and the Control Group (CG) ($t = -3.34$, $p = 0.0006$). The series of determination of cadmium concentration in blood of population that lives in this environment had shown direct effects in biochemical parameters (direct bilirubine, total bilirubine). Conclusion: Air pollution (from coal burning in power plant) and smoking were very important factors for the level of cadmium concentration in blood, which had an inhibitory effect in the syntheses of bilirubine.

Strengths and Limitations:

Strengths: Objective outcome measure. Accounted for smoking status.
Limitations: Small sample size. Weak exposure assessment. Coal mines were also located in exposed area. Not known if investigators blinded to exposure status (particularly for blood analysis). No discussion of subject recruitment. No individual data (except smoking status). Did not control for confounding factors.

Study Score and Ranking:

0.23; Low

4.1.2 PM components - measured emissions (flue gas or ambient air)

White literature

Bapna M, Sunder Raman R, Ramachandran S, Rajesh TA. 2013. Airborne black carbon concentrations over an urban region in western India-temporal variability, effects of meteorology, and source regions. Environmental science and pollution research international 20(3): 1617-31.

Abstract: This study characterizes over 5 years of high time resolution (5 min), airborne black carbon (BC) concentrations (July 2003 to December 2008) measured over Ahmedabad, an urban region in western India. The data were used to obtain different time averages of BC concentrations, and these averages were then used to assess the diurnal, seasonal, and annual variability of BC over the study region. Assessment of diurnal variations revealed a strong association between BC concentrations and vehicular traffic. Peaks in BC concentration were co-incident with the morning (0730 to 0830, LST) and late evening (1930 to 2030, LST) rush hour traffic. Additionally, diurnal variability in BC concentrations during major festivals (Diwali and Dushera during the months of October/November) revealed an increase in BC concentrations due to fireworks displays. Maximum half hourly BC concentrations during the festival days were as high as 79.8 μg m-3. However, the high concentrations rapidly decayed suggesting that local meteorology during the festive season was favorable for aerosol dispersion. A multiple linear regression (MLR) model with BC as the dependent variable and meteorological parameters as independent variables was fitted. The variability in temperature, humidity, wind speed, and wind direction accounted for about 49% of the variability in measured BC concentrations. Conditional probability function (CPF) analysis was used to identify the geographical location of local source regions contributing to the effective BC measured (at 880 nm) at the receptor site. The east north-east (ENE) direction to the receptor was identified as a major source region. National highway (NH8) and two coal-fired thermal power stations (at Gandhinagar and Sabarmati) were located in the identified direction, suggesting that local traffic and power plant emissions were likely contributors to the measured BC.

Callen MS, Lopez JM, Iturmendi A, Mastral AM. 2013. Nature and sources of particle associated polycyclic aromatic hydrocarbons (PAH) in the atmospheric environment of an urban area. Environmental Pollution 183: 166-74.

Abstract: The total PAH associated to the airborne particulate matter (PM10) was apportioned by one receptor model based on positive matrix factorization (PMF) in an urban environment (Zaragoza city, Spain) during February 2010-January 2011. Four sources associated with coal combustion, gasoline, vehicular and stationary emissions were identified, allowing a good modelling of the total PAH ($R^2 = 0.99$). A seasonal behaviour of the four factors was obtained with higher concentrations in the cold season. The NE direction was one of the predominant directions showing the negative impact of industrial parks, a paper factory and a highway located in that direction. Samples were classified according to hierarchical cluster analysis obtaining that, episodes with the most negative impact on human health (the highest lifetime cancer risk concentrations), were produced by a higher contribution of stationary and vehicular emissions in winter season favoured by high relative humidity, low temperature and low wind speed.

Celo V, Dabek–Zlotorzynska E, Zhao J, Bowman D. 2012. Concentration and source origin of lanthanoids in the Canadian atmospheric particulate matter: a case study. Atmospheric Pollution Research 3: 270-8.

Abstract: Ambient PM2.5 and PM2.5–10 samples collected at selected urban and rural sites within the Canadian National Air Pollution Surveillance (NAPS) PM2.5 Speciation Program were analyzed for lanthanoids and other elements. The average concentrations of total lanthanoids (calculated as sum of concentrations of all elements) in PM2.5 ranged from 0.059 to 0.334 ng m–3. These concentrations were two times lower than in PM2.5–10 samples and generally lower than values reported for industrial and urban areas around the world. The highest concentrations of lanthanoids were found in PM2.5 samples collected at the Halifax NS site, located near a petroleum refining complex. In addition, La/Ce and La/Sm ratios at this site were significantly higher than their natural values. Increased La–enrichment factors were also found in

Wallaceburg ON, which is located in a rural area, about 50 km downwind of two major petrochemical complexes. The results of this study demonstrate that La–enrichment factors are reliable tracers of emissions from oil refining industry.

Chan TW, Brook JR, Smallwood GJ, Lu G. 2011. Time-resolved measurements of black carbon light absorption enhancement in urban and near-urban locations of southern Ontario, Canada. Atmospheric Chemistry and Physics 11: 10407-32.

Abstract: In this study a photoacoustic spectrometer (PA), a laser-induced incandescence instrument system (LII) and an Aerosol Mass Spectrometer were operated in parallel for in-situ measurements of black carbon (BC) light absorption enhancement. Results of a thermodenuder experiment using ambient particles in Toronto are presented first to show that LII measurements of BC are not influenced by the presence of non-refractory material thus providing true atmospheric BC mass concentrations. In contrast, the PA response is enhanced when the non-refractory material is internally mixed with the BC particles. Through concurrent measurements using the LII and PA the specific absorption cross-section (SAC) can be quantified with high time resolution (1 min). Comparisons of ambient PA and LII measurements from four different locations (suburban Toronto; a street canyon with diesel bus traffic in Ottawa; adjacent to a commuter highway in Ottawa and; regional background air in and around Windsor, Ontario), show that different impacts from emission sources and/or atmospheric processes result in different particle light absorption enhancements and hence variations in the SAC. The diversity of measurements obtained, including those with the thermodenuder, demonstrated that it is possible to identify measurements where the presence of externally-mixed non-refractory particles obscures direct observation of the effect of coating material on the SAC, thus allowing this effect to be measured with more confidence. Depending upon the time and location of measurement (urban, rural, close to and within a lake breeze frontal zone), 30 min average SAC varies between 9 ± 2 and 43 ± 4 m2 g−1. Causes of this variation, which were determined through the use of meteorological and gaseous measurements (CO, SO2, O3), include the particle emission source, airmass source region, the degree of atmospheric processing. Observations from this study also show that the active surface area of the BC aggregate, which is measured by the LII as the PPS, is an important parameter for inferring the degree of particle collapse of a BC particle. In addition, PPS could be a useful measurement for indicating the importance of recently emitted BC (e.g. from gasoline or diesel engines) relative to the total measured BC in the atmosphere.

Cheng CM, Hack P, Chu P, Chang YN, Lin TY, Ko CS et al. 2009. Partitioning of mercury, arsenic, selenium, boron, and chloride in a full-scale coal combustion process equipped with selective catalytic reduction, electrostatic precipitation, and flue gas desulfurization systems. Energy and Fuels 23: 4805-15.

Abstract: A full-scale field study was carried out at a 795 MWe coal-fired power plant equipped with selective catalytic reduction (SCR), an electrostatic precipitator (ESP), and wet flue gas desulfurization (FGD) systems to investigate the distribution of selected trace elements (i.e., mercury, arsenic, selenium, boron, and chloride) from coal, FGD reagent slurry, makeup water to flue gas, solid byproduct, and wastewater streams. Flue gases were collected from the SCR outlet, ESP inlet, FGD inlet, and stack. Concurrent with flue gas sampling, coal, bottom ash, economizer ash, and samples from the FGD process were also collected for elemental analysis. By combining plant operation parameters, the overall material balances of selected elements were established. The removal efficiencies of As, Se, Hg, and B by the ESP unit were 88, 56, 17, and 8%, respectively. Only about 2.5% of Cl was condensed and removed from flue gas by fly ash. The FGD process removed over 90% of Cl, 77% of B, 76% of Hg, 30% of Se, and 5% of As. About 90% and 99% of the FGD-removed Hg and Se were associated with gypsum. For B and Cl, over 99% were discharged from the coal combustion process with the wastewater. Mineral trona (trisodium hydrogendicarbonate dehydrate, Na3H(CO3)2·2H2O) was injected before the ESP unit to control the emission of sulfur trioxide (SO3). By comparing the trace elements compositions in the fly ash samples collected from the locations before and after the trona injection, the injection of trona did not show an observable effect on the partitioning behaviors of selenium and arsenic, but it significantly increased the adsorption of mercury onto fly ash. The stack emissions of mercury, boron, selenium, and chloride were for the most part in the gas phase.

Cheng YH, Lin CC, Liu JJ, Hsieh CJ. 2014. Temporal characteristics of black carbon concentrations and its potential emission sources in a southern Taiwan industrial urban area. Environmental Science and Pollution Research International 21(5): 3744-55.

Abstract: This study investigates the temporal characteristics of black carbon and its potential emission sources, as well as the fractions of BC in PM2.5 levels in Kaohsiung urban area, which is an industrial city in southern Taiwan. Concentrations of BC and PM2.5 are monitored continuously from March 2006 to February 2010, using an aethalometer and a tapered element oscillating microbalance monitor. Additionally, the presence of organic compounds (or UV enhanced species) in particles at the sampling site is determined using the Delta-C (UVBC-BC) value. According to long-term measurement results, BC and PM2.5 concentrations are 3.33 and 34.0 μg m-3, respectively, in the Kaohsiung urban area. The ratio of BC/PM2.5 is approximately 11 %. Low concentration of BC and PM2.5 in the summer of this study period is mostly likely owing to meteorological conditions that favored dispersion of local air pollutants. Nevertheless, BC concentrations peaked markedly during morning hours (7:00-11:00), likely owing to local traffic congestion. Measurement results suggest that BC is released from local traffic activities and emitted from industrial activities at this sampling site. Additionally, Delta-C values are significantly higher than zero during January-March and November-December periods in this industrial urban area, implying that UV enhanced species can be observed. At this sampling site, these UV enhanced species do not only originate from household activity and solid waste burning but also release from industrial activities. The elevated Delta-C values during nighttime (18:00-6:00) in the autumn and winter seasons are likely related to those UV enhanced species in the atmosphere, which can be condensed on particle surface under low temperature conditions. According to long-term measurement results, significantly positive Delta-C values can be observed under temperatures <20 degrees C and relative humidity of 60-75 % in this study. Despite the household activity and solid waste burning, the major sources of particles that are bound with UV enhanced species in this sampling site are industrial parks and a coal-fired power plant.

Cherian R, Venkataraman C, Ramachandran S. 2009. Temporal variability in emission category influence on organic matter aerosols in the Indian region. Geophysical Research Letters 36: L06809.

Abstract: The dependence of carbonaceous aerosol properties, like radiation absorption and hygroscopicity, on the emission source of origin motivate this work. The influence of emission categories, including crop residue and forest burning, biofuel combustion, brick kilns, thermal power plants, diesel transport and "other industry", is estimated on organic matter (OM) surface concentrations in the Indian ocean region. The approach uses general circulation model predicted OM surface concentrations during a ship cruise, identifies probable source regions for high concentration episodes using the potential source contribution function, and estimates collocated OM emissions resolved by category. Distinct source regions identified, are the Indo-Gangetic Plain during 20-30th January, 1999, and central/south India during 1-11th March, 1999. Contributing emission categories are primarily biofuel combustion (18 Gg) during 20-30th January, but a combination of forest burning (8 Gg), biofuel combustion (7 Gg) and crop residue (5 Gg) during 1-11th March. The magnitude of emission flux rather than spatial extent of an emission category, was seen to increase its influence on the receptor. This approach can be used to investigate seasonal and inter-annual variability in emission category influence on atmospheric pollutants.

Choi H, Spengler J. 2014. Source attribution of personal exposure to airborne polycyclic aromatic hydrocarbon mixture using concurrent personal, indoor, and outdoor measurements. Environment International 63: 173-81.

Abstract: Objectives: Relative importance of multiple indoor and outdoor venues on personal exposure concentrations to pro-carcinogenic polycyclic aromatic hydrocarbons (c-PAHs) remains poorly understood. This is particularly challenging because many c-PAHs share sources and occur as a complex mixture. Accurate and precise apportionment of personal exposure according to exposure venues could aid in the understanding of human health effects due to a given source. Here, we partitioned indoor and personal exposure concentrations to seven c-PAHs and pyrene according to the indoor- and outdoor-origins. Methods: A simultaneous, integrated monitoring of personal, indoor and outdoor concentrations of nine

PAHs was conducted in 75 homes for a consecutive 48-hour period across a two-year period in Kraków, Poland. Due to few known indoor sources for chrysene, we used this PAH species as a tracer for infiltration of outdoor PAHs. Personal and indoor concentrations of seven c-PAHs and pyrene were apportioned to home indoor, nonhome indoor and outdoor origins. Results: Using Chrysenein/Chryseneout as proxy for an infiltration factor, Finf, infiltrated PAHs of outdoor origin are overall higher in concentration than those emitted from the indoor origin. Average contribution by the outdoor sources on B[a]A, B[b]F, and B[k]F were 92%, 79%, and 78% across all seasons, respectively. In contrast, in homes where a household member smoked, average contributions by the outdoor sources on B[ghi]P, B[a]P, D[ah]A, and IP were lower (i.e., 67%, 65%, 67%, and 66%, respectively). Season-averaged contributions by the outdoor sources on personal exposure to B[a]A, B[b]F, and B[k]F were 92%, 74%, and 77%, respectively. On the other hand, season-averaged home indoor source contributions on personal exposure to B[a]A, B[b]F, and B[k]F were estimated at 6%, 15%, and 19%, respectively. Similar contributions by season-averaged home indoor sources on personal exposure were estimated at 28% for B[ghi]P, 31% for B[a]P, 25% for D[ah]A, and 28% for IP. Conclusion: Of the seven c-PAHs, B[a]A, B[b]F, and B[k]F are enriched in indoor and personal exposure concentrations from the outdoor coal-combustion. B[ghi]P, B[a]P, D[a,h]A, and IP, PAHs with some of the highest carcinogenic and mutagenic potencies, are considerably enriched by cigarette smoke in addition to the outdoor sources.

Cordoba P, Font O, Izquierdo M, Querol X, Leiva C, López-Antón MA et al. 2012a. The retention capacity for trace elements by the flue gas desulphurisation system under operational conditions of a co-combustion power plant. Fuel 102: 773-88.

Abstract: Water re-circulation to the scrubber and co-combustion of coal with petroleum coke are the most significant factors that affect the retention capacity for trace elements in a power plant equipped with a forced-oxidation flue gas desulphurisation (FGD) system. The water re-circulation favours the progressive saturation of most elements in the gypsum slurry with the subsequent increase in emission by entraining particles and droplets in the outgoing gas of FGD (OUT-FGD). The co-combustion increases the content of HCl and SO2 in the gaseous stream, which enhances the formation of gaseous chlorides species, especially of Hg, and the formation of condensed species of Cu, Cr, Ni, Na, Cd, and Zn OUT-FGD, respectively. High gaseous retention capacity (83-100%) for S, Cl, F, As, and B is attained by the whole plant with a subsequent reduction in their gaseous emissions below the limits established by the European directive 2001/80/EC for large combustion plants, and also below the Pollutant Release and Transfer Register (PRTR) threshold values. The retention of Se increases from 2007 (75%) to 2008 (97%). The emissions of gaseous Hg and particulate As, Zn, and Ni exceed the PRTR values. Remediation actions for the gaseous and PM emissions are relevant given the role of the filtered water re-circulation increasing the particles emissions OUT-FGD.

Cordoba P, Ochoa-Gonzalez R, Font O, Izquierdo M, Querol X, Leiva C et al. 2012b. Partitioning of trace inorganic elements in a coal-fired power plant equipped with a wet Flue Gas Desulphurisation system. Fuel 92: 145-57.

Abstract: The abatement capacity of trace inorganic elements was studied in a large Pulverized Coal Combustion (PCC) power plant equipped with a wet limestone Flue Gas Desulphurisation (FGD) system. High proportions of most elements were retained as fly ash as consequence of the efficiency of the electrostatic precipitator (ESP, 99.6% of fly ash) and slag (11%). The most volatile elements, such as S and F are retained by the FGD gypsum, and Cl by the filtered water; whereas the moderately volatile elements, As and B, are retained mainly by fly ash, reaching very high abatement efficiencies for these elements when considering the whole plant (>92%). Selenium and Hg are still retained by the whole system with relatively high proportions (89% and 67%); however a prominently proportion is emitted; Se (11%) and Hg (29%), attaining gaseous/PM rate at the emissions reaching 0.08 and 290, respectively. The gaseous emissions are below the limits according to the European directive 2001/80/EC for large combustion plants and the PRTR threshold values with the exception of Hg emissions and particulate Se, As, Zn, Cu, Ni, and Cr. Remediation actions to prevent and/or reduce the gaseous and PM emissions as well as the determination of leachable potential of trace inorganic pollutants retained in FGD gypsum, especially F in view of its disposal, are of significant relevance.

Fang GC, Huang JH, Liu CK, Huang YL. 2012. Measuring and modeling atmospheric arsenic pollutants, total As, As(III), and As(V), at five characteristic sampling sites. Aerosol and Air Quality Research 12(2): 200-10.

Abstract: This investigation determines ambient air arsenic (As), As(III), and As(V) concentrations in total suspended particulates (TSP) and dry deposition. Calculated/measured dry deposition flux ratios of ambient air As, As(III) and As(V) were evaluated using two dry deposition models at five characteristic sampling sites during 2009-2010. The highest average concentrations of As, As(III) and As(V) in TSP and dry deposition were measured at the Quan-xing industrial sampling site during August-January. The Quan-xing site, with many industrial factories under process around there regions, its air is extremely polluted. In addition, the average dry deposition velocities for ambient air total arsenic (As) at Bei-shi, Chang-hua, He-mei, Quan-xing and Gao-mei were 0.60 (cm/sec), 0.57 (cm/sec), 0.73 (cm/sec), 0.67 (cm/sec) and 0.66 (cm/sec), respectively at these five characteristic sampling sites. The highest average seasonal variation for As, As(III) and As(V) in TSP and dry deposition were in winter and fall due to emissions from fossil fuel combustion by the nearby Taichung Thermal Power Plant (TTPP) and for household heating.

Fang GC, Huang WJ, Chen JC, Huang JH, Huang YL. 2011a. Study of ambient air particle-bound As(p) and Hg(p) in dry deposition, total suspended particulates (TSP) and seasonal variations in central Taiwan. Environmental Forensics 12(1): 7-13.

Abstract: This study investigated the ambient air particle-bound As(p) and Hg(p) levels and compositions in dry deposition and total suspended particulates (TSP) at five sampling sites in Central Taiwan (suburban/coastal, downtown, residential, industrial and wetland) during the years of 2009 and 2010. The main industrial sources of studied metals in various investigated sites include: steel, electronic, plastic, and chemical industries, the Taichung thermal power plant (TTPP), fossil fuel combustion, a science park, transportation, and waste incineration. The samples were digested with hydrochloric acid (HCl) and nitric acid (HNO3), then they were analyzed for metals by ICP-MS. The mean As(p) levels in dry deposition were the highest at Quan-xing site (industrial) and the lowest at Chang-hua site (downtown). Moreover, the mean Hg(p) levels in dry deposition were the highest at Gao-mei site (wetland) and the lowest at He-mei site (residential). In addition, the mean As(p) levels in TSP were the highest at He-mei site (residential) and the lowest at Gao-mei site (wetland). The mean Hg(p) levels in TSP were the highest at Quan-xing site (industrial) and the lowest at Gao-mei site (wetland). Regarding seasonal variation, the lowest levels in dry deposition for both particles As(p) and Hg(p) occurred in spring and summer. Finally, the lowest levels of As(p) and Hg(p) in TSP were observed in fall and winter.

Fang GC, Lin CC, Huang JH, Huang YL. 2011b. Measurement of ambient air arsenic (As) pollutant concentration and dry deposition fluxes in central Taiwan. Aerosol and Air Quality Research 11: 218-29.

Abstract: This study investigated the feasibility of monitoring arsenic (As) levels in total suspended particulates (TSP), in both dry deposition and dry deposition flux at five sampling sites located in central Taiwan during the years of 2009-2010. Experimental results indicate that the average As concentration in TSP and dry deposition was highest in Quan-xing (industrial) and lowest in Gao-mei (wetland). The mean As composition in TSP was highest in Hei-mei (residential) and lowest in Gao-mei (wetland). The average highest arsenic (As) of seasonal concentrations and compositions in TSP, dry deposition were occurred in winter and fall denotes that fossil fuel combustion by Taichung thermal power plant (TTPP) emissions and heating by household were the main reasons responsible for the high data values measured. Atmospheric concentrations of arsenic (As) were analyzed by a ICP-MS (Perkin Elmer Sciex ELAN DRC II). Finally, best-fit model can be used successfully in the prediction of ambient air pollutants around suburban/coastal, downtown, residential, industrial and wetland areas.

Gao B, Guo H, Wang XM, Zhao XY, Ling ZH, Zhang Z et al. 2012. Polycyclic aromatic hydrocarbons in PM2.5 in Guangzhou, southern China: Spatiotemporal patterns and emission sources. Journal of Hazardous Materials 239-240: 78-87.

Abstract: Fine particulate samples were simultaneously collected at six sites in Guangzhou in November-December 2009. Eighteen polycyclic aromatic hydrocarbons (PAHs) and tracers, i.e. hopanes, elemental carbon, picene and levoglucosan were measured. Three high level episodes were observed during the sampling period, likely due to accumulation effects. Back trajectory analysis revealed that the air masses for the three episodes were from eastern inland Pearl River Delta (PRD) region. There was no obvious concentration gradient for total and 5-6 ring PAHs such as benzo[g,h,i]perylene (BghiP) from urban to rural sites. However, 4-ring PAHs such as pyrene (Pyr) exhibited significantly higher levels at rural site than that at urban/suburban sites (p<. 0.01). BghiP correlated well with hopanes, elemental carbon and picene, indicating vehicular emissions and coal combustion were the sources of 5-6 ring PAHs, which were further confirmed by comparing the four tracers/BghiP ratios and IcdP/BghiP ratios in ambient samples with those from source profiles. Results indicated that vehicular emissions were no longer the dominant sources in winter season in Guangzhou.

Gao B, Guo H, Wang XM, Zhao XY, Ling ZH, Zhang Z et al. 2013. Tracer-based source apportionment of polycyclic aromatic hydrocarbons in PM2.5 in Guangzhou, southern China, using positive matrix factorization (PMF). Environmental Science and Pollution Research International 20(4): 2398-409.

Abstract: From 28 November to 23 December 2009, 24-h PM2.5 samples were collected simultaneously at six sites in Guangzhou. Concentrations of 18 polycyclic aromatic hydrocarbons (PAHs) together with certain molecular tracers for vehicular emissions (i.e., hopanes and elemental carbon), coal combustion (i.e., picene), and biomass burning (i.e., levoglucosan) were determined. Positive matrix factorization (PMF) receptor model combined with tracer data was applied to explore the source contributions to PAHs. Three sources were identified by both inspecting the dominant tracer(s) in each factor and comparing source profiles derived from PMF with determined profiles in Guangzhou or in the Pearl River Delta region. The three sources identified were vehicular emissions (VE), biomass burning (BB), and coal combustion (CC), accounting for 11 +/- 2%, 31 +/- 4%, and 58 +/- 4% of the total PAHs, respectively. CC replaced VE to become the most important source of PAHs in Guangzhou, reflecting the effective control of VE in recent years. The three sources had different contributions to PAHs with different ring sizes, with higher BB contributions (75 +/- 3%) to four-ring PAHs such as pyrene and higher CC contributions (57 +/- 4%) to six-ring PAHs such as benzo[ghi]perylene. Temporal variations of VE and CC contributions were probably caused by the change of weather conditions, while temporal variations of BB contributions were additionally influenced by the fluctuation of BB emissions. Source contributions also showed some spatial variations, probably due to the source emission variations near the sampling sites.

Gong L, Lewicki R, Griffin RJ, Tittel FK, Lonsdale CR, Stevens RG et al. 2013. Role of atmospheric ammonia in particulate matter formation in Houston during summertime. Atmospheric Environment 77: 893-900.

Abstract: Simultaneous high-time-resolution measurements of atmospheric NH3, HNO3, soluble gas-phase chloride, and aerosol species were made in Houston, TX, from August 5, 2010 to August 9, 2010. Gaseous NH3 was measured using a 10.4-μm external cavity quantum cascade laser-based sensor employing conventional photo-acoustic spectroscopy, while gaseous HNO3 and HCl were sampled using a mist chamber-ion chromatograph (IC) system. Particle chemical composition was determined using a particle-into-liquid-sampler-IC system. There was a large amount of variability in the gas phase mixing ratios of NH3 (3.0 +/- 2.5 ppb), HNO3 (287.4 +/- 291.6 ppt), and HCl (221.3 +/- 260.7 ppt). Elevated NH3 levels occurred around mid-day when NH4+ (0.5 +/- 1.0 μg m(-3)) and SO42- (4.5 +/- 4.3 μg m(-3)) also increased considerably, indicating that NH3 likely influenced aerosol particle mass. By contrast, the formation of NH4NO3 and NH4Cl was not observed during the measurements. Point sources (e.g., power plant and chemical plant) might be potential contributors to the enhancements in NH3 at the measurement site under favorable meteorological conditions. Increased particle number concentrations were predicted by the SAM-

TOMAS model downwind of a large coal-fired power plant when NH3 emissions (based on these measurements) were included, highlighting the potential importance of NH3 with respect to particle number concentration. Separate measurements also indicate the role of NH3 in new particle formation in Houston under low-sulfur conditions.

Guedes A, Valentim B, Prieto AC, Sanz A, Flores D, Noronha F. 2008. Characterization of fly ash from a power plant and surroundings by micro-Raman spectroscopy. International Journal of Coal Geology 73(3-4): 359-70.

Abstract: Fly ash samples were collected from a Portuguese power plant that bums low-sulphur coals from South Africa, U.S.A., Colombia, and Australia. The fly ashes were collected from the hoppers of the economizers, air heaters, electrostatic precipitators, and from the stack. The power plant air monitoring system was also sampled. The fly ash characterization was conducted by micro-Raman spectroscopy (MRS). The micro-Raman spectroscopic analysis permitted an efficient identification and characterization of different inorganic and organic materials present in fly ash: quartz, hematite, magnetite, calcite, glass, aluminium and calcium oxides, and different types of organic constituents. The study of the structural evolution of the unburned carbon/char material during their path through the power plant, though the use of Raman spectra and Raman parameters reveal that despite the high temperatures they reached, these materials are still structurally disordered. However, a structural evolution occurs in the char from the economizer up to the electrostatic precipitators where the char is structurally more disordered. The different features of the Raman spectra observed for carbon particles collected from the stack, together with the high range of variation of the Raman parameters, confirm the existence of different carbon particles in the stack, i.e., char and others (probably soot). The filters from the surroundings contain a variety of carbon particles with Raman parameters different from the ones obtained in the fly ash hoppers and stack. These are diesel particles as indicated by the values of W-D1, FWHMD1, FWHMG, W-G and ID1/IG obtained.

Han I, Ramos-Bonilla JP, Rule AM, Mihalic JN, Polyak LM, Breysse PN et al. 2011. Comparison of spatial and temporal variations in p-PAH, BC, and p-PAH/BC ratio in six US counties. Atmospheric Environment 45(40): 7644-52.

Abstract: An ambient air monitoring campaign was performed in six counties (Sacramento, CA; Maricopa, AZ; Anoka, MN; Jefferson, KY; Harris, TX; and Pinellas, FL) between January 2008 and September 2009. The purpose of this paper is to compare the spatial and temporal variability of black carbon (BC) and particle-bound polycyclic aromatic hydrocarbons (p-PAHs), across these counties using continuous monitoring instruments - an Aethalometer and a Photoelectric Aerosol Sensor reporting in units of μg m -3 and fA, respectively. We explored temporal trends in these measurements to assess the potential impact of local combustion sources on air quality. Median BC concentrations ranged from 0.13 to 0.53 μg m-3; and median p-PAH values ranged from 0.31 to 4.18 fA. Hourly BC and p-PAH were elevated during morning rush hour and rapidly decreased later in the morning. Nighttime increases in BC and p-PAH were also observed in most counties. Diurnal patterns of BC and p-PAH were different on weekdays compared to weekends. Profiles of hourly ratios of p-PAH/BC in combination with meteorological data can provide insight into potential sources across the sites. Hourly ratios of p-PAH/BC which peaked during early morning and late afternoon hours suggest a dominating contribution of motor vehicle sources in four of the six counties. In two counties, hourly ratios remained elevated for several hours after rush hour and did not show a distinctive peak suggesting additional sources of BC and p-PAH. Such profiles were seen in both Jefferson KY and Harris TX, and may be attributed to coal combustion, petro-chemical industry and shipping activities, respectively. These results suggest that measurements of BC and p-PAH, combined with meteorological information and emission data are potentially useful to identify combustion sources impacting air quality. More research combining BC and p-PAH measurements with detailed source apportionment data is needed to more fully evaluate the utility of these real-time measures.

Hsu YC, Lai MH, Wang WC, Chiang HL, Shieh ZX. 2008. Characteristics of water-soluble ionic species in fine (PM2.5) and coarse particulate matter (PM10-2.5) in Kaohsiung, southern Taiwan. Journal of the Air and Waste Management Association 58(12): 1579-89.

Abstract: Eleven ionic species and fine and coarse particle mass concentrations of fine (PM2.5) and coarse (PM10-2.5) particulate matter were investigated in Kaohsiung, southern Taiwan. The PM2.5 and PM10-2.5 particulate concentrations were 49-64 and 34-37 μg m(-3), respectively. Fifty-five to 64% of the particulate matter less than 10 μm in aerodynamic diameter (PM10) mass was attributed to the PM2.5. PM2.5 concentrations at Daliao (a rural and industrial complex area) were higher than at Tzuoying (an urban and industrial complex area). Ionic species contributed 45-53% and 42-45% of PM2.5 and PM10, respectively. Potassium ions (K+), sulfate (SO4(2-)), and ammonium (NH4+) were predominant in PM2.5, whereas sodium, calcium, and magnesium ions were foremost in PM10-2.5. Nitrate (NO3-) existed in both the PM2.5 and PM10-2.5. Chloride (Cl-), NO3-, and NH4+ concentrations were higher at night than during the day, and they were easily transferred into the gas phase by photochemical reactions and temperature-induced volatilization. The NH4+/SO4(2-) ratios were 2.6 and 2.5 at Daliao and Tzuoying, respectively, which indicated that both sampling sites were rich in NH4+. Therefore, ammonium nitrate would be present in the area.

Huggins FE, Goodarzi F. 2009. Environmental assessment of elements and polyaromatic hydrocarbons emitted from a Canadian coal-fired power plant. International Journal of Coal Geology 77(3-4): 282-8.

Abstract: A detailed assessment of elements was carried out at a power plant rated at approximately 760 MW of electricity using western Canadian subbituminous coal. The concentrations of elements of environmental concern (As, Cd, Cr, Hg, Ni, and Pb) in milled coals, ashes, stack-emitted materials. Speciation of As, Cr, and Ni were determined. The polyaromatic hydrocarbons (PAHs) emitted from the stack were also measured. The rates of input of elemental input for As, Cd, Cr, Hg, Ni, and Pb were 28, 0.94, 230, 0.44, 44, and 88 kg/day, respectively; of which only 0.16, 0.01, 0.40, 0.27, 0.15, and 0.04 kg/day, respectively, were stack emitted. The total stack emission of toxic elements is 1.02 kg/day, with Cr being the highest contributor to this group with 0.4 kg/day. However, Hg at 0.27 kg/day has the highest percentage rate of emission at about 60%, while Cd has the lowest at about 1%. The electrostatic precipitator (ESP) removes a significant portion of the elements indicated by their relative enrichment (RE) ratios greater than 0.7. The results show that most of the elements in milled coal are low compared to world coals and other Canadian milled coals.
Mercury is mostly (~ 81%) emitted as gaseous elemental mercury (GEM), with 19% as reactive gaseous mercury (RGM). Particulate mercury is very low and averages about 0.1% of the total mercury at this station. Most of the arsenic in the milled coal is primarily associated with pyrite or as arsenate in its less toxic form of As+5 (> 95%). In both bottom and fly ashes, more than 95% of the total arsenic is present as As+5. Chromium in the milled coal and bottom ash is mostly non-toxic (Cr+3). The more toxic Cr+6 comprise less than 5% of the total Cr in the ESP fly ash and the stack-emitted ash. Nickel in milled coal and ashes is in the form of non-toxic Ni+2, predominantly in coordination with oxygen.
The emitted PAHs include acenapthene, fluorene, 2-methyl-fluorene, phenathrene, anthracene, fluoanthene, and pyrene; which are emitted from stack at the combined rate of 3.6 g/day. The concentrations of elements of environmental concern (As, Cd, Hg, Ni, and Pb) emitted to the atmosphere by the power plant in the zone of maximum impact at ground level are lower than those listed in the Health Guidelines of the USEPA and Canadian National Air Pollution Surveillance. This is based on stable meteorological conditions, down wind from the power plant for a maximum distance of 3 km.

Huggins FE, Galbreath KC, Eylands KE, Van Loon LL, Olson JA, Zillioux EJ et al. 2011. Determination of nickel species in stack emissions from eight residual oil-fired utility steam-generating units. Environmental Science and Technology 45(14): 6188-95.

Abstract: XAFS spectroscopy has been used to determine the Ni species in particulate matter collected on quartz thimble filters in the stacks of eight residual (No. 6 fuel) oil-burning electric utility steam-generating units. Proper speciation of nickel in emitted particulate matter is necessary to correctly anticipate potential health risks. Analysis of the spectroscopic data using least-squares linear combination methods and a newly

developed method specific for small quantities of Ni sulfide compounds in such emissions show that potentially carcinogenic Ni sulfide compounds are absent within the detection limits of the method (≤ 3% of the total Ni) in the particulate matter samples investigated. In addition to the major nickel sulfate phase (NiSO4·6H2O), lesser amounts of (Ni,Mg)O and/or NiFe2O4 were also identified in most emission samples. On the basis of the results from these emission characterization studies, the appropriateness of the U.S. Environmental Protection Agency's assumption that the Ni compound mixture emitted from residual oil-fired power plants is 50% as carcinogenic as nickel subsulfide (Ni3S2) should be re-evaluated.

Jeong CH, Herod D, Dabek-Zlotorzynska E, Ding L, McGuire ML, Evans G. 2013. Identification of the sources and geographic origins of black carbon using factor analysis at paired rural and urban sites. Environmental Science and Technology 47(15): 8462-70.

Abstract: Black carbon particles, composed of forms of elemental carbon (EC), contribute significantly to regional and global warming. The origins of EC were examined in southeastern Canada as part of a source apportionment study using positive matrix factorization (PMF), performed on long-term PM2.5 chemical speciation data collected at two paired rural and urban sites. Comparisons of the urban and rural sites revealed a previously unrecognized EC-rich factor that accounted for 41-56% of the total EC in this region. This factor was characterized by the more thermally stable EC fractions that exhibit strong light absorption characteristics. While these EC fractions are often attributed to local diesel emissions, this interpretation was rejected for several reasons. The EC-rich factor was present in similar temporal patterns at both the high-traffic urban and low-traffic rural sites across this 600 km region. The geographic origins of the EC-rich factor were found to be Ohio and Western Pennsylvania regions with heavy industry and multiple coal-based electrical generating stations. The direct radiative forcing due to this EC-rich factor was roughly estimated to be +0.2 W m(-2), which represented a substantial portion of the aerosol induced warming in the region. Thus, this region was impacted by an important unidentified source of EC associated with long-range transport.

Jyethi DS, Khillare PS, Sarkar S. 2014. Risk assessment of inhalation exposure to polycyclic aromatic hydrocarbons in school children. Environmental Science and Pollution Research 21(1): 366-78.

Abstract: Polycyclic aromatic hydrocarbons (PAHs) associated with the inhalable fraction of particulate matter were determined for 1 year (2009–2010) at a school site located in proximity of industrial and heavy traffic roads in Delhi, India. PM10 (aerodynamic diameter ≤10 μm) levels were ~11.6 times the World Health Organization standard. Vehicular (59.5 %) and coal combustion (40.5 %) sources accounted for the high levels of PAHs (range 38.1–217.3 ng m−3) with four- and five-ring PAHs having ~80 % contribution. Total PAHs were dominated by carcinogenic species (~75 %) and B[a]P equivalent concentrations indicated highest exposure risks during winter. Extremely high daily inhalation exposure of PAHs was observed during winter (439.43 ng day−1) followed by monsoon (232.59 ng day−1) and summer (171.08 ng day−1). Daily inhalation exposure of PAHs to school children during a day exhibited the trend school hours > commuting to school > resting period in all the seasons. Vehicular source contributions to daily PAH levels were significantly correlated ($r = 0.94$, $p < 0.001$) with the daily inhalation exposure level of school children. A conservative estimate of ~11 excess cancer cases in children during childhood due to inhalation exposure of PAHs has been made for Delhi.

Kaivosoja T, Jalava PI, Lamberg H, Virén A, Tapanainen M, Torvela T et al. 2013. Comparison of emissions and toxicological properties of fine particles from wood and oil boilers in small (20-25kW) and medium (5-10MW) scale. Atmospheric Environment 77: 193-201.

Abstract: The aim of this study was to compare four alternatives for providing decentralized energy production in small communities in terms of their flue gas emissions and toxicological properties of the emissions. In this study, two different size classes of boilers were examined and the use of fossil fuel oils was compared against wood fuels. The lowest PM1 emission, 0.1mgMJ-1, was observed from small-scale light fuel oil combustion. In medium-scale wood combustion, PM1 emission values from a grate fired wood combustion boiler (10MW) without particulate filtration were the highest (264mgMJ-1) but were substantially reduced down to 0.6mgMJ-1 due to the usage of an electrostatic precipitator (ESP). The wood combustion particles were mainly formed of potassium salts. In light fuel oil combustion, one of the main components in

the particles was sulphate whereas in heavy fuel oil combustion also significant amounts of V and Ni were emitted. Pellet combustion produced the lowest PAH emissions. Overall, oil combustion produced higher amount of PAHs than wood combustion. This was indicated also as a higher cytotoxicity of the oil combustion samples when compared to those from wood combustion in the corresponding scale of boilers. However, when calculated on an equal mass basis, the particles collected after ESP were even more cytotoxic which can be explained by the altered chemical characteristics of the emissions in the ESP. Due to the variation in the emissions and in the toxicity of the emissions, we propose that in the long term, not only the emission levels but also the toxicity of the emissions should be taken into account in the regulations of the emission limits of the combustion plants.

Kong S, Ding X, Bai Z, Han B, Chen L, Shi J et al. 2010. A seasonal study of polycyclic aromatic hydrocarbons in PM2.5 and PM2.5-10 in five typical cities of Liaoning Province, China. Journal of Hazardous Materials 183(1-3): 70-80.

Abstract: Fourteen polycyclic aromatic hydrocarbons (PAHs) in PM2.5 and PM2.5-10 samples collected in five cities (Shenyang, Anshan, Jinzhou, Fushun and Dalian), Liaoning Province, China in 2004 and 2005 were analyzed by using a HPLC equipped with fluorescence and UV detectors. Results showed total PAHs concentrations in PM2.5 and PM2.5-10 were in the range of 75.32-1900.89 ng m-3 and 16.74-303.24 ng m-3, respectively. 90% of the total PAHs were in PM2.5. PAHs in PM2.5 had a winter to summer ratio varying from 6.5 to 125.8 while PAHs in PM2.5-10 had a ratio ranging from 1.7 to 37.6. Total PAHs concentrations were most abundant at residential/commercial sites and were fewest at an industrial site for both PM2.5 and PM2.5-10. Urban background sites showed unexpected higher PAHs concentrations. Total BaP equivalent concentration (BaPeq) for PM2.5 ranged from 7.80 to 88.42 ng m-3 in different function zones. Similarities of PAHs profiles between sampling sites and between fine and coarse fractions were compared by coefficient of divergence which indicated that remarkable differences in PAHs compositions existed. Principal component analysis (PCA) associated with diagnostic ratios revealed coal combustion and vehicle emission were the major sources for PM2.5 and PM2.5-10 associated PAHs.

Kong S, Ji Y, Li Z, Lu B, Bai Z. 2013. Emission and profile characteristic of polycyclic aromatic hydrocarbons in PM2.5 and PM10 from stationary sources based on dilution sampling. Atmospheric Environment 77: 155-65.

Abstract: The mass concentrations and profile characteristic for 18 kinds of polycyclic aromatic hydrocarbons (PAHs) in PM2.5 and PM10 from stack gases for six types of stationary sources in Shandong Province, China were studied by a dilution sampling system and GC–MS analysis method from February to March in 2010. The mass concentrations of PM2.5 and PM10 from the six types of stationary sources varied in 8.2–79.4 mg m−3 and 23.3–156.7 mg m−3, respectively. The total mass concentrations of analyzed PAHs in PM2.5 and PM10 were in the ranges of 0.40–94.35 μg m−3 and 9.16–122.91 μg m−3. The most toxic ashes were from sinter and coke oven for both PM2.5 and PM10 with high carcinogenic PAHs concentrations. BbF, Phe, NaP, BghiP, Pyr, BaP and BeP were abundant which was different from formers and one of the key reasons may be the differences of sampling methods. Diversities in PAHs compositions existed between fly ashes within PM2.5 and PM10 fractions for coke oven according to coefficient of divergence (CD) values. PAHs profiles for PM10 emitted from coke oven were different from those of other stationary sources (with CD values higher than 0.35) and for PM2.5, it was the same for sinter (with most CD values close to 0.30). There existed similar PAHs markers for fine particles emitted from stationary sources excepted for the sinter. For PM10, PAHs markers were primary 3-ring PAHs except for the coke oven with BbF, IND and BghiP as its signatures. Diagnostic ratios of BaA/(BaA + Chr), Flu/(Flu + Pyr), BaP/(BaP + BeP), BeP/BghiP and IND/(IND + BghiP) could be not well distinguished for the six types of stationary sources with the maximum/minimum ratios lower than 2 for both PM2.5 and PM10 of fly ashes which should be not used for source identification studies. The mass concentrations and source profiles of PAHs should be updated timely for size-differentiated fly ashes from various stationary sources by dilution sampling method.

Kozielska B, Konieczyniski J. 2008. Occurrence of polycyclic aromatic hydrocarbons in dust emitted from circulating fluidized bed boilers. Environmental Technology 29(11): 1199-207.

Abstract: Occurrence of polycyclic aromatic hydrocarbons (PAHs) in granulometric fractions of dust emitted from a hard coal fired circulating fluidized bed (CFB) boiler was investigated. The dust was sampled with the use of a Mark III impactor. In each fraction of dust, by using gas chromatography (GC), 16 selected PAHs and total PAHs were determined and the toxic equivalent B(a)P (TE B(a)P) was computed. The results, recalculated for the standard granulometric fractions, are presented as concentrations and content of the determined PAHs in dust. Distributions of PAHs and their profiles in the granulometric dust fractions were studied also. The PAHs in dust emitted from the CFB boiler were compared with those emitted from mechanical grate boilers; a distinctly lower content of PAHs was found in dust emitted from the former.

Li X, Zhang Y, Tan M, Liu J, Bao L, Zhang G et al. 2009. Atmospheric lead pollution in fine particulate matter in Shanghai, China. Journal of Environmental Sciences-China 21(8): 1118-24.

Abstract: The Pb-monitoring program was extended for 6 years from 2002 to 2007 at 17 representative urban sites (6 traffic, 5 industrial, and 6 residential sites), and 3 suburban sites to assess the lead pollution in fine particulate matter (PM2.5) after phasing out leaded gasoline in Shanghai. Compared with Pb levels reported in other places, the Pb pollution in Shanghai is still serious after phasing out leaded gasoline, which remains at high concentration range (213-176 ng/m3) in PM2.5 in winter. Significant spatial variation of Pb concentrations and strong seasonal variation of higher Pb concentration in winter than that in summer were detected. The size distribution of Pb in particulate matter has a unimodal mode that peaks at approximately 0.154-1.59 μm particle diameter, indicating that Pb is mainly concentrated in fine fraction. Lead in the fine fraction is enriched by a factor of 10^3-10^4 relative to Pb abundance in crust. Eight categories of Pb pollution sources were identified in the PM2.5 in the winter of 2007 in Shanghai. The important emission sources among them are vehicle exhaust derived from combustion of unleaded gasoline, metallurgic industry emission, and coal combustion emission.

Ma WL, Li YF, Qi H, Sun DZ, Liu LY, Wang DG. 2010. Seasonal variations of sources of polycyclic aromatic hydrocarbons (PAHs) to a northeastern urban city, China. Chemosphere 79(4): 441-7.

Abstract: Understanding the seasonal variations of sources of polycyclic aromatic hydrocarbons (PAHs) in air in urban region is important to the effective control of air pollution in the region. Based on a year round dataset (from August 2008 to July 2009), the sources of atmospheric PAHs in Harbin, a typical Chinese northeastern urban city, were analyzed by principal component analysis (PCA) and positive matrix factorization (PMF). The average total (gas plus particulate) PAH concentration varied from 6.3 ng m(-3) to 340 ng m(-3) with a mean of 100+/-94 ng m(-3), with higher concentrations in heating season than those in non-heating season. PCA and PMF identified similar source factors to atmospheric PAHs with obvious seasonal variation. The results obtained by PMF method indicated that the main sources were coal-fired boiler (39%), diesel engine (34%) and coal average (22%) in heating season and traffic emissions (59%), ground evaporation (18%) and coal average (17%) in non-heating season. Excellent correlation coefficients between predicted and measured concentrations of PAHs indicated that PMF was a useful model for source apportionment of PAHs in atmosphere.

Meresova J, Florek M, Holy K, Jeskovsky M, Sykora I, Burda C et al. 2010. Air pollution studies in Slovakia using aerosol filters and biomonitoring technique. Ekologia (Bratislava) 29: 294-306.

Abstract: Instrumental neutron activation analysis (INAA) and atomic absorption spectrometry (AAS) were employed in order to evaluate the concentrations of up to 36 chemical elements (heavy metals, rare earths, and actinides) in the atmospheric aerosols. Two sampling sites in Bratislava were examined. The first site, Liscie udolie, is quite a pristine location with low traffic density. The second sampling site is close to the crude oil processing plant Slovnaft. The influence of the steel industry in Velka Ida and thermal power plant in Prievidza were investigated. The most heavily contaminated sampling site, in the vicinity of the Tusimice surface coal mine in the Czech Republic, was also included in this study. The levels of pollutant concentrations were compared to those in the atmosphere of another five European sites: Krakow (Poland);

Budapest (Hungary); Ispra, Ponzone and Milan (Italy). Terrestrial moss Pleurozium schreberi and Hylocomium splendens were collected in the environs of the Slovnaft oil plant to monitor heavy metal atmospheric deposition. The elemental concentrations in moss samples were compared to the Slovakian median values and the Norwegian ones.

Moreno T, Querol X, Alastuey A, de la Rosa J, Sanchez de la Campa AM, Minguillon M et al. 2010. Variations in vanadium, nickel and lanthanoid element concentrations in urban air. Science of the Total Environment 408(20): 4569-79.

Abstract: The emission of trace metal pollutants by industry and transport takes place on a scale large enough to alter atmospheric chemistry and results in measurable differences between the urban background of inhalable particulate matter (PM) in different towns. This is particularly well demonstrated by the technogenic release into the atmosphere of V, Ni, and lanthanoid elements. We compare PM concentrations of these metals in large datasets from five industrial towns in Spain variously influenced by emissions from refinery, power station, shipping, stainless steel, ceramic tiles and brick-making. Increased La/Ce values in urban background inhalable PM, due to La-contamination from refineries and their residual products (fuel oils and petcoke), contrast with Ce-rich emissions from the ceramic related industry, and clearly demonstrate the value of this ratio as a sensitive and reliable tracer for many point source emissions. Similarly, anomalously high V/Ni values (>4) can detect the influence of nearby high-V petcoke and fuel oil combustion, although the use of this ratio in urban background PM is limited by overlapping values in natural and anthropogenic materials. Geochemical characterisation of urban background PM is a valuable compliment to the physical monitoring of aerosols widely employed in urban areas, especially given the relevance of trace metal inhalation to urban health issues.

Moreno T, Querol X, Alastuey A, Pey J, Minguillón MC, Pérez N et al. 2008. Lanthanoid geochemistry of urban atmospheric particulate matter. Environmental Science and Technology 42(17): 6502-7.

Abstract: Relatively little is known about the lanthanoid element (La to Lu) chemistry of inhalable urban atmospheric particulate matter (PM). PM samples collected during an air sampling campaign in the Mexico City area contain lanthanoid concentrations of mostly 1-10 ng m-3, increasing with mass where resuspension of crustal PM is important (low PM2.5/PM 10), but not where fine emissions from traffic and industry dominate (high PM2.5/ PM10). Samples show anthropogenic enrichment of lighter over heavier lanthanoids, and Ce enrichment relative to La and Sm occurs in the city center (especially PM10) possibly due to PM from road vehicle catalytic converters. La is especially enriched, although many samples show low La/V values (<0.11), suggesting the dominating influence of fuel oil combustion sources rather than refinery emissions. We use La/Sm v La/ Ce, LaCeSm, and LaCeV plots to compare Mexico City aerosols with PM from other cities. Lanthanoid aerosol geochemistry can be used not only to identify refinery pollution events, but also as a marker for different hydrocarbon combustion emissions (e.g., oil or coal power stations) on urban background atmospheric PM.

Nelson PF, Shah P, Strezov V, Halliburton B, Carras JN. 2010. Environmental impacts of coal combustion: A risk approach to assessment of emissions. Fuel 89: 810-6.

Abstract: This paper summarises some of the work performed in the Cooperative Research Centre for Coal in Sustainable Development (CCSD) on emissions from current power generation. A comprehensive approach was taken in the CCSD program to assessing environmental issues of concern for the power, and by implication the coal, industries. Here results of sampling on full scale operating plants are described, and detailed data on emission fluxes, particle size distributions, trace element concentrations as a function of particle size, and speciation of the trace elements are illustrated. The results show that particle capture in electrostatic precipitators (ESPs) is significantly less efficient than in fabric filters (FFs), particularly for submicron material, and that significant enrichment is observed in the finer particle sizes emitted from both ESPs and FFs. Results for the speciation of chromium, arsenic and selenium in coals, bottom ash and fly ash are also presented. The majority of chromium in fly ash is present in the less toxic Cr(3+) form. Speciation of arsenic in feed coals is variable but the dominant form of As in fly ash is the less toxic As(5+).

Nowak JB, Neuman JA, Bahreini R, Brock CA, Middlebrook AM, Wollny AG et al. 2010. Airborne observations of ammonia and ammonium nitrate formation over Houston, Texas. Journal of Geophysical Research D: Atmospheres 115, 22.

Abstract: Anthropogenic emissions of NOx (nitric oxide (NO) + nitrogen dioxide (NO2)), which in sunlight can be oxidized to form nitric acid (HNO3), can react with ammonia (NH3) to form ammonium nitrate particles. Ammonium nitrate formation was observed from the NOAA WP-3D aircraft over Houston during the 2006 Texas Air Quality Study with fast-response measurements of NH3, HNO3, particle composition, and particle size distribution. Typically, NH3 mixing ratios over the urban area ranged from 0.2 to 3 ppbv and were predominantly from area sources. No NH3 enhancements were observed in emission plumes from power plants. The few plumes with high NH3 levels from point source emissions that were sampled are analyzed in detail. While the paucity of NH 3 data in emission inventories made point source identification difficult, one plume was traced to NH3 release from an industrial accident. NH3 mixing ratios in these plumes ranged from 5 to 80 ppbv. In these plumes, the NH3 enhancement correlated with a decrease in HNO3 mixing ratio and an increase in particulate NO3 - concentration indicating ammonium nitrate formation. The ammonium nitrate aerosol mass budget in the plumes was analyzed to assess the quantitative agreement between the gas and aerosol phase measurements. The thermodynamic equilibrium between the gas and aerosol phase was examined for one flight by comparing the modeled dissociation constant for ammonium nitrate with NH3 and HNO3 measurements. The high levels of NH 3 in these plumes shifted the equilibrium toward favorable thermodynamic conditions for the condensation of ammonium nitrate onto particles.

Oliveira RL, Varandas L, Arbilla G. 2013. Characterization of polycyclic aromatic hydrocarbon levels in the vicinity of a petrochemical complex located in a densely populated area of the Rio de Janeiro, Brazil. Atmospheric Pollution Research 5(1): 87-95.

Abstract: The Petrochemical Complex of Duque de Caxias, Rio de Janeiro, is situated on a coastal strip between Guanabara Bay and a mountainous region covered with tropical forest. The complex comprises a refinery, a thermal power plant and several petrochemical industries. Higher rates of particulate-matter emissions are found in the region, mainly due to diesel emissions and the industrial activities of this area. In 2009 and 2010, samples were collected in three sites, and the 16 polycyclic aromatic hydrocarbons (PAHs) that are designated as priority pollutants by the US Environmental Protection Agency were determined. The sites are located in the vicinity of the Petrochemical Complex, one of them is on a roadside and the others are urban areas around the industrial complex. Multivariate analyses and diagnostic ratios show that the three studied areas were different, and the emissions seemed to be due to both gasoline and diesel vehicles. The carcinogenic PAHs represented the main fraction of the total PAHs determined in the particulate matter, and because the region is densely populated, these values may represent a health concern. The results indicate that regarding PAHs, the principal impact of the petrochemical complex is the high increase in the traffic of diesel vehicles and related tailpipe emissions.

Ross AB, Bartle KD, Hall S, Jones JM, Williams A, Kubica K et al. 2011. Formation and emission of polycyclic aromatic hydrocarbon soot precursors during coal combustion. Journal of the Energy Institute 84(4): 220-6.

Abstract: The polycyclic aromatic hydrocarbon (PAH) soot precursors present in flue gases from a number of coal fired appliances, ranging in capacity from a 325 MW power station to a domestic open fire, were collected by standard procedures in which both particulate and gas phase were sampled, and analysed by gas chromatography-mass spectrometry. The distribution of PAHs between particulate and vapour phase was determined. Emissions of two-and three-ring PAHs predominated, and there was a general trend of a reduction in emissions with increasing capacity. Polycyclic aromatic hydrocarbon emissions from a fluidised bed boiler were reduced when biomass was incorporated into the feed fuel. The environmental significance of the emissions was considered, and the levels of carcinogenic PAHs in the flue gas from a 325 MW power station were of the same order of magnitude as those in ambient city air. The contributions of different mechanisms to the formation of PAHs in different appliances were assigned from a comparison of the

observed relative concentrations of compounds with different numbers of rings and the results of modelling the equilibrium combustion products.

Sarkar S, Khillare PS. 2011. Association of polycyclic aromatic hydrocarbons (PAHs) and metallic species in a tropical urban atmosphere - Delhi, India. Journal of Atmospheric Chemistry 68(2): 107-26.

Abstract: Ambient respirable particles (PM10; aerodynamic diameter ≤10 μm) collected in a tropical urban environment (Delhi, India) during December 2008-November 2009 were characterized with respect to 16 US EPA priority polycyclic aromatic hydrocarbons (PAHs) and 8 major and trace metals (Fe, Mn, Cd, Cu, Ni, Pb, Zn and Cr). Concentrations of Σ16PAHs (annual mean: 74.7 ± 50.7 ng m−3, range 22.1–258.4 ng m−3) and most metallic species were at least an order of magnitude greater than values reported from similar locations worldwide. Seasonal variations in Σ16PAHs were significant ($p < 0.001$) with highest levels in winter while crustal and anthropogenic metals showed significant but mutually opposite seasonal dependence. Statistically significant associations were observed between chemical species and various meteorological parameters. The PAH profile was dominated by combustion-derived large-ring species (~85%) that were essentially local in origin. Principal component analysis–multiple linear regression (PCA-MLR) apportioned four sources: crustal dust (73%), vehicular emission (21%), coal combustion (4%) and industrial emission (2%) that was further validated by hierarchical cluster analysis (HCA). Temporal trend analysis showed that crustal sources were predominant in summer ($p < 0.05$) while the remaining sources were most active in winter. Summertime intrusions of Saharan dust were identified with the help of aerosol maps and air parcel backward trajectories. Inhalation cancer risk assessment showed that up to 3,907 excess cancer cases (357 for PAHs, 122 for Cd, 2040 for Cr (VI) and 1387 for Ni) are likely in Delhi considering lifetime inhalation exposure to these chemicals at their current concentrations.

Sarkar S, Khillare PS. 2013. Profile of PAHs in the inhalable particulate fraction: Source apportionment and associated health risks in a tropical megacity. Environmental Monitoring and Assessment 185(2): 1199-213.

Abstract: The present study proposed to investigate the atmospheric distribution, sources, and inhalation health risks of polycyclic aromatic hydrocarbons (PAHs) in a tropical megacity (Delhi, India). To this end, 16 US EPA priority PAHs were measured in the inhalable fraction of atmospheric particles (PM10; aerodynamic diameter, ≤10 μm) collected weekly at three residential areas in Delhi from December 2008 to November 2009. Mean annual 24 h PM10 levels at the sites (166.5–192.3 μg m−3) were eight to ten times the WHO limit. Weekday/weekend effects on PM10 and associated PAHs were investigated. Σ16PAH concentrations (sum of 16 PAHs analyzed; overall annual mean, 105.3 ng m−3; overall range, 10.5–511.9 ng m−3) observed were at least an order of magnitude greater than values reported from European and US cities. Spatial variations in PAHs were influenced by nearness to traffic and thermal power plants while seasonal variation trends showed highest concentrations in winter. Associations between Σ16PAHs and various meteorological parameters were investigated. The overall PAH profile was dominated by combustion-derived large-ring species (85–87 %) that were essentially local in origin. Carcinogenic PAHs contributed 58–62 % to Σ16PAH loads at the sites. Molecular diagnostic ratios were used for preliminary assessment of PAH sources. Principal component analysis coupled with multiple linear regression-identified vehicular emissions as the predominant source (62–83 %), followed by coal combustion (18–19 %), residential fuel use (19 %), and industrial emissions (16 %). Spatio-temporal variations and time-evolution of source contributions were studied. Inhalation cancer risk assessment showed that a maximum of 39,780 excess cancer cases might occur due to lifetime inhalation exposure to the analyzed PAH concentrations.

Shah P, Strezov V, Prince K, Nelson PF. 2008. Speciation of As, Cr, Se and Hg under coal fired power station conditions. Fuel 87: 1859-69.

Abstract: Coal combustion from power stations is an important anthropogenic contributor of toxic trace elements to the environment. Some trace elements may be emitted in range of valencies, often with varying toxicity and bioavailability. Hence, determination of trace element speciation in coals and their combustion products is important for conducting comprehensive risk assessments of the emissions from coal-fired power

stations. This study focuses on speciation of selected trace elements, As, Cr, and Se, in coal combustion products and Hg in flue gas, which were sampled at one Australian power station. Different analytical methods such as secondary ion mass spectrometry (SIMS), ion chromatography-inductively coupled plasma mass spectrometry (IC-ICPMS) and X-ray absorption near edge structure spectrometry (XANES) were used to determine trace element speciation in coal and ash samples. Results showed that As, Cr and Se are all present in a range of valency states in coal. Concentrations of As and Se in the bottom ash as well as the more toxic hexavalent chromium were less than the detection limits. The more toxic As3+ form in fly ash was at 10% of the total arsenic, while selenium was mainly found in Se4+ form. Hexavalent chromium (Cr6+) in fly ash was 2.7% of the total fly ash chromium. Mercury speciation in flue gas was determined using the Ontario Hydro sampling train and analysis technique. Approximately 58% of the total mercury in flue gas was released in the elemental form (Hg-0), which, among all mercury species, has the highest residence time in the environment due to lower solubility. This work summarises the performance of the selected analytical techniques for speciation of trace elements.

Shen Z, Arimoto R, Cao J, Zhang R, Li X, Du N et al. 2008. Seasonal variations and evidence for the effectiveness of pollution controls on water-soluble inorganic species in total suspended particulates and fine particulate matter from Xi'an, China. Journal of the Air and Waste Management Association 58(12): 1560-70.

Abstract: Total suspended particulate (TSP) and particulate matter less than 2.5 μm in aerodynamic diameter (PM2.5) samples were collected over Xi'an for a 1-yr period to characterize the seasonal variations of water-soluble inorganic ions and to evaluate the effectiveness of the pollution policies and controls during the past 10 yr. Mass concentrations of five cations (sodium [Na+], potassium [K+], ammonium [NH4+], calcium [Ca2+], and magnesium [Mg2+]) and four anions (fluoride [F-], chloride [Cl-], nitrate [NO3-], and sulfate [SO4(2-)]) were determined by ion chromatography. The yearly arithmetic-mean mass concentrations of the total measured water-soluble ions in TSP and PM2.5 were 83.9 +/- 58.4 and 45 +/- 34.3 μg x m(-3). The most abundant ions in TSP were SO4(2-), NO3-, Ca2+, and NH4+; whereas in PM2.5 the dominant ions were SO4(2-), NH4 +, and NO3-. Most of the ions were more concentrated in the PM2.5 than in TSP, but two exceptions were Ca2+ and Mg2+. Comparisons of the molar ratios of Mg2+/Ca2+ in TSP indicated that fugitive dust was the main source for these two ions, and the influence of soil dust from outside of the city was most evident during dust storms. The mass concentrations of SO4(2-), NO3-, , NH4+, and K+ in TSP were highest in winter and lowest in spring, but Ca2+ was much higher in spring than other seasons because of suspended mineral dust. In PM2.5, NO3- and K+ also showed winter maxima, but SO4(2-) and NH4+ were highest in summer. Calculations of ion equivalents showed that TSP samples were more alkaline than PM2.5, the latter being weakly acidic in winter and autumn. High sulfur and nitrogen oxidation ratios occurred in summer and autumn, and there was evidence for the formation of ammonium bisulfate in TSP, ammonium sulfate in PM2.5, and ammonium nitrate in both fractions. Comparisons with the results of prior studies indicate that pollution controls in Xi'an have reduced the levels of air pollution over the past 10 yr. The SO4(2-) concentration during the heating season in 2006 was only about one-eighth of that in 1996, and NH4+ decreased to one-ninth of that in 1996. Seasonal variations in the NO3-/SO4(2-) ratio are different than the patterns observed 10 yr ago, suggesting that emission sources have changed, with those from motor vehicles becoming increasingly important.

Sipos P, Kis VK, Marton E, Nemeth T, May Z, Szalai Z. 2012. Lead and zinc in the suspended particulate matter and settled dust in Budapest, Hungary. European Chemical Bulletin 1(11): 449-54.

Abstract: Urban airborne particulate matter and dust can be both ingested and inhaled so they may cause health damage due to their size, shape or toxic components. Our aim was to characterize the concentration, enrichment and host phases of lead and zinc in total suspended particulate matter (TSP) and settled dust (SD) samples from Budapest, Hungary. TSP samples were collected from the air filters placed in the respiration channels of thermal power stations, while SD samples were collected in glass pots next to a busy street. Detailed mineralogical, chemical and magnetic susceptibility analyses were carried out on the samples. The concentrations of both elements were generally higher in the TSP (330-3597 mg/kg -1 for Pb and 1342-19 046 mg/kg -1 for Zn) than in the SD samples (58-474 mg/kg -1 for Pb and 399-1140 mg/kg -1 for Zn).

Additionally, they showed moderate contamination in the SD samples, while moderate to heavy contamination in TSP samples with enrichment factors up to 4.9 for Pb and 5.3 for Zn. Transmission electron microscopy analyses showed that magnetite may contain significant amount of Zn (up to 2.60 wt%) and Pb (2.50 wt%). However, Zn could be also associated with layer silicates (up to 5.06 wt%) and Ca-carbonates. Moreover, Zn also appeared as major phase constituent in carbonates and oxides. Magnetite particles are resistant to weathering releasing its toxic components slowly to the environment, while layer silicates (and carbonates, Zn-oxides) may be the potential source of mobile toxic metals in the studied materials.

Tang Q, Liu G, Yan Z, Sun R. 2012. Distribution and fate of environmentally sensitive elements (arsenic, mercury, stibium and selenium) in coal-fired power plants at Huainan, Anhui, China. Fuel 95: 334-9.

Abstract: The present study has investigated the distribution of arsenic (As), mercury (Hg), stibium (Sb) and selenium (Se) in feed coal and its combustion by-products in two pulverized coal-fired power plants at Huainan city, Anhui province, China, both of which burned the bituminous coals. Experimental analysis of simultaneously sampled coal, bottom ash, fly ash and FGD products showed that the concentrations of As, Hg, Sb and Se in coal were in the ranges of typical Chinese power plants reported by others publications. Mercury was found to be the most volatile, whereas Sb was the least volatile. The overall material balances of As, Hg, Sb and Se were established based on the operation parameters of their respective boiler. The average removal efficiencies of As, Hg, Sb and Se by the ESP unit were 83%, 16%, 100%, and 72%, respectively, whereas those by the FGD process were 61%, 80%, 0% and 55%, respectively. The stack emission proportions of As, Hg and Se were 6%, 17% and 13%, respectively. And the total annual emissions of As, Hg and Se from two coal-fired power plants were estimated at 0.46 t, 0.04 t and 2.27 t, respectively.

Teixeira EC, Mattiuzi CD, Agudelo-Castaneda DM, Garcia Kde O, Wiegand F. 2013. Polycyclic aromatic hydrocarbons study in atmospheric fine and coarse particles using diagnostic ratios and receptor model in urban/industrial region. Environmental Monitoring and Assessment 185(11): 9587-602.

Abstract: Atmospheric fine and coarse particles were collected in Teflon filters in three cities of the region of the Lower Sinos River Basin of Rio Grande do Sul in the year 2010. The filters were Soxhlet extracted, and 14 priority PAHs were analyzed using a gas chromatograph coupled to a mass spectrometer (GC/MS). The principal emission sources of these compounds were assessed by using diagnostic ratios and receptor model: positive matrix factorization (PMF 3.0) of the US Environmental Protection Agency. The results of PAHs concentration for the studied year showed significant levels of high molecular weight (HMW) PAH, Ind, and BghiP, in PM2.5 in the winter season, showing the influence of mobile sources. The application of receptor model PMF 3.0 revealed that the main sources of PAHs were vehicle fleet (both diesel and gasoline), followed by coal combustion, wood combustion, and resuspension of dust. The results of the receptor modeling are in agreement with the data obtained by the ratio diagnostic.

Tian F, Chen J, Qiao X, Wang Z, Yang P, Wang D et al. 2009. Sources and seasonal variation of atmospheric polycyclic aromatic hydrocarbons in Dalian, China: Factor analysis with non-negative constraints combined with local source fingerprints. Atmospheric Environment 43: 2747-53.

Abstract: Vapor- and particulate-phase polycyclic aromatic hydrocarbon (PAH) samples were continuously collected at an urban site in Dalian, China, during the heating and non-heating period. There is strong temperature dependence and obvious seasonal trend for atmospheric PAHs, and significant positive correlations of atmospheric PAHs with SO2 and CO concentrations were observed. Factor analysis model with non-negative constraints (FA-NNC) combined with local and literature PAH source fingerprints was successful in source identification of particulate PAHs in the atmospheric samples. The results suggested that, in heating period, the main pollution sources were identified as coal-fired boiler emission (56%), residential coal combustion (33%) and traffic emissions (11%). As for non-heating period, the main sources were gasoline engine emission, traffic tunnel emission and coal-fired power plant, and the overall source contributions of traffic emission (gasoline engine + traffic tunnel) were 79% and coal-fired power plant 21%.

The current results support our previous study and provide new insights. This can be the first attempt to quantitatively apportion air organic pollutants using receptor models combined with local source fingerprints. The source fingerprints can be used as reference data for source apportionment of atmospheric PAHs of China.

Wang HL, Hao ZP, Zhuang YH, Wang W, Liu XY. 2008. Characterization of inorganic components of size-segregated particles in the flue gas of a coal-fired power plant. Energy and Fuels 22: 1636-40.

Abstract: Particulate matter (PM) in the range of 0.03-10 μm were collected with a 13-stage cascade impactor sampler at the outlet of an electrostatic precipitator (ESP) of a 100 MW lignite-fired power plant and were characterized by number and mass size distributions, element, and ion measurements. The number size distribution in the whole range of 0.03-10 μm appeared to be bimodal with peaks at 0.06 and 0.835 μm. The mass size distribution over 13 size-segregated fractions was also bimodal with peaks at 0.06 and 1.8 μm. Four out of 13 fractions (namely, 0.03 < D-p < 0.06 μm, 0.06 < D-p < 0.1 μm, 0.7 < D-p < 1.1 μm, and 1.8 < D-p < 2.7 μm) were selected to represent the nano, ultrafine, submicron, and fine particles in this research, respectively. In general, the highest concentrations of elements were found in the fine fraction, in which Al and Ca were the most abundant elements, followed by S, Fe, and Na. In the nano fraction, Na and S were found with the highest levels. Enrichment coefficients of pollution elements (As, Pb, S, Se, Sb, and Cd) and some trace metal elements (Zn, Cr, Ni, Cu, V, and Co) suggested that these elements were enriched in the particles with smaller size. pH measurements showed that these flue gas samples were acidic and the acidity became weaker with larger particle size. Sulfate was the most predominant anion and remained at rather high levels due to the lack of desulfurization equipment. The high sulfate/nitrate ratios could be taken as a rudimentary indicator of such coal combustion sources.

Wang X, Cheng H, Xu X, Zhuang G, Zhao C. 2008. A wintertime study of polycyclic aromatic hydrocarbons in PM2.5 and PM2.5-10 in Beijing: assessment of energy structure conversion. Journal of Hazardous Materials 157(1): 47-56.

Abstract: Sixteen priority polycyclic aromatic (PAHs) in PM2.5 and PM2.5-10 samples collected from 20 sites in Beijing, China in December 2005 and January 2006 were analyzed to determine the composition, spatial distribution and sources. Total PAHs of PM2.5 and PM2.5-10 ranged from 5.2 to 1062.2 ng m(-3) and 7.6 to 759.7 ng m(-3), respectively, categorized as heavier pollution. Among five kind of functional zones involved, industrial center, commercial area and village were heavily polluted. The mean concentration of PAHs in PM2.5 of 407 ng m(-3) was 1.67-fold of that in PM2.5-10, which was relatively high compared to the previous studies (winter in 2001 and 2002). The most evident change was the increase of Flu, BbkF and InP, which are believed to be less harmful and related to the increasing use of clean energy. However, pollution distribution was spatially heterogeneous inside the city. The most polluted sites located in the southeast of the city. Unlike previous studies, fluoranthene was the most abundant component quantified, which could be associated with increasing use of natural gas as clean energy. Compositional analysis and principal component analysis (PCA) suggested that different kinds of combustion were the main source of the PAHs in PM, though contribution of coal was still evident.

Wang YF, Chao HR, Wang LC, Chang-Chien GP, Tsou TC. 2010. Characteristics of heavy metals emitted from a heavy oil-fueled power plant in northern Taiwan. Aerosol and Air Quality Research 10: 111-8.

Abstract: The characteristics and distribution of metal contents emitted from a power plant fueled by heavy oil and its impact to the ambient atmosphere near the power plant was investigated. The current investigation measured toxic (As, Cd, Cr, Hg, Ni and Pb), anthropogenic (Ba, Cu, Mn, Sb, Se, Sr, Ti, V and Zn) and crust (Al, Ca, Fe, K and Mg) elements from a 2,000 MW heavy oil-fired power plant. Results showed the emission concentration from the power plant contributed to 17,976 kg/yr annual emission of anthropogenic elements, which was significantly higher than those from some electrical arc furnaces and coke ovens in Taiwan. For toxic metals, As, Cd or Ni concentration do not exceed target values established by the European Council (2004/107/EC) for As (6 ng/m3), Cd (5 ng/m3) and Ni (20 ng/m3). This study also applies nonparametric statistical analyses for evaluating the relationship between metal concentrations and operational parameters

(including emitted CO2, O2, flue gas emission temperature, flue gas velocity, moisture, heavy oil consumption rate, boiler steam temperature, boiler operational pressure, and electricity). Findings show negative correlations between most toxic metals (As, Cd, Cr and Hg) and operational parameters, though some pairs were not statistically significant. The current study provides only preliminary statistical results between metal concentrations and operational parameters due to small sample sizes. Further investigation requires larger sample sizes.

Yi H, Hao J, Duan L, Tang X, Ning P, Li X. 2008. Fine particle and trace element emissions from an anthracite coal-fired power plant equipped with a bag-house in China. Fuel 87(10-11): 2050-7.

Abstract: Fine particle and trace element emissions from energy production are associated with significant adverse human health effects. In this investigation, the fine particles and trace elements emitted from the combustion of pulverized anthracite coal at a 220 MW power plant were determined experimentally in the size range from 30 nm to 10 μm with 12 channels. The particulate size distributions and morphological characteristics before and after the bag-house were evaluated. The uncontrolled and controlled emission factors of particles are compared with the calculated values from the US Environment Protection Agency, AP-42. Size-classified relative enrichment factors of As, Hg, Se, Cd, Cr, Cu, Al, V, Zn, Mn, Fe were obtained. Relative distributions of trace elements between bottom ash, fly ash and flue gas are determined by mass balance method. The bag-house collection efficiencies of particles and trace elements in the particulate phase are obtained. Finally, the controlled and uncontrolled emission factors of elements of different particulate size fractions are obtained, which will provide useful information for PM2.5 and PM10 emission inventory development, toxic and hazardous pollutant emission estimates and emission standards established for metal-based pollutants from a pulverized coal-fired boiler.

Zhao J, Zhang F, Chen J, Xu Y. 2010. Characterization of polycyclic aromatic hydrocarbons and gas/particle partitioning in a coastal city, Xiamen, southeast China. Journal of Environmental Sciences 22(7): 1014-22.

Abstract: An intensive sampling program had been undertaken in autumn (October, 2008) and winter (December, 2008 and January, 2009) at urban (Xiamen University and Xianyue residential area), suburban (Institute of Urban Environment), industrial area (Lulian Hotel) and background (Tingxi Reservoir) in Xiamen, Fujian Province, to characterize the atmospheric concentration and gas-particle phase partitioning of PAHs. The average concentration of total PAHs in winter was almost 1.7 times higher than those in autumn. The log scale plot of Kp versus sub-cooled liquid vapor pressure (P^0_L) for all the data of autumn and winter season samples gave significantly different slopes. The slope for the winter samples (-0.72) was steeper than that for the autumn samples (-0.58). The partitioning results indicated that slope values varied depending on characteristics of specific site, source region and meteorological conditions which play important roles in the partitioning of PAHs. In addition, local emission sources had a stronger effect on partitioning results than long-transported polluted plume. The sources of PAHs in five sampling sites in Xiamen also have been discussed initially. Diagnostic ratios showed that the primary source of PAHs in urban, suburban and industrial area was from vehicle exhausts. While emission from petrochemical factory and power plant was another main contributor to industrial area.

Zhao J, Zhang F, Xu L, Chen J, Xu Y. 2011. Spatial and temporal distribution of polycyclic aromatic hydrocarbons (PAHs) in the atmosphere of Xiamen, China. Science of the Total Environment 409(24): 5318-27.

Abstract: An intensive sampling program was conducted from October 2008 to September 2009 at the five different environmental sites in Xiamen, Fujian Province, to study the spatial and temporal characteristics of Polycyclic Aromatic Hydrocarbons (PAHs) in the gaseous and particulate phase, respectively. The PAHs concentrations at different sites were quite distinct during four seasons. The average concentrations of PAHs in winter were about 8.4 times higher than those in spring, and the concentrations of background were 0.56 times lower than those of industrial area. In addition, the higher temperature in summer affected the particle/gas partitioning of PAHs and led to the higher concentrations of gaseous PAHs. Diagnostic ratios of PAHs, which were employed to indicate the primary sources of PAHs in Xiamen, showed that the traffic

vehicle exhaust was the largest contributor and the primary source for PAHs in Xiamen, especially in urban area; while the stationary combustion processes, such as petrochemical factories and power plants, were mainly responsible for PAHs sources in the industrial areas. The health risk of PAHs in the particulate phase was higher than those of the gaseous phase at the five sampling sites. The average toxic equivalent (BaP eq) of the benzo[a]pyrene values for PAHs were 0.14, 0.32, 1.38 and 3.59 ng m-3 in spring, summer, autumn and winter, respectively. Furthermore, the results of average BaP eq in all four seasons indicated that the health risks of particulate PAHs were higher than those of the gaseous PAHs at different sampling sites.

Zhu L, Tang J, Lee B, Zhang Y, Zhang F. 2010. Lead concentrations and isotopes in aerosols from Xiamen, China. Marine pollution bulletin 60(11): 1946-55.

Abstract: To investigate the magnitude and origin of lead (Pb) pollution in the atmosphere of Xiamen, China, 40 aerosol samples were collected from the coast of Xiamen from January to December 2003. All these samples were measured for Pb isotopic compositions ((208)Pb/(206)Pb=2.10897 +/- 0.00297, (207)Pb/(206)Pb=0.85767 +/- 0.00159, n=40) using a Multi-collector-Inductively Coupled Plasma Mass Spectrometer (MC-ICPMS). Thirty-five out of forty samples were also measured for Pb concentrations (79.1 +/- 38.3 ng/m3, n=35) by Atomic Absorption Spectroscopy (AAS). The results indicate that the Pb concentrations display significant seasonal variations while Pb isotopic ratios remain relatively constant. The Pb concentrations were high in January and February, abruptly decreased in March, remained relatively constant (but low) from April to August, and then gradually increased from September to December. This corresponds to the rainless climate in winter and rain scavenging in summer. The higher Pb concentration of Xiamen aerosols in winter and spring may be also caused by long-range transferred anthropogenic Pb during the northeastern monsoon seasons. Although the use of leaded gasoline in Xiamen was banned in 2000, our new data indicate that the Pb annual concentrations of aerosols in Xiamen increased about 12% when compared to the data measured between 1991 and 1993. Thus, Pb pollution in the atmosphere of Xiamen has not receded even after the phase-out of leaded gasoline. Our results further confirm the previous studies' conclusion that the primary source of atmospheric Pb in China, especially in South China, is the vast combustion of lead-containing coal, not leaded gasoline.

Grey literature

Dung NT, Reutergardh LB, Oanh NTK, Chi DK, Co HX. 2008. Emission of polycyclic aromatic hydrocarbons associated with particulate matter from a coal-fired power plant in Vietnam. In: Air and Waste Management Association - 7th Power Plant Air Pollutant Control 'Mega' Symposium 2008, 1281-5.

Abstract: Integrated samples of particulate matter have been taken iso-kinetically from the flue gas of Bai Bang thermal coal-fired power plant using glass fibre filters. The samples have been Soxhlet extracted with CH2CI2 and analysed by high performance liquid chromatography with fluorescence detection (HPLC/FLD) and/or gas chromatography with mass spectrometer detection (GC/MS). Anthracene, benzo[a]anthacene, phenanthrene, fluoranthene, pyrene, chrysene and benzo[a]pyrene, have been all present on the particulate matter, and the quantification of the latter five have yielded concentrations of 12.1, 6.3, 4.8, 3.0, 0.20 ng/m3 at normal conditions, emission factors of 111, 57, 43, 27, 2 ng/kg coal, and emission rates of 2207, 1122, 847, 535, 38 μg/h, respectively. The obtained concentrations, emission factors, as well as recoveries have been reduced with increased molecular weight of individual PAHs compounds.

Jabłońska M, Smołka-Danielowska D. 2008. Iron oxides particles in the air and fly ash, and their influence on the environment (preliminary studies). In: Polish Geological Institute Special Papers, 93-8.

Abstract: The paper presents preliminary data concerning sizes, distribution and composition of the most popular particles, which are formed during coal combustion, i.e. iron oxide particles. It is written only about particles of iron oxides, not describing different phases which contain iron (such as sulphides, carbonates or native iron). Particles of PM10 (Particule Matter 10) and the fallen dust were collected in several towns of the Upper Silesia. Fly ash samples from the coal combustion were separated in electrofilters. All samples were

gathered during the last years. Samples were analysed by X-ray diffraction on Philips PW 3710 instrument (with CoKa radiation) and Philips XL30 TMP scanning electron microscope equipped with EDAX system and EDS type Sapphire. In fly ashes, similar iron oxide particles were found. However, differences in concentration of accessory components were observed. The magnesioferrite, hercynite and chromite occurred in the fly ashes. Differences were also observed in grain size of the dominating particles. About 50–60 wt. % of iron oxides particles present in the atmospheric dust have diameters less then 10 mm, while about 10 wt. % of them show particles less then 2.5 mm (respirable particles). The fly ashes from the electrofilters contained a lot of iron oxide particles with the diameter range 30–80 mm (average about 70 wt. % of all iron oxides particles). Most of larger iron oxide particles originating from the coal combustion are separated in the electrofilters, but the smallest fractions (less then 10 mm) are emitted to the atmosphere. Since a lot of iron oxides particles, which diameters is less than 10 mm are observed in the air it may be assumed that these diameters are transported to long distances. Moreover, iron oxide particles which diameters are less then 2.5 mm can show a potential hazard to human health. There are preliminary studies of iron oxides, which will be continued.

Pennsylvania Department of Health. 2009. Health Consultation: First Energy Corporation, Bruce Mansfield Power Plant, Shippingport, Beaver County, Pennsylvania. Atlanta, Georgia. Available at http://www.atsdr.cdc.gov/HAC/pha/BruceMansfieldPowerPlant/BruceMansfieldPowerPlantHC03-31-09.pdf.

Abstract: At the request of the Pennsylvania Department of Environmental Protection (PADEP) and concerned community members, the Pennsylvania Department of Health (PADOH) prepared this health consultation (HC) to determine whether residents near the First Energy Generation Corporation, Bruce Mansfield Power Plant Site in Shippingport, PA (the site) were exposed to contaminants at levels that would harm their health. PADOH reviewed air, dust fall, wipes/soot, soil, and surface water sampling data. PADOH developed this health consultation under a cooperative agreement with the Agency for Toxic Substances and Disease Registry (ATSDR).
ATSDR and PADOH cannot determine if a public health threat exists for the Shippingport area residents due to emissions from the Bruce Mansfield power plant because there is insufficient sampling data. Thus, the exposures to the detected contaminants currently pose an indeterminate public health hazard to residents in the surrounding communities. Some of the sampling results, and the fact that the plant has suffered two recent operational malfunctions, warrant additional monitoring. A comprehensive air sampling plan would quantify the current and on-going community exposure levels and address any data gaps. However, future sampling data will not be able to delineate any contamination from the past operational malfunctions or past sampling data gap issues. The interpretation, conclusions, and recommendations regarding the Bruce Mansfield Site for this health consultation are specific to this area and do not necessarily apply to any other site or location.

Yin XF, Yang WT, Xue HM. 2013. PAHs emission characteristics and assessment from the coal combustion process in the large capacity power plant boilers. In: Advanced Materials Research, 2nd International Conference on Energy and Environmental Protection, 1908-16.

Abstract: Many studies have demonstrated an association between exposure to ambient Polycyclic Aromatic Hydrocarbons (PAHs) and some serious diseases, such as cancer, malformation and mutation. PAHs is thought as a carcinogenic and mutagenic compound to human health. Coal-fired power plant industry plays an important role in the observed PAHs emission process. However, the PAHs emission characteristic and environment impact in coal-fired power plant is still not fully clarified. In this study, the PAHs distribution characteristic of the flue gas and fly ash emitted from electrostatic precipitator in two coal-fired power plant boilers with the steam capacity 1000t/h and 2000t/h have been studied in China based on USEPA method 0023(sampling part). PAHs concentrations and PAHs emission factors were determined. And the correlation between PAHs emission and the steam capacity of the power plant boiler was discussed. In addition, the PAHs removal effects of air pollution control devices were also included. According to the measured PAHs emission data and the report of China statistical year book, the PAHs emission assessment from the coal combustion process in the large capacity co-fired power plant boilers have been done. Though the PAHs emission value in the large capacity power plant were present within recommended emission limits of energy

production, the problem of PAHs emission in large capacity coal-fired power plant shouldn't be ignored due to the huge amounts and long-range transport in soil, water and ambient air.

4.1.3 PM components - modeled emissions (emission inventories)

White literature

Chen J, Liu G, Kang Y, Wu B, Sun R, Zhou C et al. 2013. Atmospheric emissions of F, As, Se, Hg, and Sb from coal-fired power and heat generation in China. Chemosphere 90(6): 1925-32.

Abstract: Coal is one of the major energy resources in China, with nearly half of produced Chinese coal used for power and heat generation. The large use of coal for power and heat generation in China may result in significant atmospheric emissions of toxic volatile trace elements (i.e. F, As, Se, Hg, and Sb). For the purpose of estimating the atmospheric emissions from coal-fired power and heat generation in China, a simple method based on coal consumption, concentration and emission factor of trace element was adopted to calculate the gaseous emissions of elements F, As, Se, Hg, and Sb. Results indicate that about 162161, 236, 637, 172, and 33 t F, As, Se, Hg, and Sb, respectively, were introduced into atmosphere from coal combustion by power and heat generation in China in 2009. The atmospheric emissions of F, As, Se, Hg, and Sb by power and heat generation increased from 2005 to 2009 with increasing coal consumptions.

Chow JC, Watson JG, Lowenthal DH, Chen LWA, Motallebi N. 2011. PM2.5 source profiles for black and organic carbon emission inventories. Atmospheric Environment, 45(31): 5407-14.

Abstract: Emission inventories for black or elemental (BC or EC) and organic (OC) carbon can be derived by multiplying PM2.5 emission estimates by mass fractions of these species in representative source profiles. This study examines the variability of source profiles and its effect on EC emission estimates. An examination of available profiles shows that EC and OC ranged from 6–13% and 35–40% for agricultural burning, 4–33% and 22–68% for residential wood combustion, 6–38% and 24–75% for on-road gasoline vehicles, and 33–74% and 20–47% for on-road heavy-duty diesel vehicles, respectively. Source profiles from the U.S. EPA SPECIATE data base were applied to PM2.5 emissions from the U.S. EPA National Emissions Inventory for 2005. The total estimated EC emissions of 432 Gg yr−1 was apportioned as 42.5% from biomass burning, 35.4% from non-road mobile sources, 15% from on-road mobile sources, 5.4% from fossil fuel (e.g., coal, oil, and natural gas) combustion in stationary sources, 1% from other stationary industrial sources, and 0.5% from fugitive dust. Considering the variability in available source profiles, BC emission estimates for major sources such as open fires and non-road diesels ranged from 42 to 133 (a factor of 3) and 25 to 100 (a factor of 4) Gg yr−1, respectively. The choice of source profiles can be a major source of uncertainty in national and global BC/EC emission inventories.

Konieczynski J, Komosinski B, Jablonska M, Cieslik E. 2012. Prognosis of environmental impact of trace elements from brown coal-fired power plant "Belchatow". Archives of Environmental Protection 38: 59-72.

Abstract: A forecast of the negative impact exerted on the environment by selected trace elements in "Belchatów" Power Plant has been prepared on the basis of the results of investigations into these elements' distribution carried out as part of earlier research on coal from "Belchatów" Field and the data on updated analyses of the content of these elements in 55 brown coal samples from test boreholes. Work in "Belchatów" Power Plant, which is supplied with coal from "Szczerców" Field, will be accompanied by trace elements transfer. On the basis of the conducted investigations it has been found that the biosphere is most threatened by mercury emissions. As shown by the presented results of analyses and calculations, the emissions of mercury in "Belchatów" Power Plant are low. Mercury is accumulated chiefl y in gypsum produced in the FGD plant. The content of mercury in slag and ash is low.

Kragie SX, Ryan PB, Bergin MH, Wang S. 2013. Airborne trace metals from coal combustion in Beijing. Air Quality, Atmosphere and Health 6(1): 157-65.

Abstract: Prior studies have measured elevated ambient concentrations of hazardous metals in Beijing, attributable to coal combustion. The 2008 Olympic Games led to an intense investment in air pollution controls at the major power plants in the region, accounting for 30% of coal combustion in Beijing. Recently Chinese coal beds have been characterized in the World Coal Quality Index, facilitating the development of trace metal emission factors for Beijing coals. This study quantifies the relative value of the power plant air pollution controls in terms of public health risk from chronic exposure to trace metals. Ambient concentrations from power plants were estimated using an atmospheric dispersion model (CALPUFF), outlining spatial and temporal variations. The following toxic, refractory metals were evaluated for health risk using the USEPA Integrated Risk Information System: antimony, arsenic, beryllium, cadmium, chromium, cobalt, copper, lead, manganese, nickel, and selenium. Stringent use of power plant air pollution controls significantly reduces population risk, averting a cancer risk of 1 in 5,000. However, other sources of coal combustion, such as industrial and household uses, are more relevant to public health than power plant emissions. Coal washing has potential to reduce the hazard from these diffuse sources and avert a greater number of potential cancer cases.

Li Q, Cheng H, Zhou T, Lin C, Guo S. 2012. The estimated atmospheric lead emissions in China, 1990-2009. Atmospheric Environment 60: 1-8.

Abstract: Estimates of atmospheric emissions of lead from anthropogenic sources in China from 1990 to 2009 are presented with the information on emissions of both total lead and its spatial distribution in regions. The total emissions during the period 1990-2009 are nearly 200 000 tons. Motor vehicle gasoline combustion was the largest source of anthropogenic emissions. The estimated release of 117 800 t of lead represented 60% of the total emissions. Substantial decline occurred in 2001, when the total emissions were about 81% less than the 2000 value. The reduced lead content of motor vehicle gasoline is the primary reason for the decreased in lead emissions in 2001. After leaded gasoline was phased out, coal combustion became the principal source of emissions. Based on data on emissions from 2005 through 2009, the emissions are concentrated in eastern and central China due to the high level of coal consumption and non-ferrous metal smelting. The five provinces with the largest amounts of lead emissions are Shandong, Hebei, Shanxi, Henan and Jiangsu. These five regions produced nearly 40% of the total.

Pacyna JM, Pacyna EG, Aas W. 2009. Changes of emissions and atmospheric deposition of mercury, lead, and cadmium. Atmospheric Environment 43(1): 117-27.

Abstract: This paper reviews the information on trends of past emissions of mercury, lead, and cadmium in Europe, as well as examines current levels and future scenarios of these emissions. The impact of various factors on emission changes is discussed including the implementation of various strategies of emission controls in Europe. Future emissions are forecasted on the basis of various scenarios of economy growth in Europe, implementation of European and global legislation (e.g. the Kyoto agreement), population changes, etc. Changes of emissions of mercury, lead, and cadmium are then related to the changes of concentrations of these contaminants in air and precipitation samples at selected stations in Europe. It can be concluded that the reduction trends of anthropogenic emissions of cadmium and lead in Europe are similar to the reduction trends of air concentrations of these metals during the last 2 decades. Somewhat different relationship has been noted for changes in emissions and precipitation. In general for Europe, 60% reduction of Cd emissions was met by about 45% reductions of Cd concentrations in precipitation at the studied stations during the last 2 decades. There is a potential for further reduction of these emissions until the year 2010 up to about 37% for Cd, 51% for Pb, and 49% for Hg as estimated within various emission scenarios presented in the paper.

Shao X, Cheng H, Li Q, Lin C. 2013. Anthropogenic atmospheric emissions of cadmium in China. 79: 155-60.

Abstract: In this study, we estimated atmospheric Cd emissions from anthropogenic sources in China from 1990 to 2010 on the basis of consumption or output data and emission factors. China emitted approximately 2186t Cd to the atmosphere in 2010, with approximately 77% and 14% of the emissions arising from non-ferrous metal smelting and coal combustion, respectively. Temporal changes in the total Cd emissions were characterized by two periods of increase (1990-2000 and 2001-2010) and a short period of decrease (2000-

2001) due to application of energy-saving and cleaner production technologies. Overall, atmospheric Cd emissions increased from 474t in 1990to2186t in 2010 due to rapid economic growth, whereas energy-saving and cleaner production technologies have been in use since 2000. Spatial distribution of the atmospheric Cd emissions was dominated primarily by non-ferrous metal smelting and coal combustion. Emissions are high in Hunan and Yunnan Provinces because of high production non-ferrous metal smelting and in Shandong Province because of high coal consumption and moderate non-ferrous metal production.

Tian HZ, Cheng K, Wang Y, Zhao D, Lu L, Jia W et al. 2012a. Temporal and spatial variation characteristics of atmospheric emissions of Cd, Cr, and Pb from coal in China. Atmospheric Environment 50: 157-63.

Abstract: Multiple-year inventory of atmospheric emissions of cadmium (Cd), chromium (Cr), and lead (Pb) from coal burning in China have been established for the period 1980-2008 by using best available emission factors and annual activity data which are specified by different sub-categories of combustion facilities, coal types, and air pollution control devices. Our results show that the total emissions of Cd, Cr, and Pb have rapidly increased from 31.14 t, 1019.07 t, and 2671.73 t in 1980 to 261.52 t, 8593.35 t, and 12 561.77 t in 2008, respectively. The industrial sector ranks as the leading source, contributing similar to 88.3%, similar to 86.7%, and similar to 81.8% of the total Cd, Cr, and Pb emissions, respectively. Remarkably uneven spatial allocation features are observed. The emissions are primarily concentrated in the provinces of the northern and eastern region of China owing to the dramatic difference in coal use by the industrial and power sectors. Monthly temporal emission profiles for different sectors are established by using indexes such as monthly thermal electricity generation, monthly gross industrial output values and monthly average ambient temperature. For the power plants, there are two peaks during cold and hot season while for the industrial sector, emissions are most substantial in the summer and autumn season. Further, uncertainties in the bottom-up inventories are quantified by Monte Carlo simulation, and the overall uncertainties are demonstrated as -16% to 45% for Cd, -13% to 20% for Cr, and -21% to 48% for Pb, respectively. To better understand the emissions of these metals and to adopt effective measures to prevent poisoning, more specific data collection and analysis are necessary.

Tian HZ, Wang Y, Xue Z, Qu Y, Chai F, Hao J. 2011a. Atmospheric emissions estimation of Hg, As, and Se from coal-fired power plants in China, 2007. Science of the Total Environment 409(16): 3078-81.

Abstract: Over half of coal in China is burned directly by power plants, becoming an important source of hazardous trace element emissions, such as mercury (Hg), arsenic (As), and selenium (Se), etc. Based on coal consumption by each power plant, emission factors classified by different boiler patterns and air pollution control devices configuration, atmospheric emissions of Hg, As, and Se from coal-fired power plants in China are evaluated. The national total emissions of Hg, As, and Se from coal-fired power plants in 2007 are calculated at 132 t, 550 t, and 787 t, respectively. Furthermore, according to the percentage of coal consumed by units equipped with different types of PM devices and FGD systems, speciation of mercury is estimated as follows: 80.48 t of Hg, 49.98 t of Hg(2+), and 1.89 t of Hg(P), representing 60.81%, 37.76%, and 1.43% of the totals, respectively. The emissions of Hg, As, and Se in China's eastern and central provinces are much higher than those in the west, except for provinces involved in the program of electricity transmission from west to east China, such as Sichuan, Guizhou, Yunnan, Shaanxi, etc.

Tian HZ, Lu L, Cheng K, Hao JM, Zhao D, Wang Y et al. 2012b. Anthropogenic atmospheric nickel emissions and its distribution characteristics in China. Science of the Total Environment 417-418: 148-57.

Abstract: Nickel and its compounds are considered as potential human carcinogens, and atmospheric nickel is one of the major routes for human exposure. By applying the best available fuel-based or product-based emission factors and annual activity levels, a multiple-year comprehensive inventory of anthropogenic atmospheric nickel emissions in China is presented with temporal trend and spatial resolutions for the period of 1980-2009 from both fuels combustion sources and industrial producing processes. We estimate that the total atmospheric nickel emissions from all the sources have increased from 1096.07t in 1980 to 3933.71t in

2009, at an average annual growth rate of 4.5%. Therein, coal combustion is the leading source, attributing 63.4% of the national total nickel emissions in 2009; liquid fuels consumption ranks the second, contributing 12.4% of the totals; biofuels burning accounts for 8.4% and the remaining sources together contribute 15.8% of the totals. Significant spatial variations are demonstrated among provincial emissions and the most concentrated regions are the highly industrialized and densely populated areas like the Yangtze River Delta, the Pearl River Delta and the Beijing-Tianjin-Hebei region. Moreover, the overall uncertainties are estimated at -32.6%-37.7% by using Monte Carlo simulation, most of which come from non-ferrous metals smelting category, implying the urgent need for further investigation and field tests. This article may help to combat the increasing stress on air heavy metals pollution in China and provide useful information to calculate global mass balance models for hazardous trace elements.

Tian HZ, Wang Y, Xue ZG, Cheng K, Qu YP, Chai FH et al. 2010. Trend and characteristics of atmospheric emissions of Hg, As, and Se from coal combustion in China, 1980-2007. Atmospheric Chemistry and Physics 10(23): 11905-19.

Abstract: Emissions of hazardous trace elements in China are of great concern because of their negative impacts on local air quality as well as on regional environmental health and ecosystem risks. In this paper, the atmospheric emissions of mercury (Hg), arsenic (As), and selenium (Se) from coal combustion in China for the period 1980–2007 are estimated on the basis of coal consumption data and emission factors, which are specified by different categories of combustion facilities, coal types, and the equipped air pollution control devices configuration (Dust collectors, FGD, etc.). Specifically, multi-year emission inventories of Hg, As, and Se from 30 provinces and 4 economic sectors (thermal power, industry, residential use, and others) are evaluated and analyzed in detail. Furthermore, the gridded distribution of provincial-based Hg, As, and Se emissions in 2005 at a resolution of 1° × 1° is also plotted. It shows that the calculated national total atmospheric emissions of Hg, As, and Se from coal combustion have rapidly increased from 73.59 t, 635.57 t, and 639.69 t in 1980 to 305.95 t, 2205.50 t, and 2352.97 t in 2007, at an annually averaged growth rate of 5.4%, 4.7%, and 4.9%, respectively. The industrial sector is the largest source for Hg, As, and Se, accounting for about 50.8%, 61.2%, and 56.2% of the national totals, respectively. The share of power plants is 43.3% for mercury, 24.9% for arsenic, and 33.4% for selenium, respectively. Also, it shows remarkably different regional contribution characteristics of these 3 types of trace elements, the top 5 provinces with the heaviest mercury emissions in 2007 are Shandong (34.40 t), Henan (33.63 t), Shanxi (21.14 t), Guizhou (19.48 t), and Hebei (19.35 t); the top 5 provinces with the heaviest arsenic emissions in 2007 are Shandong (219.24 t), Hunan (213.20 t), Jilin (141.21 t), Hebei (138.54 t), and Inner Mongolia (127.49 t); while the top 5 provinces with the heaviest selenium emissions in 2007 are Shandong (289.11 t), Henan (241.45 t), Jiangsu (175.44 t), Anhui (168.89 t), and Hubei (163.96 t). Between 2000 and 2007, provinces always rank at the top five largest Hg, As, and Se emission sources are: Shandong, Hebei, Shanxi, Henan, and Jiangsu, most of which are located in the east and are traditional industry-based or economically energy intensive areas in China. Notably, Hg, As, and Se emissions from coal combustion in China begin to grow at a more moderate pace since 2005. Emissions from coal-fired power plants sector began to decrease though the coal use had been increasing steadily, which can be mainly attributed to the increasing use of wet flue gas desulfurization (WFGD) in power plants, thus the further research and control orientations of importance for these hazardous trace elements should be the industrial sector.

Tian HZ, Zhao D, He MC, Wang Y, Cheng K. 2011b. Temporal and spatial distribution of atmospheric antimony emission inventories from coal combustion in China. Environmental Pollution 159(6): 1613-9.

Abstract: A multiple-year inventory of atmospheric antimony (Sb) emissions from coal combustion in China for the period of 1980-2007 has been calculated for the first time. Specifically, the emission inventories of Sb from 30 provinces and 4 economic sectors (thermal power, industry, residential use, and others) are evaluated and analyzed in detail. It shows that the total Sb emissions released from coal combustion in China have increased from 133.19 t in 1980 to 546.67 t in 2007, at an annually average growth rate of 5.4%. The antimony emissions are largely emitted by industrial sector and thermal power generation sector, contributing 53.6% and 26.9% of the totals, respectively. At provincial level, the distribution of Sb emissions shows

significant variation. Between 2005 and 2007, provinces always rank at the top five largest Sb emissions are: Guizhou, Hunan, Hebei, Shandong, and Anhui.

Grey literature

Environmental Integrity Project. 2011. America's Top Power Plant Toxic Air Polluters. Austin, Texas. Available at http://environmentalintegrity.org/documents/Report-TopUSPowerPlantToxicAirPolluters.pdf.

Abstract: *No abstract available.*

Excerpt from Introduction:
[This report presents data obtained from U.S.EPA's Toxics Release Inventory (TRI), and accessible to the public at http://www.epa.gov/tri/. All the rankings in this report are based on 2010 annual reported emissions, the most recent data available, from facilities classified as electric utilities under the North American Industrial Classification System (NAICS).
The report focuses on 6 toxic heavy metals emitted in relatively high quantities by the electric utility industry: Arsenic, Chromium, Lead, Mercury, Nickel, and Selenium. In addition, the report presents data on emissions of the acid gas Hydrochloric acid ("HCl"). The number of power plants that reported emissions of each of these toxics varies considerably from one pollutant to the next. For example, 479 U.S. power plants reported Lead emissions to TRI in 2010, whereas only 59 power plants reported Selenium emissions. Likewise, the number of power plants reporting emissions of Arsenic (145), Chromium (234), Mercury (452), Nickel (222), and Hydrochloric acid (413), also varies considerably. This variation is partly due to the reporting threshold for TRI. Generally, the reporting requirement is only triggered if the facility produces a total of 25,000 pounds of the chemical, although for certain highly toxic, bioaccumulative, or persistent chemicals like lead and mercury, the reporting threshold is much lower. The fact that the TRI's reporting requirement is triggered based on each chemical considered individually explains some of the disparity between the number of plants reporting emissions of, for example, Lead (479 facilities) as compared to the number of power plants reporting emissions of Selenium (59 facilities).]

Strum M, Thurman J, Morris M. 2011. Memorandum: Non-Hg Case Study Chronic Inhalation Risk Assessment for the Utility MACT Appropriate and Necessary Analysis. Docket EPA-HQ-OAR-2009-0234. Available at http://www.epa.gov/ttn/atw/utility/pro/non-hg_risk_tsd.pdf.

Abstract: *No abstract available.*

Excerpt from Introduction:
[To estimate the potential for human health impacts from current emissions of HAPs other than mercury from coal- and oil-fired electric utility steam generating units (EGUs), several facilities were selected as case studies for a chronic inhalation risk assessment, and this memo documents the methods and results of the assessment for these case studies. The assessment was performed in support of the appropriate and necessary analysis for coal- and oil-fired EGUs.]

U.S. Environmental Protection Agency. 2011. Supplement to the Non-Hg Case Study Chronic Inhalation Risk Assessment In Support of the Appropriate and Necessary Finding for Coal- and Oil-Fired Electric Generating Units. EPA-452/R-11-013, North Carolina. Available at http://www.epa.gov/ttn/atw/utility/inhalationcasestudyreport.pdf.

Abstract: *No abstract available.*

Excerpt from Introduction:
[A previous document discussed the methods and results of the chronic inhalation risk assessment of hazardous air pollutants (HAPs) other than mercury from coal- and oil-fired electric utility steam generating units (EGUs) at sixteen case study facilities, which was performed in support of the "appropriate and necessary" finding for coal- and oil-fired EGUs. Several changes were made to the emissions estimates,

dispersion modeling, and risk characterization of these facilities in response to public comments on the proposed rule, and this report documents those changes and their impact on the estimated risks from the case study facilities.]

Yan SS, Zhang WQ. 2011. Coal consumption and As emission in electricity generation in China under different energy scenarios. In: Proceedings - International Conference on Computer Distributed Control and Intelligent Environmental Monitoring, 1457-61.

Abstract: This paper presents coal consumption of electricity generation in China under different energy scenarios of the given long-term energy policies. Long Range Energy Alternatives Planning 2008 (LEAP 2008) software is used to develop a simple model of electricity demand and to estimate gross coal consumption of electricity generation in China until 2030 under these scenarios. And, time-serial emission inventory of As is also built in the method of emission factors based on fuel consumptions. The results show that the coal consumption will increase by 4 times, amounting to 5.92 billion tees under BAU scenario. The total emission of As is 20.7 Mtces with an average annual growth rate of 6.6%. Under ENR scenario, the total reduction of coal consumption and As emission may reach 25.89% and 26.82% respectively compared to that in BAU scenario.

Yan SS, Zhang WQ. 2012. Coal consumption and As emission in electricity generation in Qingdao, Shandong. In: Applied Mechanics and Materials, Sustainable Cities Development and Environment, International Conference on Civil, Architectural and Hydraulic Engineering, 209-211, 1843-1846.

Abstract: This paper presented coal consumption of electricity generation in Qingdao, Shandong Province, under different energy scenarios with LEAP 2010. And, time-serial emission inventory of As was also built based on fuel consumptions. The results show that the coal consumption will increase by 3.5 times, amounting to 4.92 million tces under BAU scenario. The total emission of As is 2.7 Mtces with an average annual growth rate of 6.6%.

4.2 Dioxins and furans (and other polybrominated/polychlorinated substances)

4.2.1 Dioxins and furans - health effects

No abstracts

4.2.2 Dioxins and furans - measured emissions (flue gas or ambient air)

White literature

Bogdal C, Muller CE, Buser AM, Wang Z, Scheringer M, Gerecke AC et al. 2014. Emissions of polychlorinated biphenyls, polychlorinated dibenzo-p-dioxins, and polychlorinated dibenzofurans during 2010 and 2011 in Zurich, Switzerland. Environmental Science and Technology 48(1): 482-90.

Abstract: Persistent organic pollutants (POPs) are ubiquitous contaminants of environmental and human health relevance, but their emissions into the environment are still poorly known. In this study, concentrations of selected POPs were measured in ambient air in Zurich, Switzerland, and interpreted with a multimedia mass balance model. The aim of the combination of measurements and modeling was to back-calculate atmospheric emission rates of POPs. Measurements were performed in summer 2010 and winter 2011 and target analytes included polychlorinated biphenyls (PCBs) and polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs). Estimated emissions were higher in summer than in winter. Emission estimates for Zurich can be extrapolated to annual averages for Switzerland of 312 kg.a(-1) (39 mg.capita(-1).a(-1)), 53 kg.a(-1) (7 mg.capita(-1).a(-1)), and 3 kg.a(-1) (0.4 mg.capita(-1).a(-1), 94 g WHO98-TEQ.a(-1), 65 g I-TEQ.a(-1)) for the six indicator PCBs (iPCBs), the twelve coplanar dioxin-like PCBs (dlPCBs), and the 17

2,3,7,8-chlorosubstituted PCDD/Fs, respectively. The emission rates of iPCBs are in agreement with existing emission inventories, whereas for PCDD/Fs the emissions are five times higher than the estimates from the Swiss national emission inventory. Emissions of dlPCBs in Switzerland are presented here for the first time. Our study also provides the first seasonally resolved emission rates of POPs, which were determined with our combined measurement and modeling approach. These findings highlight the relevance of ongoing sources of POPs, even decades after regulations aiming to reduce or eliminate sources were established.

Grosso M, Biganzoli L, Rigamonti L, Cernuschi S, Giugliano M, Poluzzi V et al. 2012. Experimental evaluation of PCDD/Fs and PCBs release and mass balance of a WTE plant. Chemosphere 86(3): 293-9.

Abstract: The behaviour of waste incineration plants with respect to organic toxic trace contaminants such as PCDDs, PCDFs and, to a minor extent, PCBs, is still a matter of concern for the public opinion and the decision makers. It is therefore very important, first, to evaluate the release of these organic toxic trace contaminants in the environment during waste incineration, not only through the stack gas emission but also with the solid and liquid residues, and then to compare the total release with the input through the treated waste in order to assess the plant behaviour as a " sink" rather than a " source" of organic toxic trace contaminants. The experimental investigation carried out on an Italian full scale incineration plant has shown a total 17 PCDD/Fs and 12 dioxin-like PCBs release of 5.5-27 μg. WHO-TEQ per tonne of treated waste and an input flux of 1.6-44 μg. WHO-TEQ per tonne of waste, with the difference between the input and the output fluxes rather small and the plant behaviour toward organic trace toxic contaminants in average neutral. Results are compared with similar evaluations conducted in the last decade on a number of waste-to-energy (WTE) plants operating in Italy.

Hsieh LT, Wang YF, Kuo GH, Wang LC, Chang-Chien GP. 2009. Cluster analysis for polychlorinated dibenzo-p-dioxins and dibenzofurans concentrations in southern Taiwan. Journal of the Air and Waste Management Association 59(12): 1474-80.

Abstract: This study investigates the characteristics of polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) in the ambient air of two municipal solid waste incinerators (MSWIs: GS and RW) and a coal-fired power plant (PW) in the Kaohsiung County (KC) area in Taiwan. The results show that the toxic equivalency (TEQ) concentration in the flue gas of GS and RW averaged 0.090 and 0.044 ng international toxic equivalents (I-TEQ)/N m3, respectively. The TEQ concentration in the flue gas of PW averaged 0.050 ng I-TEQ/N m3. All PCDD/Fs concentrations from the stack flue gas are lower than the Taiwan Environmental Protection Administration emission standard. Furthermore, the mean I-TEQ concentration in the ambient atmosphere ranged from approximately 0.019 to 0.165 pg I-TEQ/N m3, much lower than the environmental quality standards for dioxins in Japan (0.6 pg TEQ/ N m3). This work classified all sampling sites into three clusters according to k-means cluster analysis. The result shows a probable direct correlation between the GS incinerator and site C. Although the concentration from the PW plant did not exceed the emission standard, it was much higher than that in Fernandez-Martinez's study. For proper environmental management of dioxins, establishing a complete emission inventory of PCDD/Fs is necessary. The government of Taiwan should particularly pay more attention to power plants to address the information shortage.

Lin WY, Wu YL, Tu LK, Wang LC, Lu X. 2010. The emission and distribution of PCDD/Fs in municipal solid waste incinerators and coal-fired power plant. Aerosol and Air Quality Research 10(6): 519-32.

Abstract: The emission and distribution of polychlorinated debenzo-p-dioxins/dibenzofurans (PCDD/Fs) was investigated in two municipal solid waste incinerators (MSWIs) and one coal-fired power plant (PP) in southern Taiwan. Samples were collected from stack flue gases (SFG), bottom residues (BR), super heater (SH), economizer (EC), semi-dry absorber (SDA), bag filter (BF), and fly ash pit (FAP) in MSWIs. Stack flue gases, bottom residues and electrostatic dust collectors (ESD) in PP were also collected. In order to compare the difference between the results of MSWIs and PP, samples from SFG, BS, and FAP in a PP were also determined. Seventeen congeners of PCDD/Fs were analyzed by utilizing a high-resolution gas

chromatograph/high-resolution mass spectrometer (HRGC/HRMS). Distributions of total PCDD/F-I-TEQ in each unit of MSWI-A and MSWI-B were SFG (0.3%, 0.07%), BR (3.9%, 0.62%), SH (0.17%, 0.24%), EC (4.2%, 0.05%), SDA (1.29%, 7.06%), and BF (90.14%, 91.97%), respectively. However, those in SFG, BS, and FAP of PP were 99.58%, 0.17%, and 0.25%, respectively. The above results indicated 99.5% PCDD/Fs were trapped in the fly ash of MWSI. On the other hand, 99.7% PCDD/Fs was emitted to the atmosphere from PP. The results of this study provide useful information for controlling PCDD/Fs in MSWIs and PP.

Mari M, Nadal M, Schuhmacher M, Domingo JL. 2008a. Monitoring PCDD/Fs, PCBs and metals in the ambient air of an industrial area of Catalonia, Spain. Chemosphere 73(6): 990-8.

Abstract: In 2005 and 2006, the levels of polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs), polychlorinated biphenyls (PCBs) and metals (As, Be, Cd, Co, Cr, Cu, Mn, Ni, Pb, Sn, Tl and V) were measured in air samples collected in an industrial area of Sant Adrià del Besòs (Barcelona, Catalonia, Spain) where a municipal solid waste incinerator (MSWI) is placed, and in a background/control area. In general terms, concentrations of all environmental pollutants were higher at the industrial site. No significant seasonal/temporal variations were observed in any of the areas. No Pearson correlation was found between the PCDD/F concentrations and the environmental conditions of the two sampling periods considered. Principal component analyses (PCA) were performed to get information on the relationship among samples, pollutants, and emission sources. The results indicate that the MSWI of S. Adrià de Besòs is not a significant emission source of the above compounds for the area under its direct influence. Moreover, a notable difference in the PCDD/F congener profiles was found between ambient air and stack gas emissions, indicating that the current levels of PCDD/Fs are more related to other potential emissions sources rather than to those from the MSWI.

Mari M, Schuhmacher M, Feliubadalo J, Domingo JL. 2008b. Air concentrations of PCDD/Fs, PCBs and PCNs using active and passive air samplers. Chemosphere 70(9): 1637-43.

Abstract: The concentrations of polychlorinated dibenzo-p-dioxins and furans (PCDD/Fs), polychlorinated biphenyls (PCBs) and polychlorinated naphthalenes (PCNs) were determined in air samples collected at four sampling sites located in two zones of Barcelona (Spain): near a municipal solid waste incinerator (MSWI) and a combined cycle power plant (3 sites), and at a background/control site. Samples were collected using high-volume active samplers. Moreover, 4 PUF passive samplers were deployed at the same sampling points during three months. For PCDD/Fs, total WHO-TEQ values were 27.3 and 10.9 fg WHO-TEQm(-3) at the urban/industrial and the background sites, respectively. The sum of 7 PCB congeners and the Sigma PCN levels were also higher at the industrial site than at the background site. In order to compare active and passive sampling, the accumulated amounts of PCDD/Fs, PCBs and PCNs in the four passive air samplers, as well as the total toxic equivalents in each sampling site were also determined. To assess the use of PUF passive samplers as a complementary tool for PCDD/F, PCB and PCN monitoring, sampling rates were calculated in accordance with the theory of passive air samplers. PUF disks allowed establishing differences among zones for the POP levels, showing that they can be a suitable method to determine POP concentrations in air in areas with various potential emission sources. Although both particle and gas phase were sorbed by the PUFs, data of gas phase congeners are more reproducible.

Ren Z, Zhang B, Lu P, Li C, Gao L, Zheng M. 2011. Characteristics of air pollution by polychlorinated dibenzo-p-dioxins and dibenzofurans in the typical industrial areas of Tangshan City, China. Journal of Environmental Sciences (China) 23(2): 228-35.

Abstract: The ambient air in vicinity of different industrial sources for PCDD/PCDFs was sampled by TSP/PM10 active samplers and passive PUF disk samplers in Tangshan City, a metropolis containing clusters of various industrial plants. The TEQ concentrations of PCDD/PCDFs ranged from 44.2 to 394.1 fg I-TEQ/m3 with an average of 169.9 fg I-TEQ/m3. 2,3,4,7,8-PeCDF was the dominant contributor to sigma TEQ, contributing 41% (12% to 55%), while 1,2,3,4,6,7,8-HpCDF, OCDD and OCDF were the major congeners for the total concentrations. The ratios of sigma PCDF/ sigma PCDD reached 2.54 on average, suggesting that de novo synthesis in thermal processes played an important role to the airborne pollution of PCDD/PCDFs. The similarities congener profiles indicated that TSP and PM10 active sampling methods are

comparable for the determination of the PCDD/PCDFs in ambient air, and the ratios of concentrations determined by the two methods suggested that the PCDD/PCDFs tended to stay in fine particles. It was found that 2,3,7,8-TCDF and OCDD were the dominating congeners in the passive PUF disks samples. Through principal components analysis, the coke industry was suggested to be a relatively high potential emission source for PCDD/PCDFs in the ambient air of Tangshan, which was possibly formed by de novo synthesis mechanism. In this study, the atmospheric impacts to the environment from different industrial sources could be ranked as follows (from high to low): coking, iron sintering, steel making, power generation and chlorinate alkali chemical production industries.

Thacker N, Sheikh J, Tamane SM, Bhanarkar A, Majumdar D, Singh K et al. 2013. Emissions of polychlorinated dibenzo-p-dioxins (PCDDs), dibenzofurans (PCDFs), and dioxin-like polychlorinated biphenyls (PCBs) to air from waste incinerators and high thermal processes in India. Environmental Monitoring and Assessment 185(1): 425-9.

Abstract: This study investigated dioxins and dioxin-like polychlorinated biphenyls in gasses emitted from waste incinerators and thermal processes in central and western parts of India. The concentrations of polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDDs/DFs) ranged from 0.0070 to 26.8140 ng toxicity equivalent (TEQ)/Nm3, and those of dioxin-like polychlorinated biphenyls (PCBs) ranged from 0.0001 x 10(-1) to 0.0295 ng TEQ/Nm3. The characteristics of mean PCDD/F I-TEQ concentration and congener profiles were studied over all the samples of air. In particular, a pattern consisting of a low proportion of dioxin-like PCBs and high proportion of PCDDs/DFs was common for all the samples from incinerators and high-temperature processes.

Tu LK, Wu YL, Wang LC, Chang-Chien GP. 2011. Distribution of polybrominated dibenzo-p-dioxins and dibenzofurans and polybrominated diphenyl ethers in a coal-fired power plant and two municipal solid waste incinerators. Aerosol and Air Quality Research 11(5): 596-615.

Abstract: In this study, the distributions of polybrominated dibenzo-p-dioxins (PBDD/Fs) and dibenzofurans and polybrominated diphenyl ethers (PBDEs) in the bottom residues of the combustion chambers (BR), the fly ashes from superheaters (SH), economizers (EC), semi-dry scrubbers (SDA), fabric filters (BF), fly-ash pits (FAP) and stack flue gases (SFG) of two municipal solid waste incinerators (MSWIs) and the bottom residue (BR), electrostatic dust precipitators (ESD), and stack flue gases (SFG) of a coal-fired power plant (TPP) were investigated. BR of combustion chambers exhibited the highest content of PBDEs and PBDD/Fs among all the units. The amount of PBDE mass found in bottom residues constituted 99.7% at MWSI-A, and 92.6% at MSWI-B and 75.1% at TPP of the total PBDE discharges, respectively; while the second highest PBDE mass observed in MSWI-A and MSWI-B was from SFG (0.146%) and EC (5.54%), respectively. In TPP, the PBDE distribution was 75.1% in BR, 12.5% in ESD, and 12.4% in SFG. The mean concentrations of PBDEs emitted from SFG of MSWI-A, and MSWI-B were 9.32 ng/Nm 3, and 7.62 ng/Nm3, respectively; however, that of PBDE discharged from SFG of TPP was only 5.43 ng/Nm3. The dominant congener found from MSWI-A,MSWI-B and TPP, was BDE-209, accounting for 65.9%, 77.7%, and 77.6% of total PBDE concentrations in SFG, respectively; whereas BDE-206 (6.01%-6.36%) was the second highest congener. Meanwhile, the PBDE emission factors from the stack flue gases were 35.6 ± 10.9 μg/ton-waste at MWSI-A, 47.6 ± 29.4 μg/ton-waste at MSWI-B and 62.9 ± 10.9 μg/ton-coal at TPP of the total PBDEs, respectively; showing the PBDE emission rates and contributions of TPP to the ambient air are actually much higher than those of MSWIs, while the PBDE concentrations in SFG of TPP were lower than MSWIs. Further investigations on the safety of BR reutilization and the impact of SFG from TPP are strongly advised.

Tu LK, Wu YL, Wang LC, Chang-Chien GP. 2012. Monitoring and dispersion modeling of polybrominated diphenyl ethers (PBDEs) in the ambient air of two municipal solid waste incinerators and a coal-fired power plant. Aerosol and Air Quality Research 12(1): 113-22.

Abstract: The concentration of polybrominated diphenyl ethers (PBDEs) in the ambient air of two municipal solid waste incinerators (MSWIs) and one coal-fired power plant (TPP) were determined. Along with the sites mentioned above, eight ambient air samples were collected. Cluster analysis was carried out to determine the relationship of PBDE characteristics between each site. Finally, PBDE dispersion modeling in the atmosphere was applied by using ISCST3 (Industrial Source Complex Short Term 3) to assess the impact of the above two municipal solid waste incinerators and one coal-fired power plant on the ambient air. The total-PBDE concentrations in the ambient air were between 24.9 and 139 pg/Nm3, averaging 59.8 pg/Nm3 (n = 16). The BDE-209, BDE-47 and BDE-207 were the most predominant three among all 30 PBDE congeners, which contributed more than 58%, 9%, and 4% of total-PBDE mass to the ambient air, respectively. The results of cluster analysis indicated that no direct correlations existed among the emission sources (MSWI-A, MSWI-B, TPP) and the receptors (sampling sites). From the results of dispersion modeling, the annual total PBDE concentration in ambient air contributed by the MSWI-A, MSWI-B, TPP together were found to be 0.0259% ± 0.0208%. Hence, the results of both cluster analysis and dispersion modeling showed that MWSI-A, MSWI-B, and TPP were definitely not the major contributors of PBDEs to the ambient air environment. The ashes collected from the air pollution control devices of both the MSWIs and the TPP are probably a more important environmental issue and therefore should be paid more attention to.

Wang LC, Lee WJ, Lee WS, Chang-Chien GP. 2010. Emission estimation and congener-specific characterization of polybrominated diphenyl ethers from various stationary and mobile sources. Environmental Pollution 158(10):3108-15.

Abstract: Here we show that combustion sources, including waste incinerators, metallurgical processes, power-heating systems and so on, are also important emitters of polybrominated diphenyl ethers (PBDEs) to the atmosphere. Geometric mean PBDE concentrations in the stack flue gases of the combustion sources ranged from 8.07 to 469 ng/Nm3. The sinter plants (24.7 mg/h), electric arc furnaces (EAFs) (11.3 mg/h) and power plants (50.8 mg/h) possessed the largest PBDE emission rates, which were several orders higher than those of the other reported sources. The occurrences of the PBDEs in the flue gases of the power plants and vehicles, as well as their PBDE concentrations statistically highly correlated with combustion-originated PCDD/Fs, revealing that PBDEs should be the products of combustion. The ranking of major PBDE emission sources in Taiwanese PBDE inventory for combustion sources was power plants (30.85 kg/year), vehicles (14.9 kg/year) and metallurgical processes (5.88 kg/year).

Wang YF, Chao HR, Wu CH, Wang LC, Chang-Chien GP, Yang HH et al. 2009. Emissions of polychlorinated dibenzo-p-dioxins and dibenzofurans from a heavy oil-fueled power plant in northern Taiwan. Journal of Hazardous Materials 163(1): 266-72.

Abstract: We measured the concentrations of polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) from the flue gas and the ambient atmosphere of a power plant fueled by heavy oil in northern Taiwan. The mean emission concentration and I-TEQ concentration of total PCDD/Fs were 0.292 ng/Nm3 and 0.016 ng I-TEQ/Nm3, respectively. All PCDD/F emission concentrations in the flue gas were supposed to meet the Environmental Protection Administration Executive Yuan, R.O.C. standard (1.0 ng I-TEQ/Nm3 from 2008). Furthermore, the mean I-TEQ concentration in the ambient atmosphere was 0.011 pg I-TEQ/Nm3, which was much lower than the environmental quality standards for dioxins in Japan (0.6 pg TEQ/Nm3). Also, the PCDD/F emission factor was 0.188 ng I-TEQ/L fuel, which was comparable to the data issued in US EPA [EPA, Locating and estimating air emissions from sources of dioxins and furans, Office of Air Quality Planning and Standards, Research Triangle Park, NC, DCN No. 95-298130-54-01, 1997] (0.2 ng I-TEQ/L of fuel). Also, the result of the correlations of PCDD/Fs and operational parameters illustrated that the positively significant correlation (r=0.502, p=0.048) was found only between PCDD/Fs (I-TEQ) and the flue gas emission temperature (125-157 degrees C). However, PCDD-TEQ/PCDF-TEQ ratios were statistically significantly associated with the decreased flue gas flow (r=-0.659, p=0.006), moisture (r=-0.612, p=0.012) and flue gas temperature (r=-0.503, p=0.047). For proper environmental management of dioxins, it is necessary to establish a complete emission inventory of PCDD/Fs, and, in particular, the government should pay more attention to power plants to address the information shortage.

Wu YL, Li HW, Chien CH, Lai YC, Wang LC. 2010. Monitoring and identification of polychlorinated dibenzo-p-dioxins and dibenzofurans in the ambient central Taiwan. Aerosol and Air Quality Research 10(5): 463-71.

Abstract: Polychlorinated Dibenzo-p-dioxins and Dibenzofurans (PCDD/Fs) in the ambient air of five sampling sites around central Taiwan were investigated. Principal components analysis (PCA), cluster analysis (CA) and the chemical mass balance (CMB) model were adopted to assess possible PCDD/F sources and their effects on the air quality levels. Field experimental results showed that the mean PCDD/F concentrations in the ambient air were 0.0526, 0.0591, 0.0339 and0.0727 pg I-TEQ/Nm3 in winter, spring, summer and autumn, respectively. Analysis of atmospheric isopleths for five sampling sites displayed that high PCDD/F concentrations were mostly close to electric arc furnace plants (EAF). Through PCA and CA, the congener profiles of ambient air sampling sites were close to medical waste incinerators (MWI),secondary aluminum smelters (ALS), EAF, waste open burning (OB) and crematories (CM). By using the CMB model, the dominant sources of PCDD/Fs in ambient air were EAF, medical waste incinerator/municipal solid waste incinerators (MWI/MSWI) and unleaded gasoline fuel vehicle/diesel fuel vehicle (UGFV/DFV), which contributed 22-23%, 17-31%and 9-22%, respectively. The above results revealed that ambient air was affected by surrounding PCDD/F sources (MWI, ALS, EAF, CM and OB). However, due to high stack height and low emission concentration, the impact of coal-fired power plant on the PCDD/F levels of ambient air was insignificant.

Zhang G, Hai J, Ren M, Zhang S, Cheng J, Yang Z. 2013. Emission, mass balance, and distribution characteristics of PCDD/Fs and heavy metals during cocombustion of sewage sludge and coal in power plants. Environmental Science and Technology 47(4): 2123-30.

Abstract: The emission, mass balance, and distribution characteristics of polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) as well as those of heavy metals (Hg, Cd, Pb, Cr, and Cu) were investigated during the cocombustion of 5%, 10%, 15%, and 20% sewage sludge (SS) in a pulverized coal power plant. The PCDD/F emissions increased from 7.00 to 32.72 pg I-TEQ/Nm3 as the amount of SS in the mixed fuel (MF) increased. High sulfur content and relatively low chlorine levels in MF resulted in lower PCDD/F emissions. SS exhibited a remarkable difference in congener profiles compared with flue gas, bottom ash, and fly ash. The negative dioxin mass balance indicated that the cofiring of SS with coal in power plants was not a source but a sink of dioxins. The concentrations and emission factors of heavy metals in flue gas and bottom ash, as well as fly ash, all exhibited a tendency to increase with increasing input values of heavy metals in MF. The distribution characteristics of the investigated heavy metals were primarily dependent on the evaporative properties of these metals. The availability of chlorine could alter the heavy metal distribution behavior. The emitted pollutants in the power plant were below the legal limits.

Grey literature

No abstracts

4.2.3 Dioxins and furans - modeled emissions (emission inventories)

White literature

Al-Dabbas,M.A. 2010. The PCDD/PCDF dioxin releases in the climate of environment of Jordan in the period (2000-2008). Journal of Thermal Science 19(2): 182-192.

Abstract: Many environment problems of the full using of several categories of processing include mining, heat generators, direct combustion of forest fires, cement production, power plant, transport, medical waste. Dioxin/furan releases from these categories are one of these environment problems. Possible lines of reducing the PCDD/PCDF (Polychlorinated dibenzo-para-dioxins/Polychlorinated dibenzofurans) releases from these categories are elucidated. The contribution of this paper is present the identification and estimation of the latest figure of dioxin/furan releases in the climate of environment of Jordan in the period 2000–2008 from the following categories (cement, aluminum, ceramic, medical waste, power plant, land fill, ferrous and non-ferrous metals, uncontrolled combustion process (biomass burning, waste burning, accidental fires in house, transport). These finding shows the sign of growth of estimated PCDD/PCDF releases from categories which did not calculated and followed after 2003. The result shows the highest PCDD/PCDF release from landfill fires (62.75 g TEQ/year), medical waste (8.8264 g TEQ/year), and transport (3.0145 g TEQ/year). Jordan seeks by next years, a reduction in total releases of dioxins and furans from sources resulting from human activity. This challenge will apply to the aggregate of releases to the air nationwide and of releases to the water within the Jordan area. Jordan should conduct air monitoring for dioxin in order to track fluctuations in atmospheric deposition levels.

Geng J, Lu Y, Wang T, Giesy JP, Chen C. 2010. Effects of energy conservation in major energy-intensive industrial sectors on emissions of polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans in China. Energy Policy 38(5): 2346-2356.

Abstract: China has set an ambitious target of increasing energy efficiency by 20% and reducing pollution discharges by 10% over the period 2006-2010. Promoting advanced technologies and closing outdated facilities are widely recognized as important measures to achieve these targets. These actions can also indirectly decrease release of polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). The objectives of this paper are to identify and quantify reductions of PCDD/F emissions to air due to measures such as phasing out of obsolete facilities in the four most energy-intensive industrial sectors. Reductions in PCDD/F emissions from power generation were estimated to be 7, 33 and 38 g I-TEQ in 2006, 2007 and 2008, respectively. For the cement industry, reductions were estimated to be 680 g I-TEQ between 2007 and 2008, and 740 g I-TEQ between 2009 and 2010. For the iron and steel industry, the reduction was estimated to be 113.3 g I-TEQ over the period 2007-2010, which includes 76.6 g I-TEQ in 2007. For the coke industry, the reduction was estimated to be 68 g I-TEQ in 2007 and 62 g I-TEQ in 2008.

Nzihou A, Themelis NJ, Kemiha M, Benhamou Y. 2012. Dioxin emissions from municipal solid waste incinerators (MSWIs) in France. Waste Management 32(12): 2273-7.

Abstract: The objective of this study was to determine whether the fear of dioxin/furan emissions from waste-to-energy plants was justified by the 2007 status of emissions of French municipal solid waste incinerators (MSWIs). All emissions were examined, plant by plant, but this paper focuses on the incinerator emission that is most frequently mentioned in the French media, toxic dioxins and furans. The study showed that there are 85 large MSWI that generate electricity or heat, i.e., waste-to-energy (WTE) plants, and 39 smaller MSW incinerators. The results showed that all French MSWI are operated well below the EU and French standard of 0.1ngTEQNm-3 (toxic equivalent nanograms per standard cubic meter) and that their total dioxin/furan emissions decreased from 435gTEQ in 1997 to only 1.2g in 2008. All other industrial emissions of dioxins have also decreased and the major source is residential combustion of wood (320gTEQ). It was extremely difficult to obtain MSWI emission data. This unwarranted lack of transparency has resulted in the public perception that MSWI plants are major contributors to dioxin emissions while in fact they have ceased to be so.

Quina MJ, Pedro RS, Gando-Ferreira LM, Quinta-Ferreira RM. 2011. A national inventory to estimate release of polychlorinated dibenzo-p-dioxins and dibenzofurans in Portugal. Chemosphere 85(11): 1749-58.

Abstract: Taking into account current environmental concerns, the main objective of this work focused a national inventory aiming to estimate the amount of polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDD/PCDF) released in Portugal in 2006. The methodology used was based on the Standardized Toolkit for Identification and Quantification of Dioxins and Furan Releases, developed by UNEP Chemicals, in 2005. The method allows the assessment of the amount of PCDD/PCDF released into the environment along five vectors involving air, water, land, products and residues. Facing some difficulties mainly regarding to the availability of data for some activities known to produce PCDD/PCDF, three scenarios (Sc1 to Sc3) corresponding to lower, central and upper estimates were established. The Sc1 scenario (lower estimate) includes the situations where in case of doubt or scarce information, reduced or none emission values were assumed, Sc2 refers to a central estimate, which is believed to be the most realistic for the Portuguese situation, while Sc3 corresponds to the worst case (upper estimate). The results obtained pointed out that the total amount of PCDD/PCDF emitted in Portugal during the period under analysis was in the range of 51.2-217.9gTEQyear -1, with the most likely value of 95.2gTEQyear -1 achieved under the Sc2 scenario. This study also showed that the methodology developed by UNEP Chemicals is a very simple one, and the main difficulty is the availability of data. The main indicators calculated in this study were 8.98μg TEQ/(yearperson) by taking into account the total amount of PCDD/PCDF released, and 3.63μgTEQ/(yearperson) when only air emissions were considered.

Relvas H, Lopes M, Coutinho M. 2013. Portuguese inventory of dioxins and furans atmospheric emissions. Chemosphere 93(8): 1569-77.

Abstract: This article presents the results of the most recent estimation of polychlorinated dibenzo-p-dioxins (PCDD) and dibenzofurans (PCDF) atmospheric emissions in Portugal, which has covered the period 2004-2009 and includes 27 emission sources types. The results are compared with previous emissions inventories published for Portugal. The main objective of this work is to provide relevant information about the amounts of the compounds that are released into the atmosphere in Portugal, and identify their major sources and trends. The methodology involved the identification of relevant sources, the collection of information to characterize these sources, the selection of appropriate emission factors and their application to estimate the emissions. Furthermore, several studies conducted in Portugal were considered, namely reports from PCDD/PCDF measurements performed in some industrial facilities. The inventory covered 27 emission sources types. However the results show that only 8 were relevant, i.e. with emission amounts greater than 1 g I-TEQ year(-1). The total emissions of PCDD/PCDF in Portugal reached between 40 and 105 g I-TEQ year(-1), for the period of 2004-2009. The largest emission source and at same time with greater variation is forest fires, with emissions between 3 g I-TEQ year(-1) and 67 g I-TEQ year(-1) in 2008 and 2005, respectively. Excluding the emissions from forest fires, the total emission is more or less constant over the years and around 37 g I-TEQ year(-1).

Ren Z, Zheng M. 2009. Impacts of human activities on dioxins emissions at national scale. Chemosphere 76(6): 853-9.

Abstract: In this study, the dioxins emissions from 51 countries were investigated by multivariate statistical analysis, and the correlations between dioxins emissions and some aspects of human activities were discussed at national scale. For the 51 countries mentioned in this paper, the total emissions are 36.0 kg-TEQ yr -1, and the average values of annual dioxins emissions (from 2000 to 2007) per capita and per unit GDP are calculated to be 18.3 g-TEQ million-people -1 yr -1 and 6.7 g-TEQ billion-USD -1 yr -1, respectively. Furthermore, as the three leading industrial emission sources of dioxins, power generation and heating, ferrous and non-ferrous metal production and waste incineration contribute 45.1% to the total emission in all. It is also worthy to note that the uncontrolled combustion processes release about 40% of the total emission. From the correlations between the dioxins emissions and the factors of human activities, population and land area could be tentatively suggested to be positive indicators to dioxins emissions. Specially, GDP per capita

would roughly be a negative indicator to the emissions from the uncontrolled combustion processes, and GDP would roughly be a positive indicator to emissions from the other sources.

Grey literature

No abstracts

4.3 Other pollutants (radionuclides, volatile organic compounds, acid gases, amines/nitrosamines)

4.3.1 Other pollutants - health effects

No abstracts (see Multiple pollutants (Section 3.5.1))

4.3.2 Other pollutants - measured emissions (flue gas or ambient air)

White literature

Aytekin H, Bayata S, Baldik R, Celebi N. 2008. Radon measurements in the Catalagzi Thermal Power Plant, Turkey. Radiation Protection Dosimetry 128(2): 251-3.

Abstract: The Catalagzi Thermal Power Plant (CTPP) (41°30'48.4"N and 0.31°53'41.5"E) is located at nearly 13 km North-east of Zonguldak city, which is located at the West Black Sea coast in Turkey. The middling products with high ash content of bituminous coals are used in this plant. Seasonal radon concentration measurements have been carried out by using CR-39 plastic track detectors in and around the CTPP. The annual average radon concentration has been found to vary from a minimum of 39.8 +/- 28.9 Bq m(-3) in the ash area to a maximum of approximately 75.0 +/- 15.7 Bq m(-3) in the service building of the power plant. The annual average radon concentration in the dwellings of the thermal power plant colony of the plant is 71.0 +/- 33.4 Bq m(-3). The effective dose has been found to vary from 0.38 to 0.71 mSv y(-1) with a mean value of 0.56 mSv y(-1), which is lower than the effective dose values 3-10 mSv given as the range of action levels recommended by International Commission on Radiological Protection: Protection against radon-222 at home and at work, ICRP Publication 65 (1993).

Fujita K, Muraoka D, Ogawa T, Kitamura H, Suzuki K, Saito S. 2013. Evaluation of amine emissions from the post-combustion CO2 capture pilot plant. Energy Procedia 37: 727-734.

Abstract: In this work, we evaluated amine emissions from 10ton-CO2/day scale pilot plant in Mikawa Power Plant of Sigma Power Co. Ltd. within TS-1 solvent. Firstly, we investigated that how sampling gas flow rate affects measured value of amine concentration in flue gas by using on-line sampling method with PTR-MS analyzer. It was found that the error from an iso-kinetic sampling rises sharply for lower sampling velocities and in the range of higher sample stream velocities, however the error is lower. Secondly, we compared between beginning of operation and 2,800 hours operation in terms of amine emissions at Mikawa pilot plant under one set of conditions. At beginning of operation, there were no degraded amines in TS-1 solution. Thus, there were no amine emissions of degraded amines. However, at 2,800 hours operating, in addition to TS-1 emissions, some quantity of emissions of degraded amines were detected even though degraded amines were much less than TS-1 main amine in TS-1 solution. Toshiba improved operating conditions such as plant system, water wash system to reduce the amount of amine emissions. As a result, the latest tests showed lower emissions of less than 1 ppm(v/v) at 2,800 hours operation. A concentration of degraded amine [D] in TS-1 solution at 2,800 hours operation, which was nearly detection limit, was lower than other degraded amines. Nevertheless, degraded amine [D] accounted for the greater part of amine emissions after water wash was improved. This result suggested that it is crucial to reduce the volatility of emitted degraded amines in order to improve performance of suppression amine emissions further. Then,

finally we evaluated effect of addition acid to reduce the volatility of degraded amine [D]. The results in diluted aqueous amines at 40 °C showed that effectiveness of acid for reducing amine volatility is in the order: sulfuric acid > oxalic acid carbonic acid produced by 10%CO2 > boric acid.

Manousakas M, Fouskas A, Papaefthymiou H, Koukouliou V, Siavalas G, Kritidis P. 2010. Indoor radon measurements in a Greek city located in the vicinity of lignite-fired power plants. Radiation Measurements 45(9): 1060-7.

Abstract: This work presents indoor radon measurements in 42 dwellings in the city of Megalopolis, Southern Greece, located in the vicinity of 2 lignite-fired power plants and examines the effect of season, floor level and age of the dwellings on indoor radon concentration. The radon measurements have been carried out using the LR-115, type II and CR-39 alpha track detectors in "closed-can" geometry. The average annual indoor radon concentration (GM) was found to be 52 Bq m-3, which is well below the recommended action level of the European Union. This value corresponds to an annual effective dose to the population of 1.3 Â± 0.4 mSv. Season and age of the examined dwellings represent factors that affected significantly the indoor radon in Megalopolis, while the effect of floor level appeared to be not significant. Radium activity concentration values, measured by gamma-ray spectrometry in 20 sub-samples of six soil cores (60-135 cm depth), collected from the surrounding area of the city, were found to be consistent with the Greek and world average values. Based on the results of this study, it is concluded that the effect of the lignite-fired power plants on indoor radon concentration in Megalopolis' dwellings was not significant.

Grey literature

Durrenberger CJ, Spinhirne J, Webb A, McDonald-Buller E, Brown J. 2008. Evaluation of VOC concentrations in Victoria, Texas. In: Proceedings of the Air and Waste Management Association's Annual Conference and Exhibition, 3841-5.

Abstract: Victoria County, TX, and the neighboring counties of Calhoun, Jackson, Refugio, Goliad, De Witt, Lavaca, and Jackson are located in southeastern Texas along the Gulf Coast and have a significant industrial base associated with oil and natural gas production, chemical production, and electric power generation. Although the region is currently in attainment with the National Ambient Air Quality Standard for ozone concentrations averaged over 8-hr, it frequently experiences daily maximum 8-hr averaged ozone concentrations of 69-82 ppb. 1-Hr VOC canister samples were collected at the Memorial Park sampling site in Victoria, TX, during September and October 2005, 2006, and 2007. The modeled concentrations were compared to the measured values for total hydrocarbons, ethylene, and isoprene found from this sampling. The VOC emissions in the emissions inventory in the Victoria area were likely to be lower than the actual emissions.

Liu S, Wang B, He J, Tang X, Luo W, Wang C. 2012. Source fingerprints of volatile organic compounds emitted from a municipal solid waste incineration power plant in Guangzhou, China. In: 2011 International Conference of Environmental Science and Engineering, 106-15.

Abstract: Air samples of a municipal solid waste power plant were collected for the investigation from chimney, discharge workshop, boundary site and downwind receptor sites during regular operational period as well as overhaul period. In the regular operational period, 29 VOC species were detected from the discharge workshop and 25 VOC species from the plume of chimney. Average total VOC concentration at the discharge workshop site was 57.70 ± 19.55 μg/m3 which was primarily composed of aromatic compounds and alkanes, but it was up to 270.63 ± 2.84 μg/m3 in the plume of chimney which mainly included aromatic compounds and halohydrocarbons. In the overhaul period, average total VOC concentration was 59.70±0.91 μg/m3 in the discharge workshop and 326.35 ± 151.68 μg/m3 in the chimney. Aromatics, halohydrocarbons and alkanes were indentified as the significant VOC fingerprints among which chlorobenzene and tetrachloroethylene were two unique VOC molecular markers of the power plant. Moreover, the VOC emission inventory of Chinese MSWI power plant was estimated approximately, it indicated that annual emission amount of the VOCs from the nationwide MSWI power plants reached 38.6tons in 2005 and would rise to 81.80 tons in the end of 2010.

4.3.3 Other pollutants - modeled emissions (emission inventories)

White literature

Bo Y, Cai H, Xie SD. 2008. Spatial and temporal variation of historical anthropogenic NMVOCs emission inventories in China. Atmospheric Chemistry and Physics 8(23): 7297-316.

Abstract: Multiyear emission inventories of anthropogenic NMVOCs in China for 1980–2005 were established based on time-varying statistical data, literature surveyed and model calculated emission factors, which were further gridded at a high spatial resolution of 40 km×40 km using the GIS methodology. Results show a continuous growth trend of China's historical NMVOCs emissions during the period of 1980–2005, with the emission increasing by 4.2 times at an annual average rate of 10.6% from 3.91 Tg in 1980 to 16.49 Tg in 2005. Vehicles, biomass burning, industrial processes, fossil fuel combustion, solvent utilization, and storage and transport generated 5.50 Tg, 3.84 Tg, 2.76 Tg, 1.98 Tg, 1.87 Tg, and 0.55 Tg of NMVOCs, respectively, in 2005. Motorcycles, biofuel burning, heavy duty vans, synthetic fibre production, biomass open burning, and industrial and commercial consumption were primary emission sources. Besides, source contributions of NMVOCs emissions showed remarkable annual variation. However, emissions of these sources had been continuously increasing, which coincided well with China's economic growth. Spatial distribution of NMVOCs emissions illustrates that high emissions mainly concentrates in developed regions of northern, eastern and southern coastal areas, which produced more emissions than the relatively underdeveloped western and inland regions. Particularly, southeastern, northern, and central China covering 35.2% of China's territory, generated 59.4% of the total emissions, while the populous capital cities covering merely 4.5% of China's territory, accounted for 24.9% of the national emissions. Annual variation of regional emission intensity shows that emissions concentrating in urban areas tended to transfer to rural areas year by year. Moreover, eastern, southern, central, and northeastern China were typical areas of high emission intensity and had a tendency of expanding to the northwestern China, which revealed the transfer of emission-intensive plants to these areas, together with the increase of biomass open burning.

Buke T. 2013. Evaluation of radioactive emissions of lignite-fired power plants in Turkey using the Analytic Hierarchy Process. Kerntechnik 78(5): 437-42.

Abstract: Radioactive emissions of 13 lignite-fired power plants in Turkey are of great concern to the public and to scientists alike. The purpose of this study is to evaluate these power plants, according to their radioactive emissions by using the Analytic Hierarchy Process. Control criteria are in particular Ra-226, Th-232, K-40 and U-238 emissions from the power plants. These control criteria are weighted according to the objective assessment. The calculations are repeated for three different objective assessments of control criteria namely the mortality risk coefficients for inhalation, ingestion, external exposure of Ra-226, Th-232, K-40 and U-238. It has been calculated that the Can lignite-fired power plant is ranking first while the Soma-B plant is ranking last according to the radioactive emissions of the power plants when the average of three different objective control criteria are used in the calculations.

Cheng HR, Guo H, Saunders SM, Lam SHM, Jiang F, Wang XM et al. 2010. Assessing photochemical ozone formation in the Pearl River Delta with a photochemical trajectory model. Atmospheric Environment 44(34): 4199-208.

Abstract: A photochemical trajectory model (PTM), coupled with the Master Chemical Mechanism (MCM) describing the degradation of 139 volatile organic compounds (VOCs) in the troposphere, was developed and used for the first time to simulate the formation of photochemical pollutants at Wangqingsha (WQS), Guangzhou during photochemical pollution episodes between 12 and 17 November, 2007. The simulated diurnal variations and mixing ratios of ozone were in good agreement with observed data (R-2 = 0.80, P < 0.05), indicating that the photochemical trajectory model - an integration of boundary layer trajectories, precursor emissions and chemical processing - provides a reasonable description of ozone formation in the Pearl River Delta (PRD) region. Calculated photochemical ozone creation potential (POCP) indices for the region indicated that alkanes and oxygenated organic compounds had relatively low reactivity, while alkenes and aromatics presented high reactivity, as seen in other airsheds in Europe. Analysis of the emission

inventory found that the sum of 60 of the 139 VOC species accounted for 92% of the total POCP-weighted emission. The 60 VOC species include C-2-C-6 alkenes, C-6-C-8 aromatics, biogenic VOCs, and so on. The results indicated that regional scale ozone formation in the PRD region can be mainly attributed to a relatively small number of VOC species, namely isoprene, ethene, m-xylene, and toluene, etc. A further investigation of the relative contribution of the main emission source categories to ozone formation suggested that mobile sources were the largest contributor to regional O3 formation (40%), followed by biogenic sources (29%), VOC product-related sources (23%), industry (6%), biomass burning (1%), and power plants (1%). The findings obtained in this study would advance our knowledge of air quality in the PRD region, and provide useful information to local government on effective control of photochemical smog in the region.

de Koeijer G, Talstad VR, Nepstad S, Tønnessen D, Falk-Pedersen O, Maree Y, Nielsen C. 2013. Health risk analysis for emissions to air from CO2 Technology Centre Mongstad. International Journal of Greenhouse Gas Control 18: 200-207.

Abstract: A health risk analysis for the emissions to air from the CO2 Technology Centre Mongstad (TCM) has been executed. TCM is the world's largest facility for testing and improving technologies for CO2 capture, and is located at the West coast of Norway. The risk analysis was an important fundament for the application for an emission permit for the amine based post-combustion CO2 capture unit. The highest risk was assessed to be the exposure of the population to uncertain concentrations of nitrosamines and nitramines in air and drinking water. Nitrosamines and nitramines are groups of possible degradation products formed from amines. The components within these two groups have variable degrees of carcinogenicity. Nitrosamines are formed from amines in the CO2 capture process and in the atmosphere, while nitramines are assumed to form only in the atmosphere. The risk was analyzed by comparing the sum of concentrations of nitrosamines and nitramines in air and fresh water with recently available guidelines. The concentrations were obtained by modelling atmospheric chemistry, dispersion, deposition by precipitation and degradation in fresh water with novel methods that were developed during the application process. Moreover, the nitrosamine and nitramine concentrations were measured in air and fresh water lakes prior to start-up as a baseline. TCM's conclusion was that the risk was acceptable. The Norwegian Climate and Pollution Agency granted TCM a permit in November 2011.

Karl M, Wright RF, Berglen TF, Denby B. 2011. Worst case scenario study to assess the environmental impact of amine emissions from a CO2 capture plant. International Journal of Greenhouse Gas Control 5(3): 439–447.

Abstract: Use of amines is one of the leading technologies for post-combustion carbon dioxide capture from gas and coal-fired power plants. This study assesses the potential environmental impact of emissions to air that result from use of monoethanol amine (MEA) as an absorption solvent for the capture of carbon dioxide (CO2). Depending on operation conditions and installed reduction technology, emissions of MEA to the air due to solvent volatility losses are expected to be in the range of 0.01–0.8 kg/tonne CO2 captured. Literature data for human and environmental toxicity, together with atmospheric dispersion model calculations, were used to derive maximum tolerable emissions of amines from CO2 capture. To reflect operating conditions with typical and with elevated emissions, we defined a scenario MEA-LOW, with emissions of 40 t/year MEA and 5 t/year diethyl amine (DEYA), and a scenario MEA-HIGH, with emissions of 80 t/year MEA and 15 t/year DEYA. Maximum MEA deposition fluxes would exceed toxicity limits for aquatic organisms by about a factor of 3–7 depending on the scenario. Due to the formation of nitrosamines and nitramines, the estimated emissions of DEYA are close to or exceed safety limits for drinking water and aquatic ecosystems. The "worst case" scenario approach to determine maximum tolerable emissions of MEA and other amines is in particular useful when both expected environmental loads and the toxic effects are associated with high uncertainties.

Trotti F, Liziero F, Zampieri C, De Zolt S. 2009. Impact to public and environment of Norm industries in Italy. Radiation Protection Dosimetry 137(3-4): 310-3.

Abstract: Italian legislation requires companies undertaking certain work activities involving naturally occurring radioactive materials (NORM) to check compliance with action levels (1 mSv y(-1) for workers, 0.3

mSv y(-1) for the public). A project is being carried out by ARPAV and other Environmental Agencies to estimate doses to members of the public from NORM from several activities (refractory and tile industry, integrated steelworks, phosphate industry, aluminium production, coal-fired power plants). Activity concentration values of residues have been compared with general clearance levels given in Radiation Protection 122 part 2 and, in several cases, these levels appeared to be exceeded. Doses due to air emissions from stacks, from wastes in disposal sites and from the use of fertilisers in agriculture have been calculated through simulation models (PC-Cream, Resrad, Unscear algorithms), which produce fairly low dose estimates. A major problem for NORM control in Italy at the moment is the lack of official technical and legislative rules (concerning, for instance, residues and effluents management).

Zhang Y, Xu J, Zhang Y, Zhang J, Li Q, Liu H, Shang M. 2014. Health risk analysis of nitrosamine emissions from CO2 capture with monoethanolamine in coal-fired power plants. International Journal of Greenhouse Gas Control 20: 37–42.

Abstract: Monoethanolamine (MEA)-based chemical absorption is extensively used in the capture processes of coal-fired power plants from flue gas. However, chemical carcinogens, such as nitrosamine, are released during MEA degradation, especially at the top of the absorber. This study analyzed five CO2 capture power plants with various capacities, and investigated nitrosamine exposure concentration at downwind direction. Tolerant exposure concentration was calculated under 10^{-4} and 10^{-6} risks during the health risk assessment. Safety distances D' for the five scenarios (365, 3000, 40,000, 146,000, and 1,000,000 t/a) were calculated as first screening under the typically meteorological conditions over North China Plain (mixing height 1000 m, wind speed 5 m/s measured at reference anemometer height of 10 m, and atmospheric stability D). The emission rate and discharge height will affect the safety distance D'. When nitrosamines are directly emitted from absorber, the values D' are 0, 0, 0, 1580, and 5700 m based on 10−6 risks. When nitrosamines are emitted from stacks of power plant, the health risks of nitrosamines can be negligible. Although the results were very uncertain, the health effects of nitrosamine emissions should be concerned and further studies are necessary to thoroughly investigate the emission rate of nitrosamines.

Grey literature

Commonwealth Scientific and Industrial Research Organisation (CSIRO). 2012. Australian National Low Emissions Coal Research and Development Project: Environmental Impact of Amine-based CO2 Postcombustion Capture (PCC) Process. Activity 3: Estimated emissions to the atmosphere from amine based PCC processes for a black coal fired power station based on literature and modelling. Available at http://cdn.globalccsinstitute.com/sites/default/files/publications/39966/estimatedemissions-opt.pdf.

Abstract: Chemical solvents using amines are the most likely technologies to be deployed in the near future to capture CO2 from industrial flue gases. These solvents have excellent effectiveness and efficiency to absorb CO2 in the flue gas from fossil fuel power plants operating with low partial pressures. In addition, these solvents can be regenerated and injected back into the process to capture more CO2. However, their degradation products may produce new pollutants which could be emitted to the atmosphere. This case study analyses the latest information available in the public domain and employs the Aspen-Plus process simulator to estimate the atmospheric emissions of degradation products from an aqueous MEA solvent.

Karl M, Brooks S, Wright R, Knudsen S. 2009. Amines Worst Case Studies: Worst Case Studies on Amine Emissions from CO2 Capture Plants (Task 6). Norwegian Institute for Air Research, NILU OR 78/2008, Norway. Available at http://co2.nilu.no/LinkClick.aspx?fileticket=qNhKgZGUHjM%3D&tabid=2549&mid=5547&language=en-GB.

Abstract: *No abstract available.*

Excerpt from Introduction and Conclusion:
[In this report effects of amine emissions from the CO2 capture plant are studied in terms of worst case scenarios and possible range of emission rates. The concept of critical levels and critical loads is applied to quantify the impact of amines and degradation products on ecosystems and human health.]
[In this report several aspects of the pollution from the CO2 storage plant are studied. This report provides an estimate of the deposition of amines, secondary products, and also of airborne nitrogen to ecosystems. Expected concentrations and deposition fluxes are calculated with dispersion models for: 1. unity emissions; 2. maximum emissions; 3. maximum tolerable emissions; of the CO2 capture technology.]
[The worst case studies reveal that possible emissions of nitrosamines and nitramines could be a serious problem to human health and/or aquatic organisms. The effect of nitrosamines and nitramines should thus be ranked as an aspect of higher risk than that of airborne nitrogen.]

Appendix A: Review Form Template

Study title (Author, Year)

Checklist for Assessing the Quality of Quantitative Studies[1*]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A
1	Question / objective sufficiently described?				
2	Study design evident and appropriate?				
3	Method of subject/comparison group selection or source of information/input variables described and appropriate?				
4	Subject (and comparison group, if applicable) characteristics sufficiently described?				
5	If random allocation was possible, was it described?				
6	If blinding of investigators/subjects was possible, was it reported?				
7	Exposure measure(s) well defined and robust to measurement / misclassification bias? Means of assessment reported?				
8	Outcome well defined and robust to measurement / misclassification bias? Means of assessment reported?				
9	Sample size appropriate?				
10	Analytic methods described/justified and appropriate?				
11	Some estimate of variance is reported for the main results?				
12	Controlled for confounding?				
13	Results reported in sufficient detail?				
14	Conclusions supported by the results?				

Scoring:

-Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0).
-Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring.
-Calculation of summary score:

Total sum = (number of "yes" * 2) + (number of "partials" * 1). __

Total possible sum = 28 – (number of "N/A" * 2). __

Summary score: total sum / total possible sum. __/__ = __

-Quality ranking[2]: High (0.80–1), Moderate (0.51–0.79), Low (≤0.50)

Study Score and Ranking:

Strengths and Limitations:

Strengths:
Limitations:

[1] Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. AHFMR, Edmonton, Canada. Available online at http://www.ihe.ca/documents/HTA-FR13.pdf.

[2] Squires JE, Hutchinson AM, Bostrom AM, O'Rourke HM, Cobban SJ, and Estabrooks CA. 2011. To what extent do nurses use research in clinical practice? A systematic review. *Implement Sci.* 6:21.

* Note: The checklist used in the current review was slightly modified from its original form: items 6 and 7 were combined (now item 6) to apply a single criterion for blinding; and item 8 was divided into two items (now items 7 and 8) to allow for a separate assessment of exposure and health outcome.

[1] Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. AHFMR, Edmonton, Canada. Available online at http://www.ihe.ca/documents/HTA-FR13.pdf.

[2] Squires JE, Hutchinson AM, Bostrom AM, O'Rourke HM, Cobban SJ, and Estabrooks CA. 2011. To what extent do nurses use research in clinical practice? A systematic review. *Implement Sci.* 6:21.

* Note: The checklist used in the current review was slightly modified from its original form: items 6 and 7 were combined (now item 6) to apply a single criterion for blinding; and item 8 was divided into two items (now items 7 and 8) to allow for a separate assessment of exposure and health outcome.