Industrial and Mobile NOx Control Practices and Options

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Overview

- Basic NOx formation and control concepts
- US regulatory programs for NOx
- NOx controls for
  - Natural gas fired boilers and turbines
  - Other industrial sources
  - Large nonroad mobile diesel engines
  - Stationary source engines

NOx Formation

- Thermal NOx, fuel NOx
- Thermal NOx-oxidation of molecular nitrogen in the combustion air
  - for nitrogen-free fuels, thermal NOX is the primary component of NOX emissions.
  - sensitive to temperature and can be controlled by appropriately controlling peak temperature in the furnace.

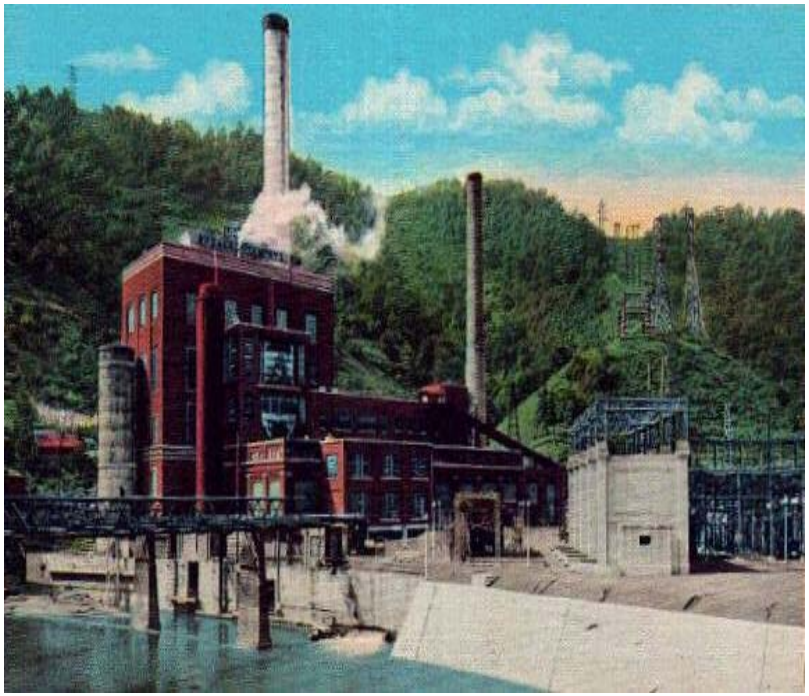
Fuel NOx

- Fuel NOx-oxidation of chemically bound nitrogen in the fuel
  - In fuel-lean combustion of fuels containing nitrogen (e.g., coal), fuel NOX contributes significantly to total NOX emissions
  - Formation of fuel NOX depends on the availability of oxygen to react with the nitrogen during coal devolatilization and the initial stages of combustion

Alberta NOx emissions Projections

Sector	**NOx Emissions (kilotonnes as NO2) in noted Year**		
	2005	**2010**	**2015**
Electric Power Generation	***102***	***113***	***115***
Upstream Oil and Gas (including oil sands and oil sands mine fleets)	***413***	***506***	***564***
Petroleum Refineries	4.6	4.8	5.0
Cement	5.0	4.8	4.9
Chemical (major chemical industries are petrochemical and fertilizer)	27	29	32
Pulp and Paper	4.2	4.8	5.2
Iron and Steel	0.22	0.23	0.24
Nonferrous Metals Smelting and Refining	0.44	0.46	0.49
Transportation (on-road and off-road excluding oil sands mine fleets)	***166***	***126***	***102***
Residential Heating	7.0	6.9	7
Commercial and Institutional Heating	5.1	4.9	4.7
Natural Sources e.g. forest fires	31	31	31
Total	**766**	**832**	**872**

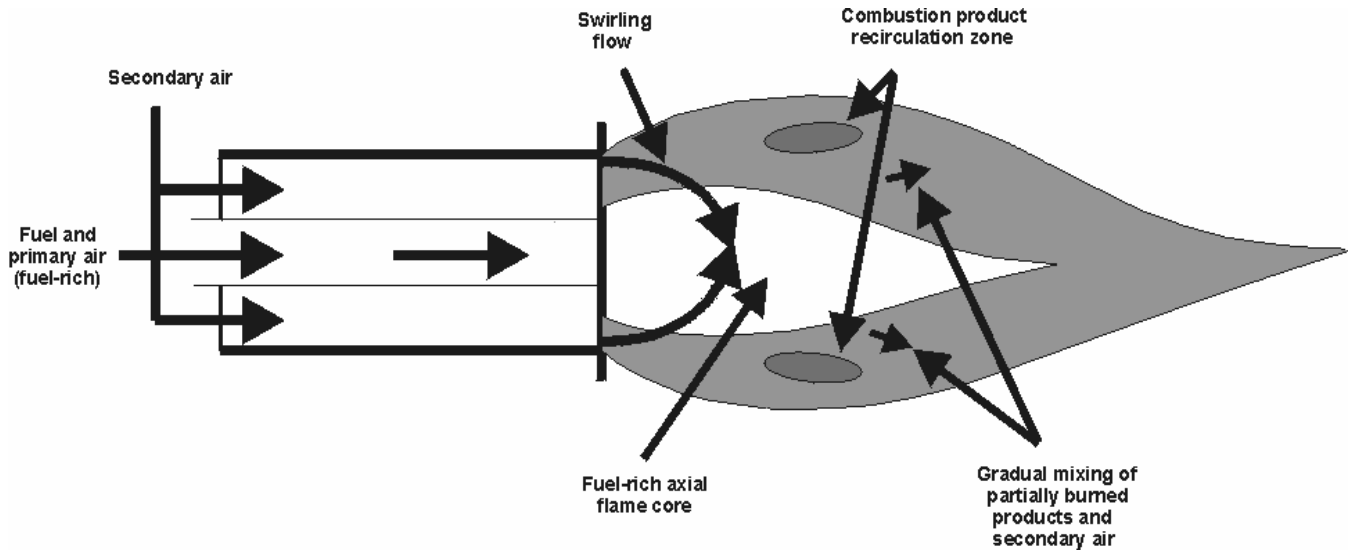
Control Technologies



- Primary (combustion) – decrease the production of NOx in the primary combustion zone
  - Widely used - low NOx burners (LNBs) and overfire air (OFA)
- Secondary (post-combustion) - reduce the NOx already present in the flue gas
  - Widely used - reburning, selective non-catalytic reduction (SNCR), and selective catalytic reduction (SCR)

Low NOx Burners

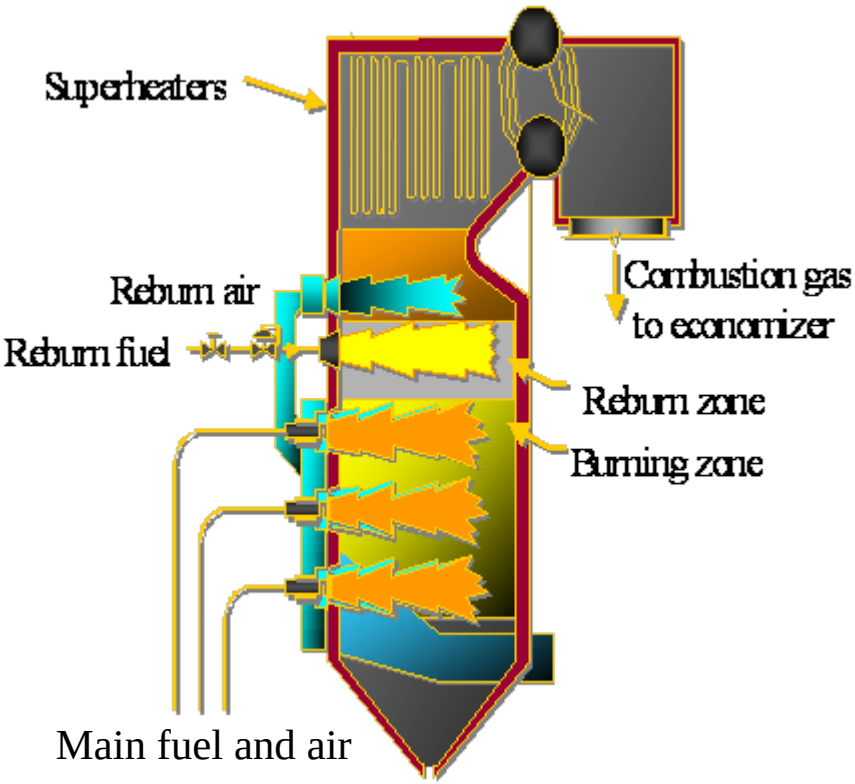
- Limits NOx formation by delaying complete mixing of fuel and air
- Can provide reductions in excess of 50%



Overfire Air

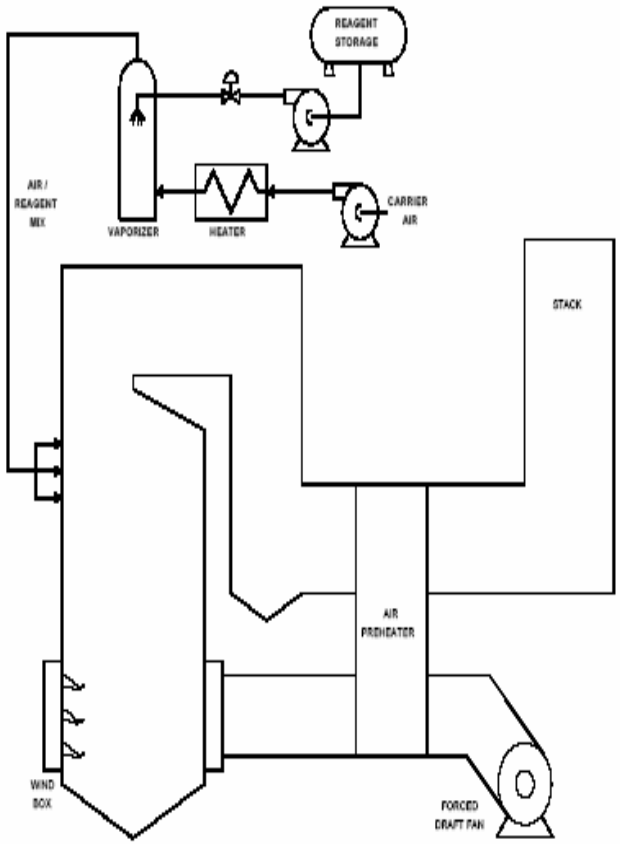
- 5 to 20% of the total combustion air is injected through ports located downstream of the top burner level
  - Burners operate at lower than normal air-to-fuel ratio resulting in NOx control, OFA added to achieve complete combustion
  - Can be used with LNB to increase NOx reduction by 10 to 25%

Reburning



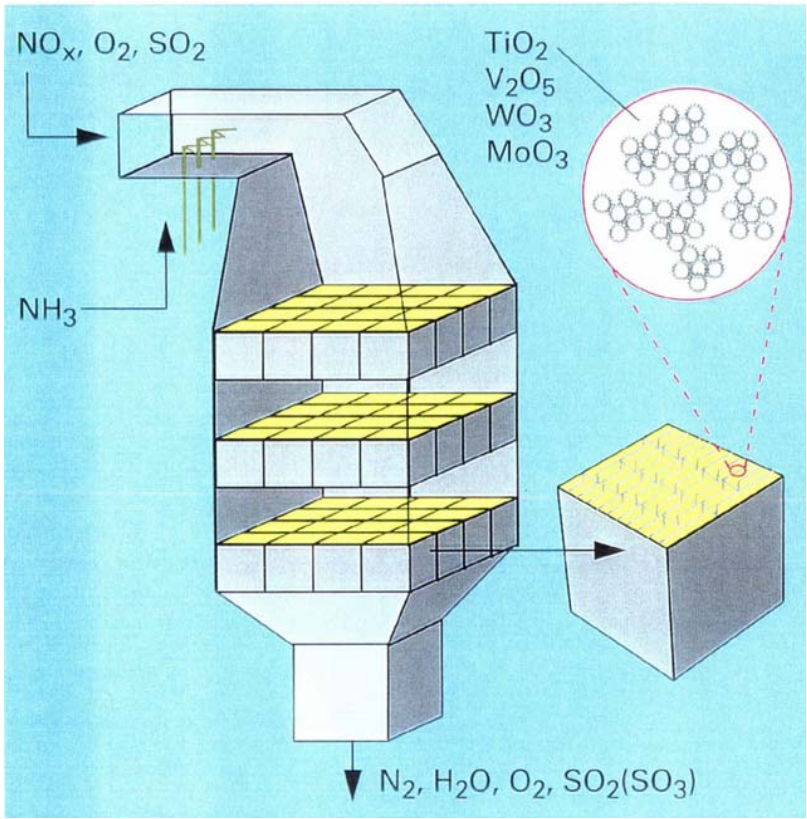
- Reburn fuel (natural gas, coal, other fuels) is injected to provide 15-25% of total heat input
- ≥50% NOx reduction, mercury and SO_2 reduction
- Low capital costs
- Fuels costs, availability of adequate residence time
- Applications: cyclone, wall, tangential; 33-600 MWe

Selective Non-Catalytic Reduction (SNCR)



- Urea or NH3 injection, generally between 980 to 1150 ^{o}C
- 30 to 60 % NOx reduction
- Low capital costs, easy retrofit
- Load following, NH3 slip, performance on larger boilers
- Applications: cyclone, wall, tangential; 50-620 MW

Selective Catalytic Reduction (SCR)



- NH3 injection, generally between 350-400 ^oC
- More than 90 % reduction is possible
- Capital intensive, space requirements, NH_3 slip, SO_3 emissions, catalyst deactivation
- “high dust” (most common) before PM controls vs “low dust” (after PM controls)

US regulations affecting NOx

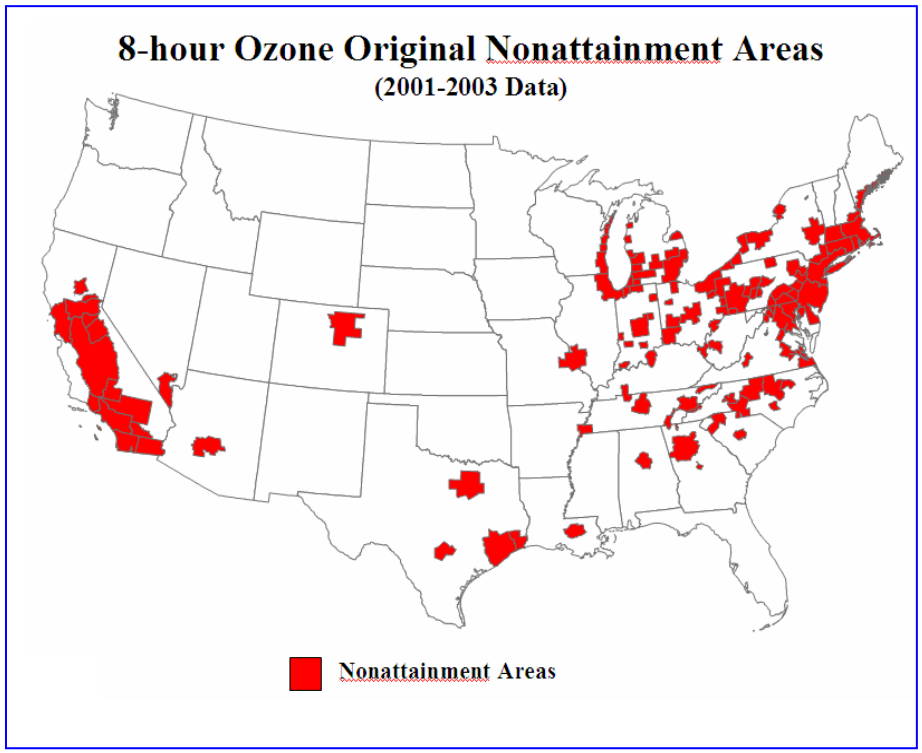
- Ozone air quality standards. NOx is precursor and many areas need NOx reductions.
- New source performance standards (national emissions standards)
- Technology reviews for new major sources
  - Cutoff usually > 100 tpy
  - Case-by-case permit limits
- Interstate transport:
  - NOx SIP call (1998)
  - Clean air interstate rule (2005)

Ozone

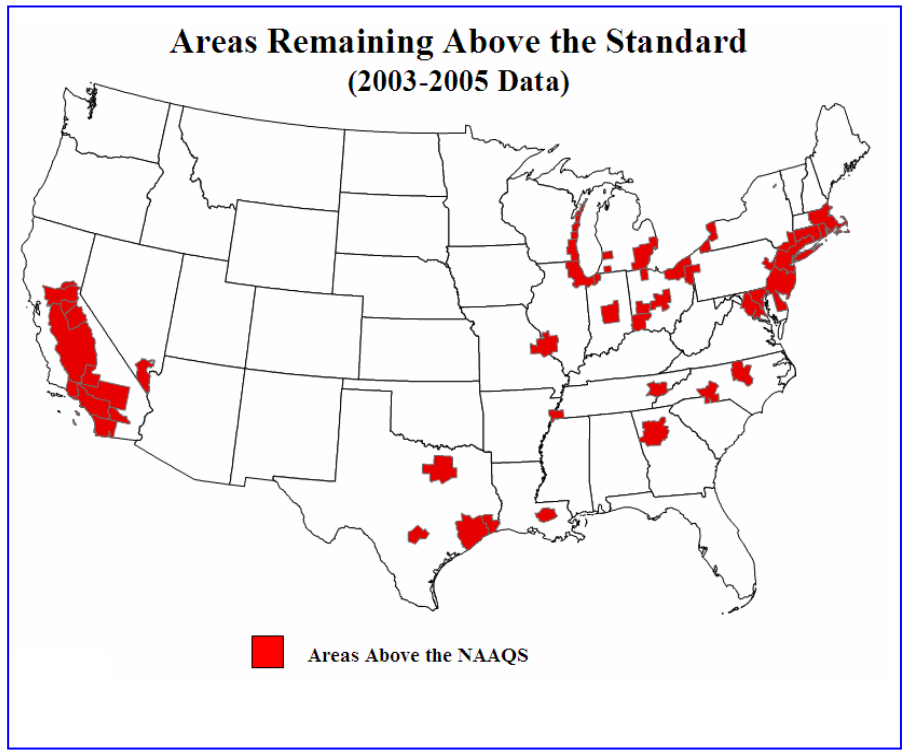
- Many urban areas in the US (with population of 150 million) were not meeting the 8-hour ozone standard in 2004
- Much progress being made in large part due to regional NOx reductions

Ozone areas remaining above the 8-hour National Ambient Air Quality Standard

April 2004

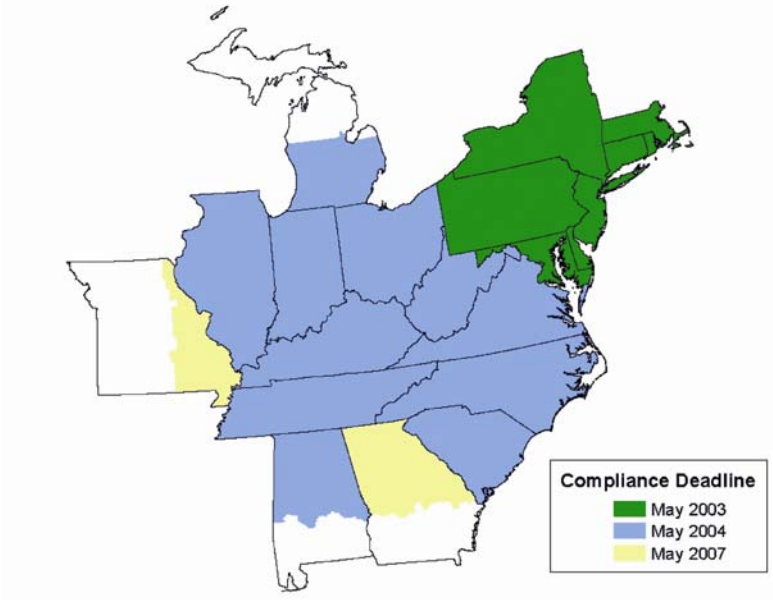


End of 2005



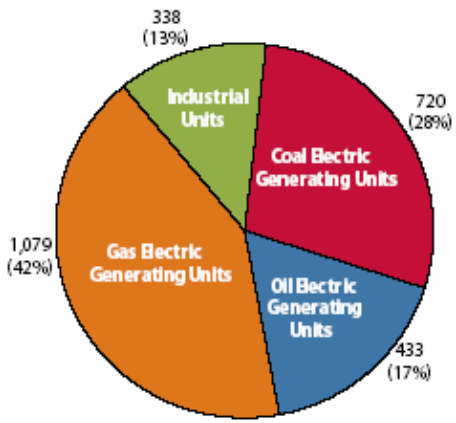
Background: NOx Budget Trading Program

NO_X SIP Call Region Program Implementation



EPA is currently reconsidering Georgia's inclusion in the NO_x SIP call

Total NBP Units by Type in 2005

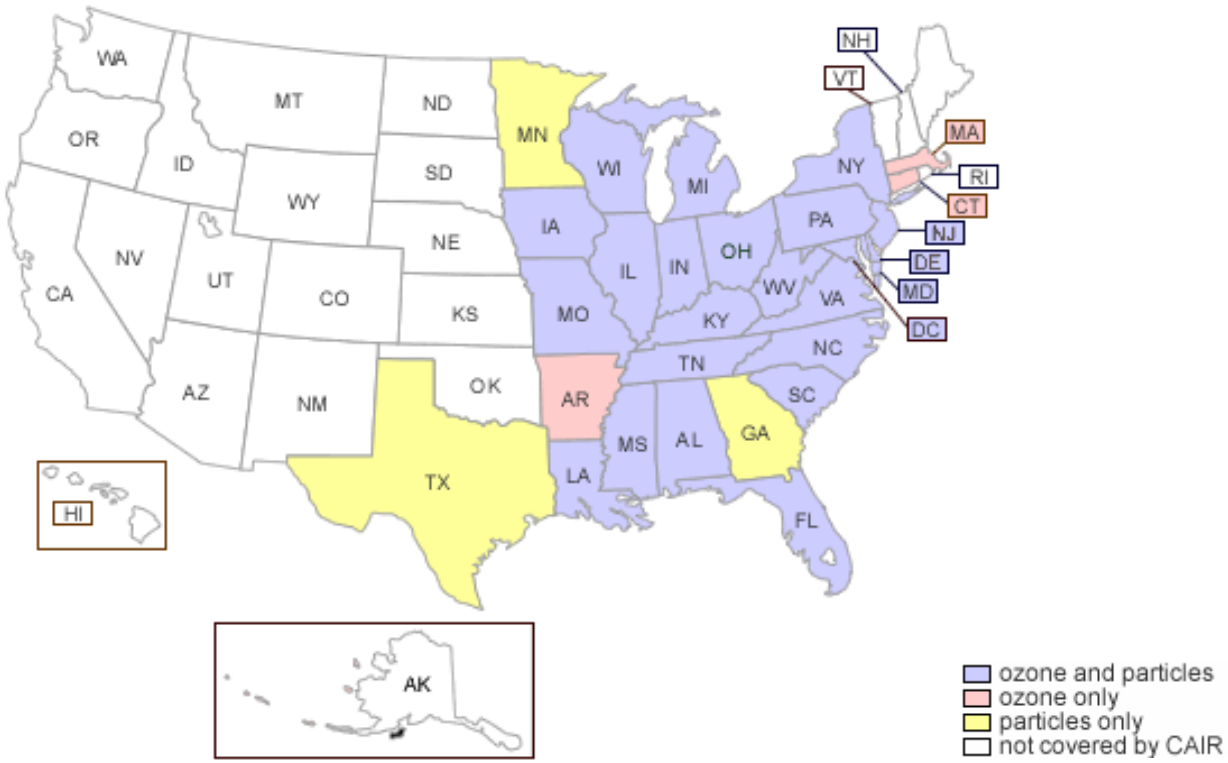


- **All states chose to achieve NO_x SIP call reductions through trading program which allows sources to buy and sell allowances.**
- **Program includes electric generating units and large industrial boilers and turbines**
- **The 2004 control period for non OTC states was for a shorter than normal ozone season, May 31 to September 30.**
- **In 2005, all affected sources were required to comply for the full ozone season, May 1 to September 30.**

2570 affected NBP Units in 2005

- **13%** Industrial Units
- **87%** Electric Generating Units

Clean Air Interstate Rule (CAIR) (2005)



CAIR– further reductions in utility boiler NOx emissions

Projected Annual NOx Emissions from Power Plants with the Final Clean Air Interstate Rule		Annual NOx (*Million Tons*)				
		2003	2009	2015	2020	Full Implementation of CAIR
Emissions without CAIR	CAIR Region	3.2	2.7	2.8	2.8	N/A
	Nationwide	4.2	3.6	3.7	3.7	N/A
CAIR Caps	CAIR Region	N/A	1.5	1.3	1.3	1.3
Emissions with CAIR	CAIR Region	N/A	1.5	1.3	1.3	1.3
	Nationwide	N/A	2.4	2.2	2.2	2.2
Percent Reduction with CAIR (Relative to 2003)	CAIR Region	N/A	52%	61%	61%	61%
	Nationwide	N/A	42%	48%	48%	48%

**As further explained in the note below, the region covering annual SO_2 and NOx varies slightly from the ozone season NOx regi*

***The final CAIR includes a compliance supplement pool of NOx allowances (roughly 200,00 allowances) for the annual progra which could lead to slightly higher annual NOx emissions than are stated here.*

** See additional notes below*

Current budget trading program vs CAIR

- Current (often referred to as “NOx SIP call”):
  - based on 0.15 lb/MMBTU for the ozone season.
  - Reflected reductions from electric generating units, large industrial boilers >250 MMBTU/hr, cement kilns, and some combustion turbines and stationary IC engines
- CAIR: electric generating units only
  - 2015 projected average of about 0.11 lb/MMBTU
  - http://epa.gov/cair/pdfs/finaltech06.pdf

More information on NOx Budget Trading Programs

- Recent report: NOx Budget Trading Program: 2005 Program Compliance and Environmental Results

- http://www.epa.gov/airmarkets/fednox/

- CAIR: www.epa.gov/cair

New source review

- New sources:
  - New source performance standards (NSPS) developed by EPA/OAQPS based on “best demonstrated technology”
  - Permits:
    - PSD (for clean air areas) requires best available control technology BACT
    - Nonattainment area new source review requires somewhat more stringent lowest achievable emission rate (LAER)

Info on recent BACT/LAER determinations

- RACT/BACT/LAER Clearinghouse
- RBLC data base contains case-specific information on technologies required in stationary sources permitting
- Information by State and local permitting agencies.
- Clearinghouse also contains a regulation data base that summarizes EPA emission limits required by NSPS, NESHAP, MACT standards.
- http://www.epa.gov/ttn/catc/rblc/htm/rbxplain.html

New Power Plants

- Trends: towards coal-fired units, fewer natural gas
- NOx limits:
  - SCR, combustion controls
  - typically in 0.05-0.10 lb/MMBTU, trending towards 0.05
- Beginning to see some integrated gasification-combined cycle (IGCC) applications (July 06 report on IGCC environmental footprint: http://www.epa.gov/airmarkets/articles/IGCCfactsheet.html)

Natural gas-fired Industrial boilers

- New source performance standard for boilers >100 MMBTU/hr heat input (29 MW) issued in Feb 2006
  - 0.20 lb/MMBTU (86 ng/Joule)
  - For natural gas, can meet with combustion controls only
- Major source (PSD/NSR) permitting would result in much lower limits
  - Recent Permit in AZ: 0.0125 lb/MMBTU (about 10 ppm)
- Similar requirements in San Joaquin Valley State ozone Implementation Plan requirements. 9 ppm limit in rule 4306.

Gas Turbines

- Before recent trends, many electricity generating unit permits were for natural gas-based combined cycle gas turbines
- Limits for NOx: typically based on SCR, NOx limits of 2-5 ppmvd (at 15% O2)
- Good summary of available and developing technologies: California Air Resources Board Report to Legislature on Gas-Fired Power Plant NOx Controls and Related Impacts
  http://www.arb.ca.gov/energy/noxlegrpt/report.doc

Cement Kilns

- EPA/OAQPS Reports on NOx controls for cement kilns : 1994 and 2000

- OAQPS has prepared detailed draft report on NOx from recent permitting (all are preheater/precalciner kilns).
- New sources:
  - 10 BACT determinations for NOx since 2002, 3 pending
  - Emissions limits of 2.0 lb/T in recent permits
  - Controls vary: all require combustion controls, most require SNCR, none SCR

- Contact is Bill Neuffer: neuffer.bill@epa.gov

Cement kilns (cont)

- For 1998 NOx budget trading program, NOx budgets based on “highly cost effective” controls <$2000/ton
- For cement kilns, 30% reduction based on LNB and mid-kiln firing considered “highly cost-effective”

Other industrial sources – example NOx controls

- Glass plants
  - –Container (LNB, SNCR 40% control)
  - – Glass plants –flat (Oxyfiring 40%; SCR 75%; SNCR 40%)
  - – Pressed (LNB 40%, SCR 75%)
- Asphalt plants: LNB + flue gas recirc 50%
- Refineries-FCC units LNB + FGR
- Iron and steel mills:
  - – Annealing furnaces 50-80% LNB → LNB + SCR
  - – Galvanizing LNB 50% ; LNB + FGR 60%
  - – Reheating Furnaces: LNB 50% LNB + FGR 77%
- Fiberglass- recuperative furnaces (LNB 40%)
- Lime kilns (Mid kiln firing, LNB 30%)

Mobile Source engines

- New onroad and nonroad engines regulated by EPA/OTAQ. Ann Arbor, MI]
- Key rules
  - Onroad
    - 2001: “2007 Heavy-Duty Highway Rule“
      - stringent NOx limits for trucks and buses beginning with 2007 model year
  - Nonroad
    - 1998 “Tier 2 and 3” Nonroad rule
    - 2004 “Tier 4” “Clean Air Nonroad Diesel Rule”
      - Standards phased in 2011-2014

Tier 4 Nonroad standards

TABLE II.A–2.—TIER 4 NO_X AND NMHC STANDARDS AND SCHEDULE

Engine power	Standard (g/bhp-hr)		Phase-in schedule (model year) (percent)			
	NO_X	NMHC	2011	2012	2013	2014
25 ≤ hp < 75 (19 ≤ kW < 56)	3.5 NMHC+NO_X[a]		.....	.....	100%	.....
75 ≤ hp < 175 (56 ≤ kW < 130)	0.30	0.14	[b]50	[b]50	[b]100	
175 ≤ hp ≤ 750 (130 ≤ kW ≤ 560)	0.30	0.14	50	50	50	100
hp > 750 (kW > 560)	See table II.A–4					

Notes: Percentages indicate production required to comply with the Tier 4 standards in the indicated model year.

[a] This is the existing Tier 3 combined NMHC+NO_X standard level for the 50–75 hp engines in this category. In 2013 it applies to the 25–50 hp engines as well.

[b] Manufacturers may use banked Tier 2 NMHC+NO_X credits from engines at or above 50 hp to demonstrate compliance with the 75–175 hp engine NO_X standard in this model year. Alternatively, manufacturers may forego this special banked credit option and instead meet an alternative phase-in requirement of 25/25/25% in 2012, 2013, and 2014 through December 30, with 100% compliance required beginning December 31, 2014. See sections III.A and II.A.2.b.

Tier 4 Large Engine (>750hp) NOx Standards (g/bhp-hr)

- Generator sets < 1200 hp
  - 2011: 2.6
  - 2015: 0.5 [aftertreatment-based]
- Generator sets >1200 hp
  - 2011: 0.5
- Mobile machinery (all other equipment):
  - 2011: 2.6
  - 2015: 2.6 (further study of aftertreatment)

How large is “large?”

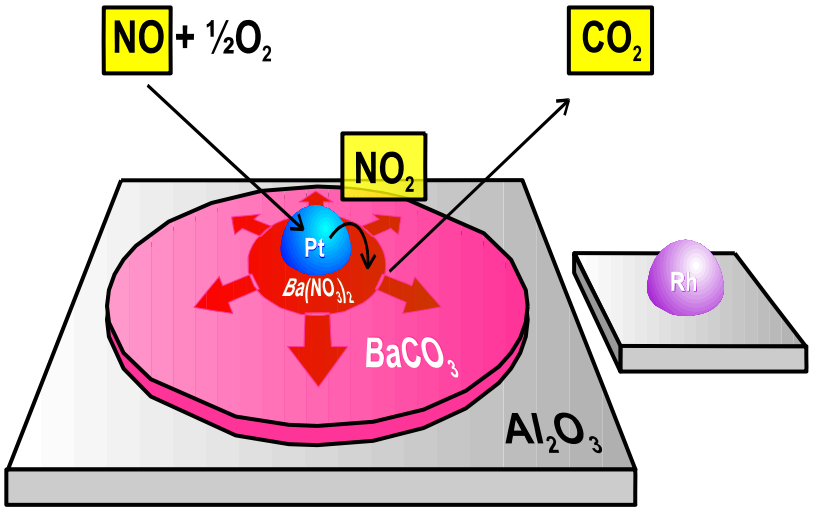
NOx aftertreatment

- SCR (concerns on need for reagent tank refilling)
- NOx adsorber

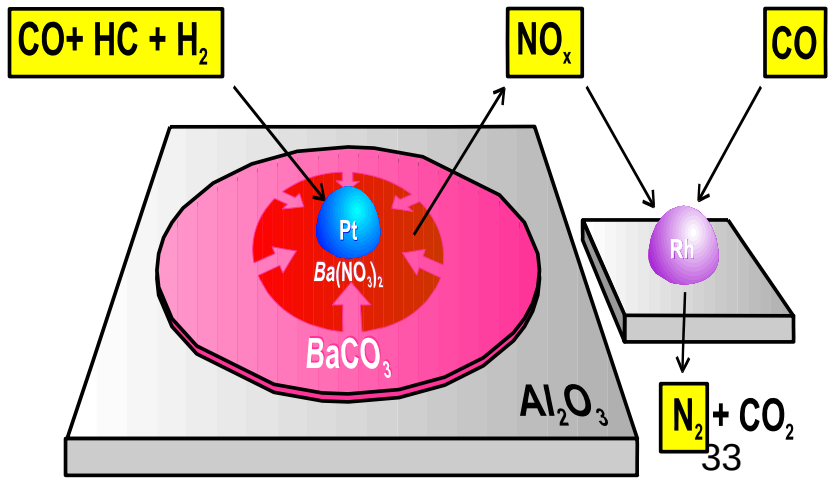
NOx Adsorber Catalysts (bi-modal operation)

3-way-catalyst + storage component

Storage Step
Lean (normal) Diesel Operation



NOx Reduction Step
Rich (abnormal) Diesel Operation



>750 engines (cont)

- Gen sets vs “mobile machinery”
- Gen sets: NOx limits assume aftertreatment
- Mobile machinery: deferred setting aftertreatment-based standards
  - Concerns: harsh applications, levels of vibration, varying operations
  - Commitment to further study. No conclusions yet.
  - Contact-- Byron Bunker: bunker.byron@epa.gov

Mobile Source References

- EPA websites for further information:
  - EPA models for nonroad engine emissions calculations: http://www.epa.gov/otaq/nonrdmdl.htm
  - In-use testing program: http://www.epa.gov/oms/regs/hd-hwy/inuse/420f05021.htm
  - Retrofit program including technology verification process: http://www.epa.gov/otaq/retrofit/retrofittech.htm

Stationary engines

- In US, an engine “stationary” if at same location for >12 months (seasonal operations create some exceptions)
- Examples: most remote gensets, engines at some industrial sites
- New stationary diesel engines regulated by EPA/OAQPS. Recent rule extends nonroad diesel limits to stationary source engines.
- Engines > 500 hp located at major sources also regulated by air toxics standards
- Regulations for stationary spark-ignited engines were proposed in July and will be finalized by December, 2007.
- Contact: Mr. Jaime Pagán (919) 541 5340