FINAL

Review of Odour Prevention and Mitigation Tools for Alberta

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Submitted to:

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EXECUTIVE SUMMARY

The Clean Air Strategic Alliance (CASA) was established in March 1994 with the vision to ensure that the air in Alberta will have no adverse odour, taste or visual impact and have no measurable short or long term adverse effect on people, animals or the environment (CASA, 2014a). Identifying odour as a new priority, the Odour Management Working Group (OMWG) was formed in January 2013 to establish a new multi-stakeholder working group that would engage focused discussion at advancing odour management in Alberta. Realizing that odour management is a complex issue, the OMWG/OMT decided to divide the work into seven specific topics and objectives. The seven different mechanisms for management of odours in Alberta are broken down to the following:

- Complaints
- Odour Assessment
- Health
- Prevention/Mitigation
- Enforcement/Role of Regulation
- Education/Communication/Awareness
- Continuous Improvement

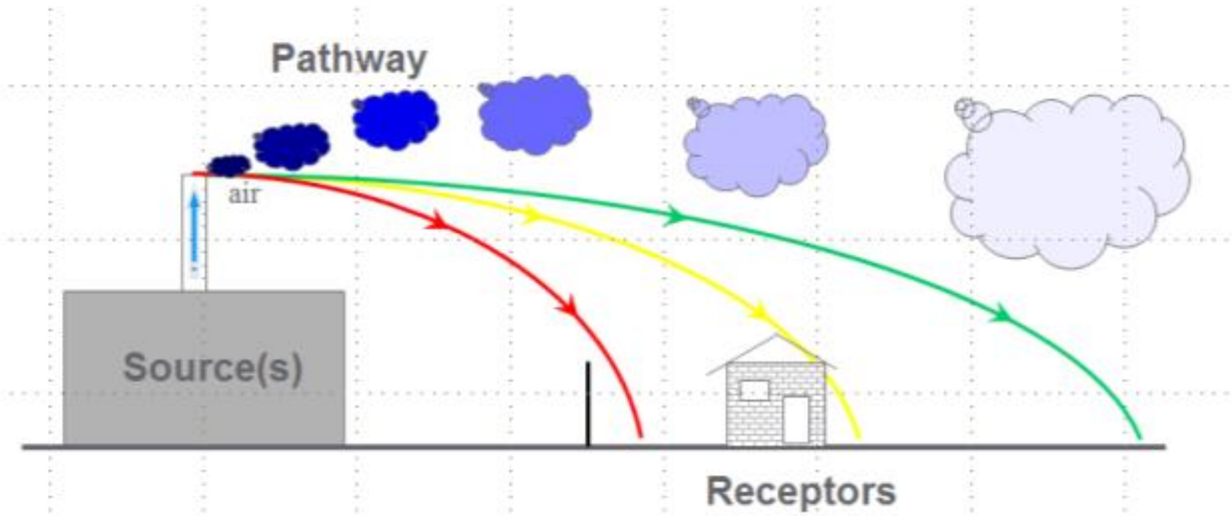
This study is in support of the Prevention and Mitigation Task Group (PMTG), which is responsible for reviewing and identifying odour prevention and mitigation tools that may have application in an Alberta context. The PMTG's objectives are to provide a suite of tools that can be applied to help prevent and mitigate odour issues from arising. Work is ongoing within other topic areas under supervision of their respective Task Groups.

Although it is not well understood exactly how the human nose differentiates odours, the human nose can detect more than 1 trillion different odours, using 400 types of scent receptors (Bushdid et al., 2014). The term odour is typically used to describe the human olfactory response to a mixture of individual components or odorants. Several parameters have been developed to characterize an odour.

- Intensity
- Odour Concentration
- Hedonic Tone
- Character

Odours are one of the most common air pollution complaints in Alberta (CASA, 2013).

Prevention and mitigation can be described as a suite of tools used to prevent or lower odorant emissions or reduce the occurrence of adverse odour effects. Prevention refers to actions or solutions that avert the creation of odours, such as material substitution. Mitigation techniques are more commonly used and target odours after they are generated. To effectively study and manage odours, an understanding of how odours are created, transported and affect humans is required. One common model used to study odours is the Source-Pathway-Receptor (SPR) conceptual model, which generally traces how substances move from an origin to a final destination. This model can apply to various materials and different media and has been used in environmental studies such as impact, health and environmental assessments.

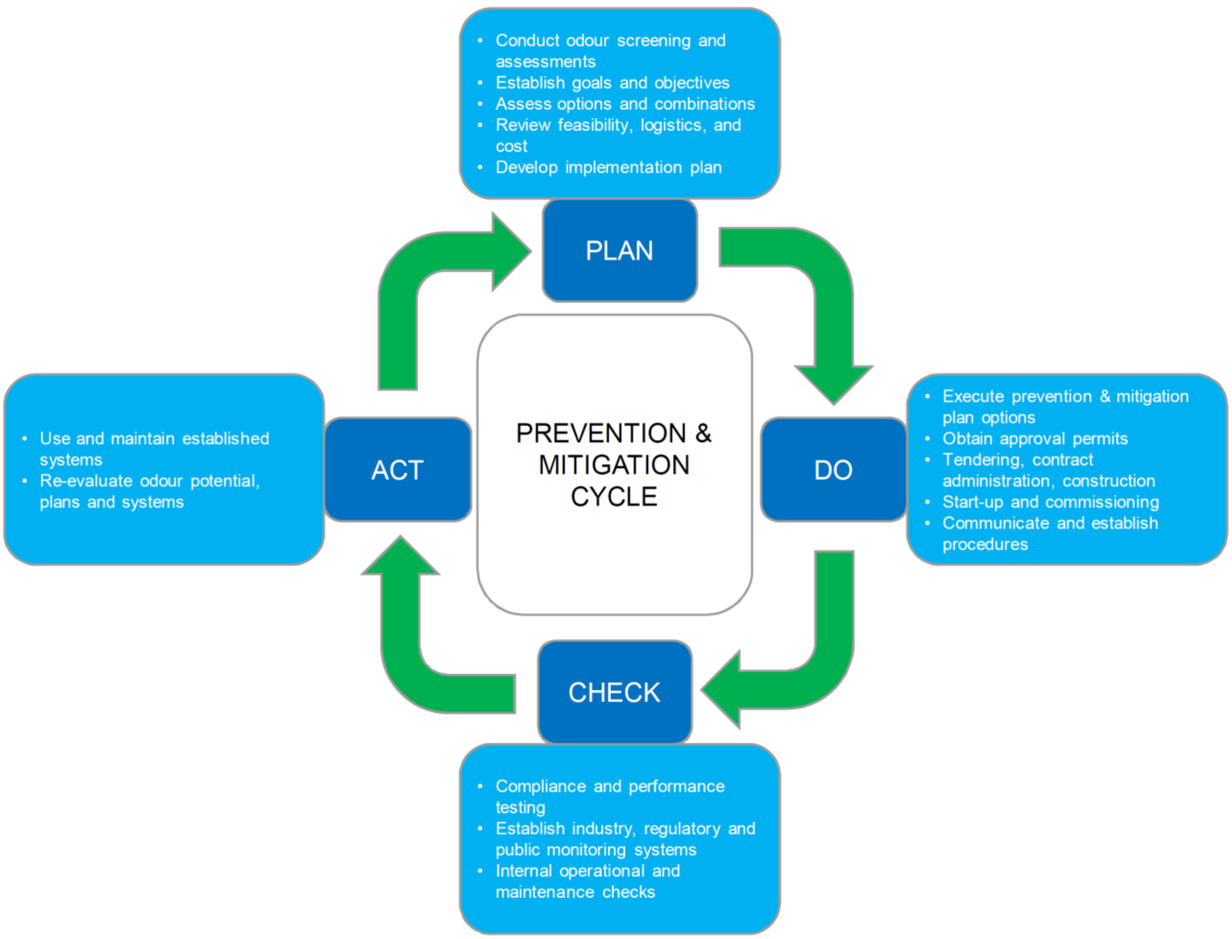


The nature of the source determines and defines how the odour is released into the environment. The odorants will travel through an air pathway, carried by wind that may pass by a fence, trees and or other objects. Finally, individuals at places where people dwell, work, learn, meet, etc., become the receptor which may or may not be adversely affected by the odorants. All three components of the model must be linked for a potential odour exposure or adverse effect to occur (DEFRA, 2007). Prevention techniques block the linkages in the model, while mitigation options reduce the severity of the adverse effect.

The Plan, Do, Check and Act model is a basic management principle, which allows for the good management and improvement of products and systems. The concept is based on the scientific method and the origin of the model is from Dr. W. Edwards Deming's lecture in Japan in 1950 (Moen R. & Norman C., 2014). It provides a framework for improvement and its cyclic nature can be self-regulating (IAQM, 2014). The PDCA model can be adopted for environmental management systems related to air quality, specifically odour prevention and mitigation. Planning documents, such as prevention and mitigation plans (PMP), should be 'living' documents that are constantly evaluated and adjusted as needed (Bull et al., 2014; DEFRA, 2006). Generally, the four phases include the following:

- Plan – includes initial discovery, screening and assessment of the odour potential of the site or facility and then establishing appropriate goals and objectives. Review of possible options, scenarios and their probability to reduce adverse effects will lead to the adoption of a plan to move forward.

- Do – involves implementing the adopted plan and installing or establishing the prevention and mitigation tools and monitoring requirements.
- Check – during implementation, ensure systems are commissioned according to requirements. Establish and use the monitoring systems and internal checks to evaluate the systems.
- Act – maintain and re-evaluate the odour potential, plans and systems. Act and improve as needed.



Tools for odour prevention and mitigation must be established with goal and objectives. The suite of tools developed in this report has been divided into general categories and summarized below. Tools can target specific parts of the source-pathway-receptor model or implemented at several locations. Many of the tools target the source of odours and can work better for different types of sources (point, line, area, volume and multi sources).

Land Use and Planning Development is a pathway tool, which generally works by setting the pathway distance or buffer zone between potential odour sources and sensitive receptors. This tool is mainly preventative and applies to all types of sources. Effective use of land use and development planning tools requires the participation and active engagement of multiple stakeholders who often have conflicting goals. Establishing planning protocols and conditions to the individual nature of the odour at a site or facility is complex and requires skill (DEFRA, 2010).

Site Management is a key consideration that can prevent and mitigate odour sources from a potential and existing facility (Anderson *et al.*, 2003). Some of the major considerations for overall site management are: existing sites, modified or proposed sites, the nature of odorant, and regulatory regime.

Raw Materials, Formulation, Process & Operational Modifications are prevention techniques with the objective of stopping or reducing the creation of odorants. They can apply equally to all types of processes and source types. Simple operational modifications, such as improved housekeeping and minimizing leaks can result in good management improvements for area, volume and line sources. Knowledge and review of the facility process flows and operations is required to identify possible opportunities while minimizing impacts to facility production.

Management Planning Groups and Guides are considered a prevention tool that can be used at any type of source. This tool refers to the organization and benefits of common interest groups and development of best management practices. Management planning groups can take various forms, ranging from regulatory committees, industry groups, non-governmental organizations and community based groups. At the same time, it is common to have these management groups and bodies publish guides and documentation on process, air emissions, permitting requirements, innovation in technology and regulation changes.

Establishing Community and Neighbourhood Relations are classified as a prevention and mitigation tool used at the receptor to adjust the odour sensitivity and tolerance of the community. Attempts to solve odour nuisance issues often over-emphasize technical solutions. One underestimated aspect of odour management is the public opinion of the facility within the local community. A negative outlook from the surrounding neighbours may diminish any benefits obtained from using prevention and mitigation tools. By engaging the community in two-way dialogue, cooperation and trust is fostered. An actively engaged and informed community may lead to more realistic expectations regarding odours (Longhurst *et al.*, 2004). The community itself can also become a valuable source of qualitative data, providing valuable data to be used by other prevention and mitigation tools (Anderson *et al.*, 2003).

Real-time Downwind Monitoring is a prevention and mitigation tool, if the monitored parameters are representative of the odour, frequently monitored (real-time), and if appropriate action levels are established. ‘Real-time’ refers to continuous and near instant reporting of monitoring results. With near instantaneous knowledge of odorants, alerts can be provided and corrective actions can be quickly taken to reduce the potential for the odour effect to become more significant. Corrective actions can be built into operating procedures and further automated to interact with the facility processes

Atmospheric Dispersion Optimization and Pathway Buffering will affect odour when travelling through a pathway before reaching a receptor. Optimizing discharge parameters is a mitigation technique used at the source that will affect the pathway while the odour will disperse and dilute. Improved dispersion measures are most often implemented to reduce impacts of wind induced turbulence caused by buildings and structures in the vicinity of the odorous discharge. Shelterbelts and artificial windbreaks are environmental barriers or pathway buffers that modify the pathway and change the amount of dispersion and dilution as the air moves. Trees and shrubs contained within multiple rows with varying heights provide dispersion and dilution as well as erosion & snow protection, wildlife habitat, while reducing wind related energy losses and enhancing landscapes.

Engineering Controls are put in place at the source of the SPR model in order to mitigate odour emissions before they are released to the atmosphere or travel towards receptors. Since there are many odorous substances, a variety of different types of engineering controls are available which use physical, chemical and biological principles to mitigate odours. Engineering source controls are sometimes referred to as ‘end of pipe’ or ‘back end’ solutions which signify their implementation at the end of the process. Engineering controls are divided into five broad categories and include (but not limited to): absorption, adsorption, biological, thermal and condensation systems.

Masking and Neutralizing Agents are sprayed, mixed and applied to odorous liquids, surfaces or gases to mitigate adverse odour effects. Masking and neutralizing agents act in the form of a mitigation tool, or can be used for the prevention of odour releases at the source. Agents that are applied directly to the odorous substance can mask, inhibit and prevent odour releases from being created or leaving the source. Surface treatments are mainly used in livestock facilities, bio-waste facilities and compositing sites where the sources have large surface areas and agents can be applied with ease (Jacobs *et al.*, 2007). When applied to the odorous gases, agents act as mitigation tools to reduce the odour impact.

Receptor Based Tools are typically used for multi-sources and requires the cooperation of various parties to properly implement. Receptor tools can be used reactively as the “last chance” to resolve odour issues or reactively by progressive planning groups. Some receptor tools include, restricting the receptor land uses, warning signage, agreement clauses and receptor mitigation. There is limited research and case studies on the use of these tools and even less information about their effectiveness.

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MEMBER OF THE PINCHIN GROUP

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1.0 INTRODUCTION

1.1 Clean Air Strategic Alliance

The Clean Air Strategic Alliance (CASA) was established in March 1994 with the vision to ensure that the air in Alberta will have no adverse odour, taste or visual impact and have no measurable short- or long-term adverse effect on people, animals or the environment (CASA, 2014a). Using a collaborative consensus process, CASA is a multi-stakeholder group comprised of industry, government and non-government organization representatives. Part of the defined mandate is to focus on strategic air quality planning and prioritizing air quality concerns. In that respect, the CASA team have worked on diverse projects such as animal health, climate change, electricity frameworks and vehicle emissions.

Identifying odour as a new priority, the Odour Management Working Group (OMWG) was formed in January 2013 to establish a new multi-stakeholder working group that would engage focused discussion at advancing odour management in Alberta. After developing the Project Charter the OMWG was re-formed into the Odour Management Team (OMT). Realizing that odour management is a complex issue, the OMWG/OMT decided to divide the work into seven specific topics and objectives. The seven different mechanisms for management of odours in Alberta are broken down to the following:

1. Complaints
2. Odour Assessment
3. Health
4. Prevention/Mitigation
5. Enforcement/Role of Regulation
6. Education/Communication/Awareness
7. Continuous Improvement

Each topic is championed by a Task Group responsible for scoping and providing various deliverables dealing with aspects of odour management in Alberta. Using the deliverables from the Task Group, the ultimate goal of the OMT is to develop a good practice guide for assessing and managing odour in Alberta.

1.2 Purpose and Scope of Study

This study is in support of the Prevention and Mitigation Task Group (PMTG), which is responsible for reviewing and identifying odour prevention and mitigation tools that may have application in an Alberta context. The PMTG's objectives are to provide a suite of tools that can be applied at the source, the pathway and the receptor to help prevent and mitigate odour issues from arising. This study will support the objectives by

- Outlining the role of prevention and mitigation within odour management
- Conducting a cross-jurisdictional review to identify and inventory best practices for preventing and mitigating odour
- Reviewing best practices for managing odour at the interface between odorous activities and receptors
- Analyzing best practices to determine their applicability to Alberta
- Providing user friendly guides, summary charts and graphics

Work is ongoing within other topic areas under supervision of their respective Task Groups. Several other topics are discussed and referenced in this study to help support the development of prevention and mitigation tools. For further details the reader is encouraged to review the other reports.

2.0 BACKGROUND

2.1 Odour

Although it is not well understood exactly how the human nose differentiates odours, the human nose can detect more than 1 trillion different odours, using 400 types of scent receptors (Bushdid *et al*., 2014). The term odour is typically used to describe a mixture of individual components or odorants and the resulting odour from combining different odorants is not straightforward. Odours can cause a positive or negative response. Different people will describe and rate the same odours differently, making the study of odours somewhat subjective. Initially, a family living beside a bakery may enjoy waking up every morning to the smell of freshly baked goods. After ten years, the family may consider moving to a different location as a result of the ongoing bakery odour.

Due to the subjective nature of odours, several parameters have been developed to characterize an odour. A good understanding of the nature of the odorant is required to first assess potential odour sources, determine the probability of adverse effects and develop suitable prevention and mitigation options. The nature of odorants can be characterized by the following parameters.

- **Intensity** describes the perceived qualitative strength and is rated on a ranking system by an odour assessor. Typically more offensive odours (rotting food, wastes) will have a higher response. The common ranking system used in North America has the following ranking:
  0-No odour → 1-Slight Odour → 2-Moderate Odour → 3-Strong Odour → 4-Extreme Odour

- **Odour concentration** is a quantitative measure indicating intensity of the odour. It determines the amount of dilution air needed so that the odour is just detected or recognized by an odour assessor. If a sample of odorous air requires ten additional parts of non-odorous air to be barely detected, that sample would have an odour concentration of 10 odour units.
- **Hedonic Tone** is another ranking system which describes or rates the pleasantness or unpleasantness of the odour. An assessor can describe the odour as 'most pleasant' or 'least pleasant'. It is generally rated on a scale of -5 to +5 with '-' being unpleasant and '+' being pleasant.
- **Character** is described by relating the odour to eight general categories and providing a scale on how intensely the odour matches the general category. The different categories are sometimes referred to as an odour wheel and include: floral, fruity, vegetable, earthy, offensive, fishy, chemical and medicinal.

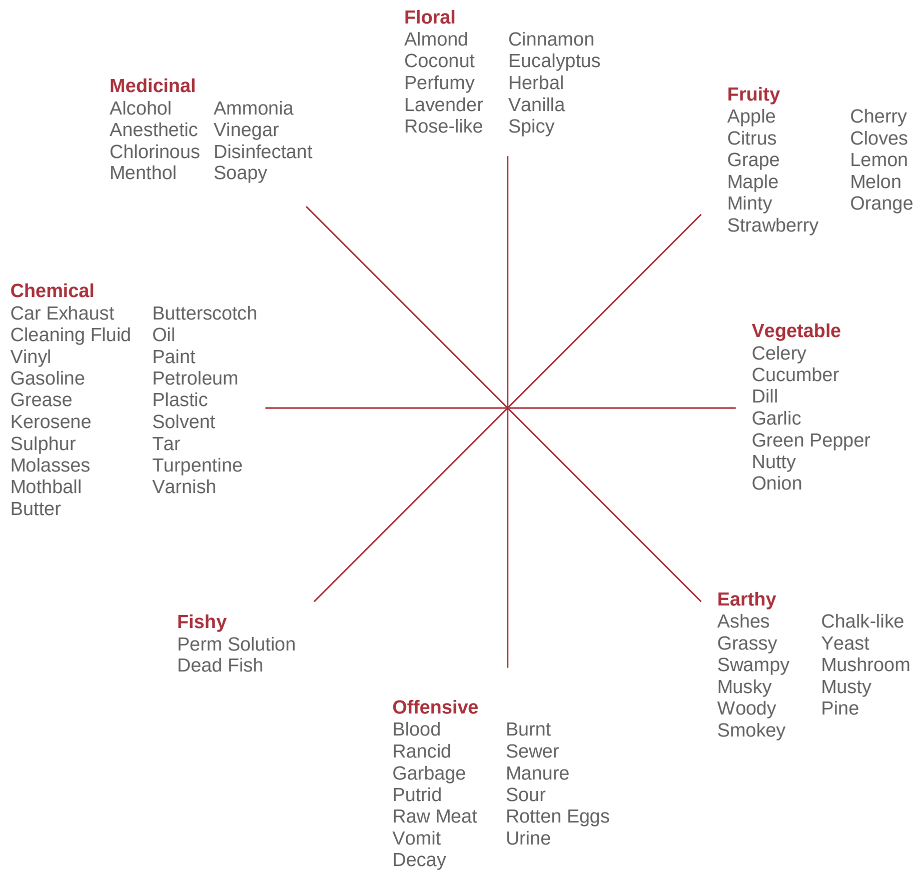


Figure 1: Odour Character Wheel
(Graphic courtesy of St. Croix Sensory Inc., St. Croix, MN, USA)

Odours are one of the most common air pollution complaints in Alberta (CASA, 2013). An adverse odour effect is defined as "impairment of or damage to the environment, human health or safety or property" and is a prohibited emission in Alberta (RSA, 2000a). The bakery described earlier, may be in a situation where they are releasing a prohibited emission or odour due to the adverse effect on the family. This type of adverse effect is related to 'nuisance' which describes a loss of enjoyment of property or life. Other odorants can also have direct and indirect effects on health. What could have been done to avoid the situation of the family near the bakery? There are many factors to consider when managing odours.

2.2 Mechanisms for Managing Odours

Although this report focuses on managing odours by using prevention and mitigation tools, several other mechanisms are closely related and will be discussed. Mechanisms can be developed and used in different ways based on the user and requires the collaboration of government, industry, public and other stakeholders. Two of the more important mechanisms relating to prevention and mitigation are odour assessment and the role of enforcement and regulation.

One of the first questions when managing odours is when does an adverse effect occur and how is it assessed or measured? An adverse effect can occur if impairment of the environment occurs (RSA, 2000a; Bull *et al*. 2014). This impairment can be classified as nuisance determined by annoyance and complaints or classified as a health risk (both classifications are being studied by a CASA working group). The human reaction to odours can vary depending on each individual. Science, technology and methods have been developed to quantify and assess odours, and the Odour Assessment Task Group (OATG) conducted a review of odour assessment tools and practices. On the health side, the CASA Health Task Group has developed a background document summarizing current knowledge about the relationship between odour and human health.

Enforcement and the Role of Regulation are directly linked to both assessment and prevention/mitigation topics. Regulators and governments can have a large role in the management of odours. They can initially set targets or goals relating to 'odour limits' and when adverse effects occur, inspectors can investigate and confirm potential emitters. Government approvals and orders can stipulate odour emitters to provide prevention and mitigation options, specify technology requirements and implement odour management plans. A study dealing with enforcement and regulation is being completed by the Enforcement and Role of Regulation Task Group (ERoRTG).

2.2.1 Prevention and Mitigation

Prevention and mitigation can be described as a suite of tools used to prevent or lower odorant emissions or reduce adverse odour effects. Prevention refers to actions or solutions that avert the creation of odours, such as material substitution. Techniques that prevent odour creation are typically the most effective and least costly, but require potential changes in the raw materials, processes, operations or final product. Mitigation techniques are more commonly used and target odours after they are generated. An example is an end of pipe (e.g., exhaust vent) solution that removes or destroys odorants from emitted gases.

Selecting prevention and mitigation tools can be developed into a strategy that outlines alternatives, scenarios and a preferred path forward. Elements of prevention and mitigation strategy development are outlined in Section 3.0 and the specific tools are described in Section 4.0.

2.3 Source-Pathway-Receptor Conceptual Model

To effectively study and manage odours, an understanding of how odours are created, transported and impact living organisms is required. One common model used to study odours is the Source-Pathway-Receptor (SPR) conceptual model, which generally traces how substances move from an origin to a final destination. This model can apply to various materials and different media and has been used in environmental studies such as impact, health and environmental assessments. This model can play a large role in odour assessment, especially when determining if an adverse effect has occurred or may occur.

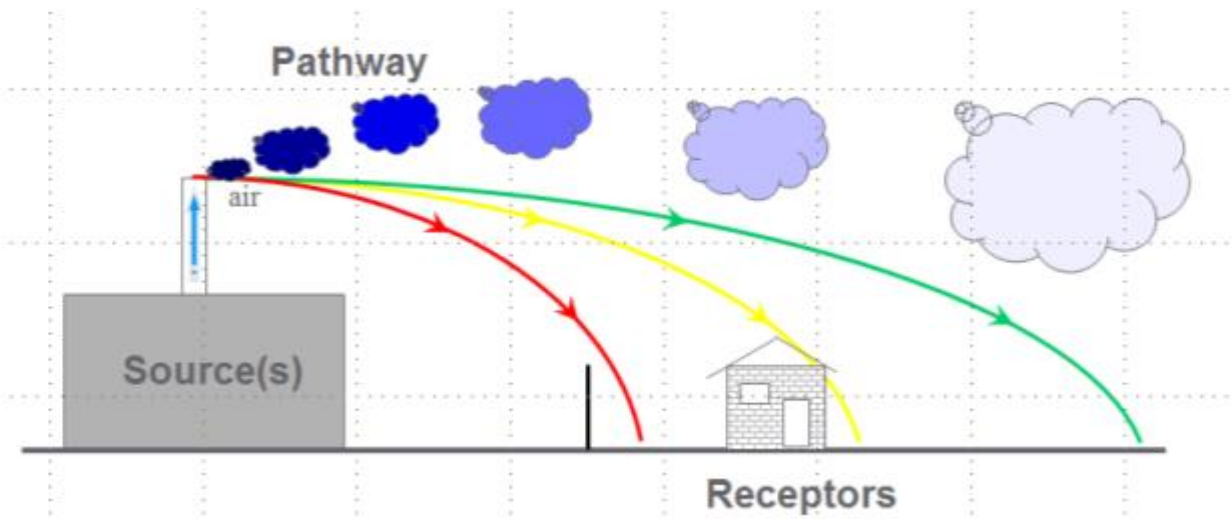


Figure 2: Source-Pathway-Receptor Conceptual Model

Using the previous bakery example, the bakery oven or exhaust vents are the *sources*. The nature of the source determines how the odour is released into the environment. The odorants will travel through an air *pathway*, carried by wind that may pass by a fence, trees or other objects. Finally, individuals at places where people dwell, work, learn, meet, etc., become the *receptor* which may or may not be adversely affected by the bakery odorants. All three components of the model must be linked for a potential odour exposure or adverse effect to occur (DEFRA, 2007). Prevention techniques block the linkages in the model, while mitigation options reduce the severity of the components. In this study, the SPR model will be used to classify the different types of prevention and mitigation tools used in Alberta (See Section 4.0 for specific tools).

2.3.1 Source Types

The nature of the odour sources influences how they are formed, transferred, released into, and behave in the environment. Facilities should have a good understanding of their odour sources and how different mitigation and prevention tools can affect source types. In Alberta, source types can be generally grouped into five (5) different categories:

- **Point sources** are single entity, easily identifiable sources that have well defined exhaust parameters (velocity, temperature, odour rate). They can be elevated or located at ground level. A stack is the most common and familiar type of point source.
- **Area sources** are two dimensional sources without a physical height. The surface dimensions are known, however the odour emission is diffusive and may not be uniform or well understood. A sewage or tailings lagoon is an example of an area source.
- **Volume sources** are similar to area sources, but they have a known height dimension. Odour emanating from a volume source can be diffusive, non-uniform and hard to determine. A building with general windows or openings, housing an odorous process, can be a volume source. An industrial complex such as a refinery or chemical processing plant can be considered and assessed as a volume source.
- **Line sources** are long and narrow sources. This type of source is not common; however vehicle exhaust from roadways can be classified as a line source.
- **Multi-sources** are a collection of different sources within a group, facility or study area. A complex facility or collection of industries with many individual sources can be comprised of roadways, tanks, piping and stacks. This source relates to places where there are multiple sources operating and the cumulative effect needs to be considered.

Additional information on source types and the how odour is assessed at the source can be found in the OATG report, “Review of Odour Assessment Tools and Practices for Alberta (CASA, 2014b). Most facilities will have a combination of different source types. The use of a multi-source model may prove beneficial when managing odours on a larger scale. Generating an inventory of odorous sources is a key component of odour assessment and management. Source types and their applicable prevention and mitigation tools will be discussed in Section 4.0.

2.3.2 Pathways

Pathways are another consideration for odour planning since they are typically unique and outlined on a case-by-case basis. They can be generally characterized by weather conditions, terrain and the surrounding landscapes. Weather conditions include the wind direction, speed and atmospheric stability which can predict the movement and behaviour of odorants. Since weather is seasonal and constantly changing, large climate data sets are used to ensure most likely and worst case outcomes are assessed. The surrounding terrain and landscapes interact with the weather conditions by providing elevated, depressed, smooth or obstructed surfaces for odorants to travel through, over or around. Landscapes can be large uniform areas or a mix and combination of several types of terrain. For odour assessments, pathways can be qualitatively estimated and quantitatively modeled. Some of the specific Alberta weather conditions and landscapes are described below.

- **Prevailing winds** that transport odours downstream. Northwest and west winds are the predominant winds in Alberta during the summer months. In most locations all wind directions are possible, but will occur less frequently than the predominant direction.
- **Grasslands** and **parklands** (23.5% of total land area), typically flat and have low level and/or sparse vegetation. This landform type leads to good, unimpeded transport of odorants.
- **Boreal forest** (57.5% of total land area), consists of light and dense sections of forested areas, grasslands, parklands and hilly regions. Depending on the density and height of the forest coverage, transport of odorants is reduced in this type of landform.
- **Foothills** (10% of total land area), comprising of continuous hilly regions of low to moderate heights. Hilly areas can shelter and divert as well as funnel or concentrate odorants. Vegetation density and height can reduce odour movement.
- **Mountainous** areas (7.5% of total land area), similar to foothill areas, but can offer complete shelter or diversion of odorants. Concentration and funneling of odorants can occur from elevated sources onto lower receptors. Pockets of vegetation can reduce odour movement.
- **Canadian Shield** (1.5% of total land area) areas can be flat with rolling hills and slopes, numerous water bodies and vegetation. Odour movement is enhanced when compared to grasslands and parklands due to smoother surfaces which can lack consistent low level vegetation. (Natural Regions Committee, 2006)

For new facilities, it can be beneficial to locate operations to avoid a condition where the prevailing winds or landscapes can impact a nearby community. As the physical distance increases in a pathway (to a receptor), there is more opportunity for odours to disperse and dilute. Increasing the pathway distance by placing barriers or increasing the distance is a technique that can be used to mitigate odour effects (See Section 4.1 & 4.7.2).

2.3.3 Receptors

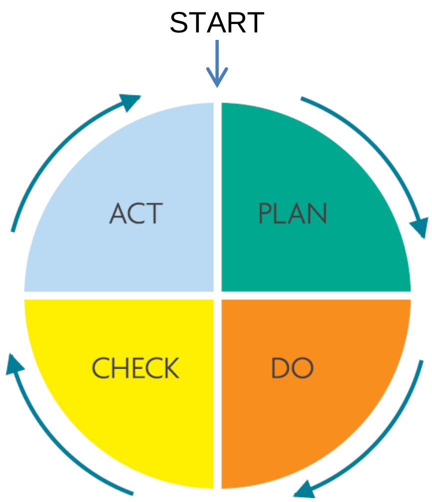
Based on the definition of adverse odour effect, individuals at places where people dwell, work, learn, meet, etc. can be classified as receptors. For odour management, humans are typically the only receptors of interest. Certain types of land uses can contain higher priority receptors such as those living in residential areas. Receptors are an important consideration in planning because individual receptors will have different responses to similar odorants. The receptor's sensitivity can drastically alter the perception of an odour. Chronic exposure to an odour may desensitize a receptor's response; however in some instances the receptor may become less tolerant to the exposure. Individual circumstances (i.e., medical conditions, allergies, etc.) can result in increased or hyper sensitivity in receptors. The human psychological response is often unpredictable. For example, an odour from a perceived essential or valuable operation (regular seasonal fertilizer spreading in an agricultural area) maybe more tolerated, where as other operations may elicit a Not In My Backyard (NIMBY) effect. Receptors and odour effects are sometimes described in terms of frequency, intensity, duration, odour offensiveness, and location (FIDOL).

- **F**requency – how often is a receptor exposed to odour
- **I**ntensity – the receptor's perception on the strength of the odour
- **D**uration – the duration of exposure
- **O**ffensiveness or **O**dour Unpleasantness – the character of the odour using the hedonic tone scale (from Section 4.2.2)
- **L**ocation – where the exposed occurs, related to the land use and intended activities (Bull et al., 2014)

Receptors are the only true measure or indication of adverse odour effect and can provide invaluable information. The type of receptors and their proximity to a facility will influence the odour assessment and levels of prevention and mitigation tools employed.

2.4 Plan, Do, Check, Act Model for Prevention and Mitigation

The Plan Do Check Act (PDCA) model is a basic management principle, which allows for the good management and improvement of products and systems. The concept is based on the scientific method and the origin of the model is from Dr. W. Edwards Deming's lecture in Japan in 1950 (Moen R. & Norman C., 2014). It has gone through revisions over the years, but the underlying principle is that the model is applicable to all types of organizations, groups and levels. It provides a framework for improvement and its cyclic nature can be self-regulating (IAQM, 2014). The four main phases of the cycle are shown on the following page.



Plan – establish objectives, needs and processes

Do – implement the plan, execute the process

Check – study the results and compare, review for gaps

Act – determine differences and act to correct or change

Figure 3: Plan, Do, Check, and Act Model (IAQM: 2014)

The PDCA can be adopted for environmental management systems related to air quality and odour. The International Organization for Standardization has a series of ISO 14000 standards on environmental management that uses the principles of PDCA. The Environmental Agency in the United Kingdom, suggests using the PDCA model for environmental management systems in their document, "How to Comply with Your Environmental Permit" (Environment Agency, 2011). Another organization, the Institute of Air Quality Management (IAQM) states that odour management planning should follow basic management system principles, such as the PDCA model (Bull et al., 2014). Section 4.0 will outline how the model will be adopted for prevention and mitigation planning.

3.0 PREVENTION AND MITIGATION CYCLE

Odour prevention and mitigation planning is a systematic and cyclical approach towards minimizing adverse odour effects from sites and facilities. Planning documents, such as prevention and mitigation plans (PMP), should be 'living' documents that are constantly evaluated and adjusted as needed (Bull *et al.*, 2014; DEFRA, 2006). By being continuously improved, the plan can be incorporated into more formalized environmental and management systems and protocols. To assist in the development and visualization of prevention and mitigation planning, the Plan, Do, Check and Act model, described in Section 2.4, can be adopted as outlined in Figure 4.

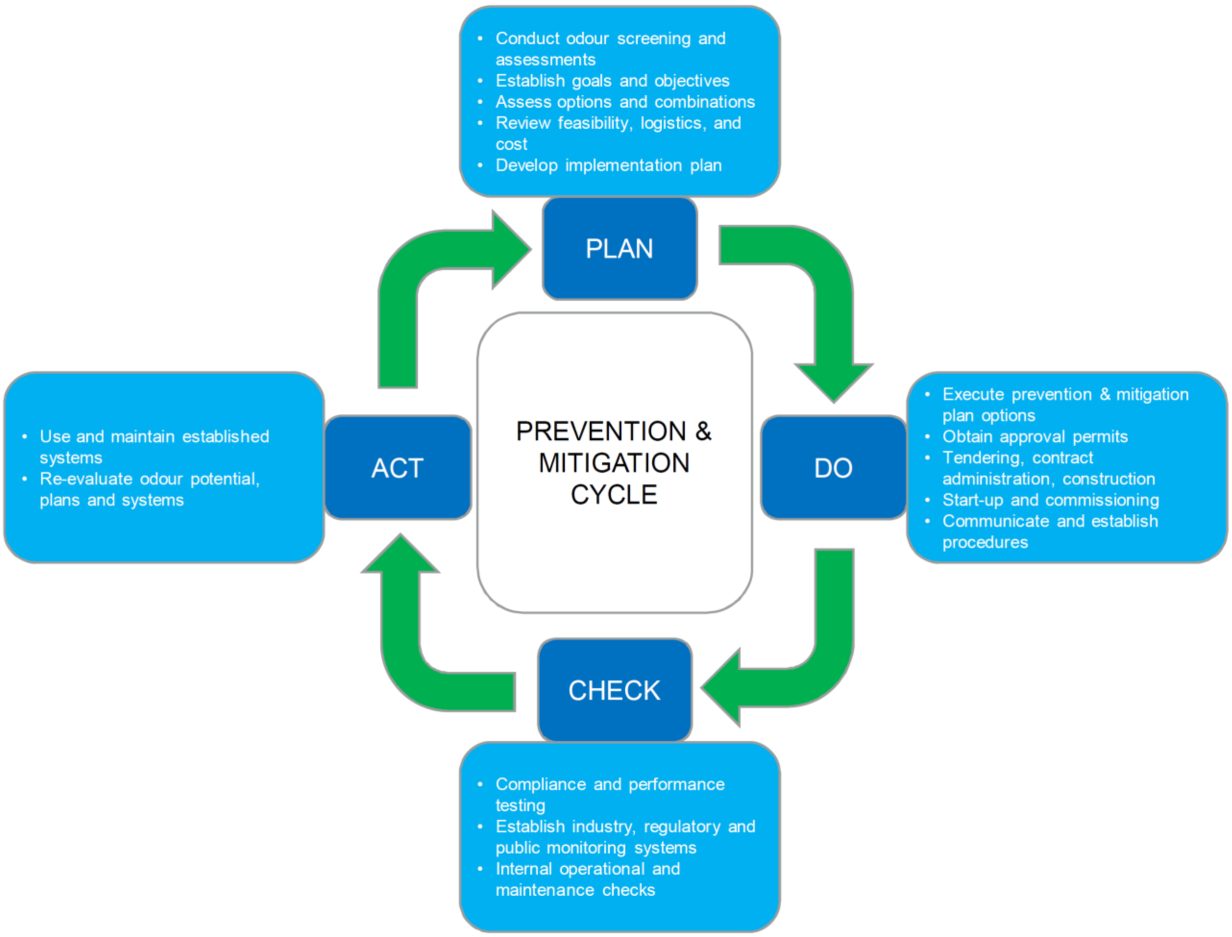


Figure 4: Odour Prevention & Mitigation - Plan, Do, Check, Act

Formalized guidance on odour management and prevention/mitigation planning have indicated different phases and requirements be included in the plan (Bull *et al*., 2014; Anderson *et al.* 2003; Stoaling, 2013, 2013; DEFRA, 2010; ARD, 2011) Generally, the four phases include the following:

- Plan – includes initial discovery, screening and assessment of the odour potential of the site or facility and then establishing appropriate goals and objectives. Review of possible options, scenarios and their probability to reduce adverse effects will lead to the adoption of a plan to move forward.
- Do – involves implementing the adopted plan and installing or establishing the prevention and mitigation tools and monitoring requirements.
- Check – during implementation, ensure systems are commissioned according to requirements. Establish and use the monitoring systems and internal checks to evaluate the systems.

- Act – maintain and re-evaluate the odour potential, plans and systems. Act and improve as needed.

As part of the process, several key considerations must be addressed by the facility and those reviewing the facility's approval. Chart A1, Appendix A provides a guideline for facility owners, planners and regulators to consider when dealing with odour producing operations. The PDCA model is further detailed in Chart A2, which provides a flow diagram of the individual steps. The detailed flow diagram has categorized three main stages:

- Screening and Assessment - Plan (Section 4.1)
- Prevention and Mitigation – Plan & Do (Section 4.2)
- Monitoring and Evaluation – Check & Act (Section 4.3)

The individual components are described in sections 3.1 to 3.4 below, and should be read in conjunction with the detailed flow chart. Information provided in this section is intended as guidance material and information and should be tailored to suit the specific sites and situations. Information and expertise from published odour management guides have been reviewed and used in the development of this guidance material. Some existing odour management planning guides and example documents include:

- Odour Management Plan for Alberta Livestock Producers (ARD, 2011)
- Managing Air Emissions from Confined Feeding Operation in Alberta (CASA, 2008)
- Hydrocarbon Odour Management Protocol for Upstream Oil and Gas Point Source Venting and Fugitive Emissions (AER, 2014a)
- Odour Guidance for Local Authorities (DEFRA, 2010)
- Guidance on the Assessment of Odour for Planning (Bull *et al.*, 2014)
- Code of Practice on Odour Nuisance from Sewage Treatment Works (DEFRA, 2006)
- An Industry Guide for the Prevention and Control of Odours at Biowaste Processing Facilities (Jacobs *et al.*, 2007)
- Good Practice Guide for Assessing and Managing Odour in New Zealand (Anderson *et al.*, 2003)
- Technical framework: assessment and management of odour from stationary sources in New South Wales (DEC, 2006)

3.1 Screening and Assessment (Plan)

The initial start point in the PMP flow chart frames the question, "does the facility have the potential for odours?" A facility can be proactive and initiate the planning process; however it is often started by an external trigger such as an environmental order or a neighbour complaint. This screening step is a qualitative judgement of the facility's odour potential based on the existing facility, industry and expert knowledge, and external sources. Operators are likely to be aware of their odour potential and best suited to screen the facility along with industry experts.

For facilities that have the 'likely' potential for odours, further definition and scoping is required to determine the extent of odour potential. This is typically done within a formalized odour assessment task that may include:

- Characterizing and sampling the odours and sources
- Ranking and analysing the odour sources and contributions
- Assessing adverse odour effects using atmospheric air dispersion models
- Analysing and ranking the odour source contributions to adverse effects
- Determining the intensity and frequency of adverse effects

Conclusions from odour screening and assessment are put together using a 'weight of evidence' approach (Bull *et al.*, 2014). 'Weight of evidence' incorporates the results of multiple assessment tools and information sources and differs from the more traditional air quality assessments which are mainly based on a single threshold value. The outcomes of the odour assessment will determine if the probability for adverse odour effect is likely or not. The information developed will help establish measureable goals and targets for the next stage, prevention and mitigation. Additional resources in conducting an odour assessment can be found in the references: Bull *et. al*., 2014; CASA, 2014b; DEFRA, 2006; DEFRA, 2010; Jacobs, 2007; Anderson *et al.* 2003.

If the facility determines that the outcome is 'not likely' for either the potential for odours or the probability for adverse effects, a formalized prevention and mitigation stage is not recommended. Facilities would be encouraged to utilize some prevention and mitigation tools to establish communications, a complaints protocol and to conduct periodic operational reviews. This would be seen as a gesture of being a 'good neighbour' and maintaining a proactive strategy.

Few facilities can be screened as to generating no odours. If that is the case for the facility, a formal odour assessment and prevention and mitigation review is not necessary. The facility should use internal and external monitoring and evaluation systems to ensure ongoing operation and development will continue to have no potential for odour.

3.2 Prevention & Mitigation Strategy Development (Plan)

The aim of this stage is to develop a prevention/mitigation strategy towards reducing or eliminating the probability for adverse odour effect. The baseline degree of likelihood and probability were determined in the previous stage Screening and Assessment.

Based on the odour assessment, regulatory landscape and other external and internal policies, a facility should first establish goals and targets. Does the facility want to completely eliminate or reduce potential for adverse effect, or reduce them and to what degree? The next step is to review and assess all options for reducing adverse effects using the inventory of tools described later in the study (Section 4.0) and generally categorized below:

- Land Use
- Site Assessment and Development Plan
- Management Planning Groups and Guides
- Establishing Community and Neighbourhood Relations
- Real-time Downwind Monitoring
- Atmospheric Dispersion Optimization and Pathway Buffering
- Engineering Controls
- Masking and Neutralizing Agents
- Receptor Based Tools

Development of the tools should be generally reviewed in the order shown above as some of the initial tools can redefine and provide support to the latter tools. For example land use requirements may prohibit the construction of a facility within a certain area. A best management guide may outline steps and protocols to minimize odours, reducing the development effort. Another example is establishing good community relations may lessen the need for engineering controls. There are several synergistic effects from the list of tools.

With a variety of prevention and mitigation options developed, the next step is to assess feasibility and logistics. Facilities should review and select tools and options from the standpoint of being practical (operation and maintenance), available (new or established technology) and reasonable to implement (technically and economically feasible). What are others doing and what best available technologies (BAT) are available? Which tools are better suited for the facility and location? Expert information may already be available from management planning groups and guides, such as industry bodies, Alberta ESRD, Canadian Council of Ministers of the Environment (CCME). Solutions should be practical, easy to operate and maintain, and economically feasible.

The benefit or impact of implementing a tool can be difficult to assess and is usually a prediction. Certain tools are easier to assess the impact of, such as the use of process modifications, engineering controls, improved atmospheric dispersion and masking/neutralizing agents. These tools affect the quantitative characteristics of odours and, as a result, it is easier to measure outcomes. Effectiveness of other tools, such as establishing community and neighbourhood relations cannot be easily determined or assessed, and can at times have negative impacts if improperly implemented.

Most facilities will use a variety of prevention and mitigation tools and the feasibility and impact must be assessed based on the synergistic effects. As the assessment becomes more complicated, decision matrices, advanced air dispersion modeling and statistical models are sometimes used to help predict the combined effects of using multiple tools. Once the scenarios and combinations of tools are established, an economic assessment should be completed and factored into the decision making process. Preferred cost models should be employed that review both capital and operating costs in relation to effectiveness. However, it may be difficult to cost certain tools such as land use planning and establishing community relations.

3.3 Implementation Planning and Execution (Plan and Do)

The next step is to summarize all of the findings and develop an implementation plan that will achieve the goals and change the probability for adverse effects from ‘likely’ to ‘not likely’. This plan is typically detailed in a formal document, sometimes called an abatement plan or odour management plan. The entire process does not have to be completed in one cycle and at times it takes a few iterations to develop the best path forward. Planning is typically done internally by the facility and depending on the complexity and profile, third party reviews by industry experts and/or regulators may be beneficial to obtain feedback.

Implementation planning can also include: interim plans to address shorter term measures for reducing odour impact while a larger program is implemented; or contingency plans to address measures to be undertaken in event elements of the implementation fail to meet their intended objectives.

Executing the implementation plan is part of the ‘Do’ phase of the PDCA model. This phase generally includes obtaining approvals and permits, detailed design, contract tendering, retaining expertise, contract administration, construction, and commissioning.

Depending on the type and scope of development, approvals and permits are required by ESRD, municipal authorities and/or specialized industry bodies (AER, NRCB etc.). This can provide another opportunity to establish neighbour and community relations through the approvals mechanisms or voluntary measures.

During detailed design and construction, it will be determined exactly how the tools will be installed and implemented. It is important to consider how operators will use and maintain equipment. Providing easier to use and access options will ensure that prevention and mitigation tools are properly used and not neglected. Other good project management practices should be used to ensure implementation is properly completed with respect to logistics, scheduling and cost control.

3.4 Monitoring and Evaluation (Check and Act)

After implementation of the prevention and mitigation tools it is important to check that systems are working and effective. Monitoring can occur during and after implementation. This step represents the Check and Act phases of the prevention and mitigation planning cycle.

Monitoring during implementation can take the form of inspections, commissioning, start-up and performance testing activities for installation of new equipment. These requirements should be considered during the development of specification and contract documents. Once implementation is complete, monitoring can take a variety of forms. They are broadly categorized into three groups; industry, regulatory and public monitoring.

1. Industry monitoring consists of the systems and procedures put into place by the facility. Some examples include:
   - Quality monitoring to ensure that materials, equipment, ancillaries, etc. are within expected criteria and tolerances related to odour generation.
   - Operations and process monitoring to determine if new systems are working as intended to reduce odorants
   - Source sampling, measurements and analysis to quantify the reduction in odorants from sources
   - Fence-line and ambient monitoring to confirm and assess off-site reduction
2. Regulatory monitoring comprises the systems and procedures based on regulatory guidance and requirements. Some examples include:
   - Site reviews and inspections from government representatives
   - Tracking of complaint history
   - Orders to implement monitoring and sharing of monitoring data
   - Ambient monitoring by regulator owned/operated stations
3. Community monitoring comprises the systems and procedures put into the community. Community feedback typically takes the form of odour surveys, diaries or complaints.

An odour monitoring plan should be developed which details the type of monitoring systems in place and how the systems are used to evaluate the implemented prevention and mitigation tools. Monitoring and improvements should consider that outcomes can be different depending on whether the facility is operating normally or under upset conditions. The monitoring plan can be formalized into an existing maintenance and environmental system to ensure that periodic updates, re-evaluations and continual improvements occur.

4.0 TOOLS FOR ODOUR PREVENTION AND MITIGATION

A list and description of odour prevention and mitigation tools is provided in this section. Each tool will be described as a prevention or mitigation tool and how it interacts with the source, pathway or receptor. Benefits and considerations of each tool will be listed along with some relevant examples. Source and pathway tools are described in Sections 4.1 to 4.9, while receptor based tools are outlined in Section 4.10. Chart A3, Appendix A provides a visual chart that places the tools into different categories according to the source, pathway and receptor model.

4.1 Land Use and Development Planning

Land use and development planning is a pathway tool that generally works by setting the pathway distance or buffer zone between potential odour sources and sensitive receptors. This tool is mainly preventative and applies to all types of sources. Land use and development planning tools requires the participation and active engagement of multiple stakeholders, who often have conflicting goals. Establishing planning protocols and conditions to the individual odour nature of a site or facility is complex and requires skill (DEFRA, 2010). This tool can fall under the following broad categories;

- Establishment of buffering zones around odour sources by regulator designation or purchase/lease of adjacent lands.
- Minimum set back distances, which allow or prevent building or expansion if distances are not met.
- New or specialized permitting requirements for prevention and mitigation at facility sites. Negotiated on a first permit basis where possible.
- New or specialized permitting requirements at receptor sites to provide confidence that new development will not be impacted by existing facilities.
- Creating discretionary powers for development officers within zoning by-laws to manage nuisance odours for new facilities.
- Participating in proposed land use amendments. Facilities with the potential for odour should be aware of encroaching development and re-zoning applications.

- Restricted and negotiated uses on source and receptor land zones (e.g. light industrial only or low density residential).

Land use zones and plans describe general areas where certain types of receptors are reasonably expected to be present or living. Official land use definitions and boundaries are typically provided by the municipalities within Alberta. The government of Alberta is currently working on developing higher level land use frameworks for seven major regions within Alberta. Typical land use zones include:

- Residential
- Commercial
- Industrial
- Agricultural
- Urban Services
- Direct Control Provision/Overlays, Protected Areas (City of Edmonton, 2014)

Receptors in land use zones that are residential typically have the highest importance when ensuring no adverse effects occur. Certain institutional land uses, such as hospitals, care facilities and schools, within the Urban Services group are also considered with high priority. These areas represent places where people spend a majority of their time, expect a high level of amenity or where they may be more vulnerable or susceptible to odour effects. These locations are often termed as ‘sensitive’ receptors or land uses (Bull *et al.*, 2014).

Using these land use zones and applicable bylaws, facilities and development planners review the feasibility of locating operations or modifying operations within the area. Odour related issues can be reviewed during the submission/review of a Development Permit, which is typically required in Alberta to approve the use of a site within the community. Some municipalities also require a ‘business license’. These municipal permits can be an effective tool for facilities to first identify their potential odorous operations and then for municipalities to manage potential nuisance odour effects. Specialized permitting requirements such as odour abatement plans, prevention and mitigation plans, could be requested from the facility as part of the permit. Development permits should also be reviewed for proposed receptor developments (residential, institutional etc.) or rezoning that may allow development in a potentially odour impacted area. Showing that the new receptor development will not be adversely impacted may be a specialized permit requirement in these cases. Municipalities with existing nuisance odour bylaws would have more justification in requesting and implementing specialized odour permitting requirements, such as the clause in the City of Edmonton’s Community Standards Bylaw, 14600 (Part II, 6[1][f]).

Development planning may also require additional provincial reviews and approvals. With respect to odours, the Alberta ESRD and NRCB (for agricultural related projects under AOPA) may also be part of the development planning phase. Although certain bylaws exist, provincial requirements and authorization may take precedence over municipal requirements. Often the municipal development permit approval may include clauses or conditions that applicable provincial approvals must be obtained. All parties will have to work together to minimize potential adverse odour effects.

Land use and development planning can become contentious as land uses and receptors become more densely situated. The principle of “first in time, first in right” is sometimes cited during these situations. This principle outlines that a long standing land user is justified in carrying on their regular activities, even if a new land user has moved into adjacent land and stated that a nuisance is being created. Adherence and approval from several Alberta legislatives pieces such as the Municipal Government Act, AOPA, ESRD and other prescribed conditions regarding setback distances may give facilities the sense of entitlement to operate. Even with this specific ‘legislative protection’ from encroaching developments the general trend in Canadian courts is that principle of “first in time, first in right” is not a valid defence with respect to tort law nuisance. No matter how long a land user has been at a site, they have no right to cause impairment or nuisance on adjacent non-owned lands (Linden *et al*. 2014). Parties affected by nuisance can leverage municipal odour bylaws, the adverse effect clause in the EPEA and finally tort nuisance case law. This discussion will receive further debate as land uses become denser in Alberta. Facilities should be aware of proposed developments around their sites, responsibilities, case laws and proactively participate in the development planning process. Some of the benefits and considerations related to land use and development planning are summarized as follows.

Benefits	Considerations
• As a prevention tool, can drastically reduce or eliminate potential for odour adverse effects • Limits the risk of conflicting land uses or changes in land use	• Multi-stake holder process with conflicting goals • Buffering zones and set back distances may not be suitable for densely developed areas • Due to the nature of odour, cases may still require other tools

Some examples of land use and development planning are provided in the next paragraphs. Since the 1970’s, Alberta’s confined feeding operations have had facility guidance and requirements based on minimal distance separation (ARD, 2014b). The latest requirements are outlined in the Agricultural Operation Practices Act (AOPA) and Regulations, Standard and Administration Regulation (RSA, 2002a). The minimal distance separation (MDS) is based on several factors which include: an odour production based on species, odour category objectives, dispersion factors based on topography, surrounding land use and climate. The MDS is based on empirical data collected throughout the decades and provides guidance to operators and the Natural Resources Conservation Board (approving body).The Capital Region board, a multi-municipality group representing several municipalities around the Edmonton area, have recognized and adopted a new land use type called buffer regions. The purpose of Regional Buffer Areas is to separate land uses based on safety and risk management, compatibility and conservation. The policy is aimed at establishing a common approach to assess and mitigate risks particularly relating to the industrial nature of the capital region, which member municipalities would adopt (Capital Region Board, 2009). The Capital Region Board has developed toolkits and guidance material for the various municipalities. Figure 5 shows the buffer zone, which include the ‘Industrial Heartland’ in the northeast area, as well as the Strathcona Industrial area in northeast Edmonton.

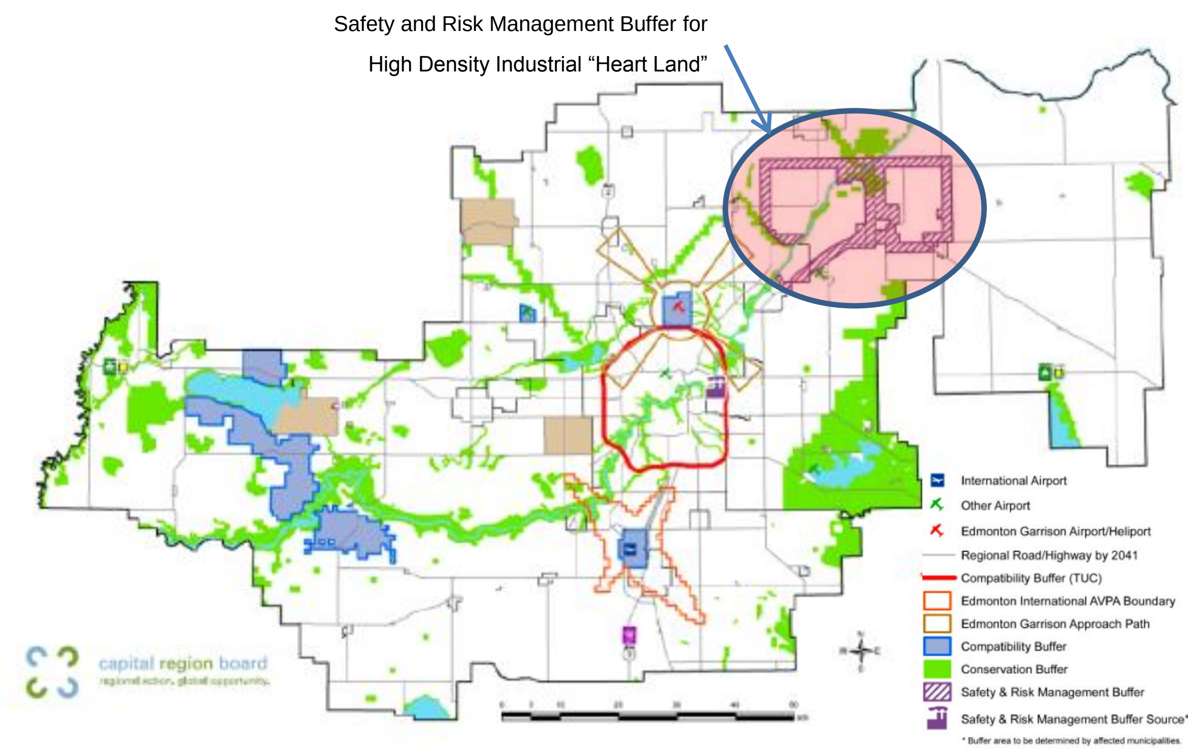


Figure 5: Buffer Land Use Regions around Edmonton (Capital Region Board, 2009)

Alberta’s Municipal Government Act, Subdivision and Development Regulation, includes provisions for minimum separation distances for wastewater treatment and landfill sites (RSA, 2002b). In other jurisdictions, organizations promoting the use of buffer or minimal set back distances include the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAF), Victoria State Australian Environmental Protection Agency, and University of Minnesota.

4.2 Site Management

Site planning and development can be a key consideration that can prevent and mitigate odour sources from a potential and existing facility (Anderson *et al.*, 2003). Some of the major considerations for site management are described in the following sections.

4.2.1 Existing, Modified or Proposed Sites

Existing, modified or proposed sites can all benefit from prevention and mitigation planning, however each requires slightly different approaches. Existing and modifying sites have a limited selection of feasible prevention options compared to proposed sites. Land use designations have already been assigned and potentially sensitive receptors may be encroaching on the facility. Sites can be located in densely populated areas, which may require an assortment of prevention and mitigation tools to lessen the adverse impact.

Proposed sites generally have more and easier opportunities to apply prevention techniques. Sites can be located away from sensitive receptors and suitable buffer zones established. Newer, innovative technologies and guides can be used during planning and design to further prevent and mitigate odorant emissions. Although there is more flexibility when selecting the right tools for proposed sites, the exact composition and offensiveness of odours is uncertain. Direct odour assessment tools such as sampling and complaints records are not available to characterize the odour potential for proposed sites.

4.2.2 Nature of Odorant

Odour intensity, duration, frequency and character all have an influence on the potential to create an adverse effect. Varying combinations of these characteristics also have an influence on the potential for adverse effects. For example, a frequently occurring odour with moderate intensity and pleasant fruity smell may not cause a complaint, whereas an infrequent odour with low intensity but offensive smell may in fact generate multiple complaints. Some odours are inherently more offensive and may require multiple tools to effectively mitigate. Sources that are dominated by one odorant may be relatively easier to prevent and mitigate than mixtures, which may actually increase in offensiveness after mixing. Some compounds in mixtures can also mask other compounds, so that they are not detected until the target compound is mitigated; thereby necessitating the use of additional tools for prevention and mitigation.

With knowledge of the odour nature and receptor response, appropriate prevention and mitigation goals can be set and suitable combinations of prevention and mitigation options can be reviewed. Facilities need to be familiar with their odour inventory. Additional information on the nature of odorants and odour assessment can be found in a variety of reports (Anderson *et al*., 2003; Bull *et al*., 2014; CASA, 2008; CASA, 2014; DEFRA, 2006; DEFRA, 2010; Jacobs *et al*., 2007; Stoaling, 2013, 2013)

4.2.3 Land Use and Development Planning

The effective use of land use zoning, buffering and setbacks is a prevention and mitigation tool listed in Section 4.1. Facilities should take note of the surrounding land use and be aware of potential changes to zoning designations. Adverse odour effects tend to occur closer to the source and complaints are more frequent in denser receptor areas. When planning for a new site, care and consideration should be taken to locate in an advantageous location in relation to potential receptors.

4.2.4 Regulatory Regime

As discussed in Section 2.1, odours causing an adverse effect are prohibited under EPEA. The ambient air quality objectives are used as one reference point to determine if an adverse effect may occur. The air quality objectives list several odorants, but do not provide an odour intensity value. A review of Alberta's odour regulatory environment has found that existing air quality objectives are generally not appropriate for minimizing potential odour impacts (Chadder *et al.*, 2013). It should be noted that Alberta facilities that are meeting their environmental regulatory requirements may still cause odour impacts or nuisance. In Alberta, odour regulatory guidance and tools come in the form of:

- Stipulating discharge requirements as part of environmental permits (EPEA)
- Issuing environmental protection orders to remedy offensive odours (EPEA/AER)
- Controls required for facilities with potential to generate hydrogen sulphide from liquid storage (AER)
- Establishing air quality objectives for odorants such as H_2S (EPEA)
- Agricultural Operations Practices Act (AOPA) and supporting guides
- Adopting air quality guidance related to odour from CCME and BLIERS

An adverse odour effect can also occur if 'impairment' of the environment occurs, however the definition of 'impairment' is not provided in the EPEA. Defining when odour impairment occurs is not an easy task and may use the FIDOL factors described earlier in Section 2.3.3. Considerations include

- How many receptors are being impacted?
- How often does a receptor have to observe an unpleasant odour to be impaired?
- For how long does this have to occur?

This characterization is important for first identifying a potential impact, and then essential for setting measurable goals and objectives in prevention and mitigation planning. Facilities should approach the problem knowing that the threshold for impairment may be an unknown or a moving target and that planning and implementation can take several iterations.

4.3 Raw Materials, Formulation, Process & Operational Modifications

Modifications to raw materials, formulations, processes and operations are prevention techniques with the objective of stopping or reducing the creation of odorants. They can apply equally to all types of processes and source types. Simple operational modifications, such as improved housekeeping and minimizing leaks can result in good management improvements for area, volume and line sources. Knowledge and review of the facility process flows and operations is required to identify possible opportunities while minimizing impacts to facility production.

Within many industry sectors, it is often the inventory of raw materials that are responsible for the release of odorous emissions through the various processes and operations. As well, processes and operations may generate products, by-products and waste streams that, in themselves, create odorous emissions. Odorous emissions can be created by one single process or activity, or be a result of a variety of processes and operations. Odour intensity, frequency and duration can also fluctuate over time based on many factors, such as raw material blends, production schedules and rates, and process operating parameters and phases. A facility should carefully review their material flows, processes and operations to better understand the mechanisms leading to odour emissions. Tracing the origins of odour release will be beneficial to identify opportunities towards reducing odours.

Examples of raw material and formulation modifications:

- Substituting an odorous raw ingredient with a less odorous alternative
- Adding an ingredient that suppresses or reduces the odorant release

Examples of process modifications:

- Preventing the release of odours through use of: physical, chemical, biological and natural covers, enclosures, or other physical barriers
- Reducing turbulence and other disturbances that provide energy and opportunity for odorant release
- Reducing the operating temperatures or residence times of equipment and processes
- Reducing anaerobic conditions

Examples of operational modifications:

- Optimizing processing and operational activities towards favourable times and conditions that lead to reduced off-site impacts
- Better management and storage of odorous products and inventory
- Incorporating monitoring and feedback systems for operations

- Leak detection and correction procedures
- Better housekeeping, preventative maintenance and clean up procedures (e.g. clean-up residue & spills)

Benefits and considerations related to raw materials formulations, process and operational modifications are summarized below.

Benefits	Considerations
• Prevention techniques can drastically reduce or eliminate potential for odour • Operational/maintenance modifications can be simple and easy to implement	• Material substitutions can require expensive and timely trials • Process changes may affect the quality of products

Relative to specific industries or sections, several guides and documents are available outlining raw materials, formulation, process & operational modifications. Examples are

- The document "Odour Management Plan for Alberta Livestock Producers", provides a checklist of process and operational procedures that can be used to gauge the odour potential (ARD, 2011).
- The recently published status update on the recommendations of the AER Peace River Proceedings indicate that AER will require all produced gases to be diverted from directly releasing into the environment (e.g., through the use of covers and enclosures) and eventually prohibit all fugitive release. Recommendations also include implementing a leak detection protocol and establishing maximum leak repair time.
- Processes to improve odour management are listed in the document, "Manure Odour Management and Bioenergy Feasibility Analysis (Alberta Energy, 2009), which lists techniques to control and inhibit odour formation. Adjusting animal diets, manure moisture content and increasing aerobic conditions during composting are some of the proposed operational modifications
- "A Review of Beneficial Management Practices for Managing Undesirable Air Emissions from Confined Feeding Operations" reviews the use and effectiveness of permeable covers, bottom loading of liquid manure, animal composting and dust palliatives. (Edeogu, I., 2011)
- Department for Environment, Food and Rural Affairs (DEFRA). 2006, Code of Practice on Odour Nuisance from Sewage Treatment Works. London.
- Jacobs et al., 2007. An Industry Guide for the Prevention and Control of Odours at Biowaste Processing Facilities, Northamptonshire.

4.4 Management Planning Groups and Guides

These groups and guides are considered to be a prevention tool that can be used at any type of source. This tool refers to the organization and benefits of common interest groups and development of best management practices. Management planning groups can take various forms, ranging from regulatory committees, industry groups, non-governmental organizations and community based groups. At the same time, it is common to have these management groups and bodies publish guides and documentation on process, air emissions, permitting requirements, innovation in technology and regulation changes. These guides can be industry specific or generic but most guides are typically developed by a multi stakeholder group.

Often the expertise available within management planning groups allows for the development of practice guides which detail the generation and formation of odour within a specific industry. The expertise is diverse and can be firsthand knowledge of what prevention and mitigation tools work within a facility. These guides do not directly prevent or mitigate odour effects, but require the facility to review and adopt the best options towards this end.

Management groups and establishing good community relations (Section 4.5) can be implemented together by sharing information and inviting community input and participation. Even if there are no issues or potential of odour effects, it can be beneficial to establish or join management groups as the facility develops and operates.

Benefits	Considerations
• Collects and provides practical knowledge from various sources	• Does not directly prevent or mitigate odour emissions unless effectively implemented
• Guides are targeted at specific industries, processes or operations and provide relevant information	• Material may take time to be published and can become dated over time
• Implementation of tools developed by management planning groups are typically proven to be effective and more universally accepted by regulators and the general public	• Can be general in nature leaving interpretation and detailed planning at the discretion of the user

In Alberta, there are many multi-stakeholder associations and groups and some are highlighted in the case studies provided in section 5.0 of this document. Some examples of guides developed are:

- Hydrocarbon Odour Management Protocol for Upstream Oil and Gas Point Source Venting and Fugitive Emissions – Alberta Energy Regulator
- Best Management Practice, Management of Fugitive Emissions at Upstream Oil and Gas Facilities – Canadian Association of Petroleum Producers
- Flaring Seminar and Best Practices – Sundre Petroleum Operators Group
- Managing Air Emission from Confined Feeding Operations in Alberta – CASA
- Prevention and Mitigation Tools for the Alberta Context – CASA (this document)
- Odour Management Plan for Alberta Livestock Producers, ARD
- Shelterbelts for Livestock Farms in Alberta, ARD

Management groups play a key role in the front end expert discovery and managing ongoing odour challenges. In the absence of established facility or industry guides, or in addition to them where they exist, a facility should not delay establishing a prevention and mitigation plan which may include initiating or joining a management group. Several facilities and groups in Alberta have already discovered the benefit and rewards of establishing groups. This trend is likely to continue as needs are identified and development in some key industries continue to progress.

4.5 Establishing Community and Neighbourhood Relations

This tool can be classified as a prevention and mitigation tool that is used at the receptor, which adjusts the odour sensitivity and tolerance of the community. It is not source specific and can apply to all types of sources. This tool has synergistic benefits when combined with management planning groups. Even if there are no issues or potential of odour effects, it can be beneficial to establish and maintain community relationships as the facility develops and operates. It can, however, be hard to evaluate the effectiveness of establishing community relationships as there are no simple metrics.

Attempts to solve odour nuisance issues often over-emphasize technical solutions. One underestimated aspect of odour management is the public opinion of the facility within the local community. A negative outlook from the surrounding neighbours may diminish any benefits obtained from using prevention and mitigation tools. By engaging the community in two-way dialogue, cooperation and trust is fostered. An actively engaged and informed community may lead to more realistic expectations regarding odours (Longhurst *et al.*, 2004). The community itself can also become a valuable source of qualitative data, providing valuable information to be used by other prevention and mitigation tools (Anderson *et al.*, 2003).

Some examples of establishing relations include:

- Conducting tours of the facility

- Organizing public information workshops, providing information about the facility process, odour potential and odour mitigation/prevention plans
- Sharing monitoring data or establishing odour quality index/warnings
- Initiating community odour surveys or odour diaries
- Establishing and soliciting a formal complaints protocol or establishing community odour monitors with odour diaries
- Establishing a community liaison group
- Involvement/participation in other industry and community groups

For future proposed facilities, establishing community relations should be closely tied to any required impact assessments or permit requirements. Existing facilities need to review and develop a 'best approach' to their community relation plan. The components of community and neighbourhood relations can be determined proactively by the facility or in some cases, reactively as required by a regulatory body. Some of the benefits and considerations of this tool are listed below.

Benefits	Considerations
• Creates a partnership, rather than adversarial environment	• Each community is different, requiring a custom approach and relation plan
• Applicable for proposed and existing facilities	• Difficult to evaluate effectiveness
• Can provide additional qualitative data for other tools	• Does not reduce odour emission or transmission

Proceeding 1769924, which was initiated by the AER in 2013, established a panel of hearing commissioners to conduct a proceeding into odours and emissions from heavy oil operations in the Peace River Area. The proceedings encouraged written and oral statements from any interested party including impacted residents, operators, regulatory bodies and independent experts (AER, 2014a). The proceedings concluded in March 2014 with many parties having a greater understanding of the issue and a list of recommendations to address and reduce adverse odour effect. Several key pieces of guidance documents and proposed governmental rulings were created as well as other prevention and mitigation tools to be established. These proceedings engaged community members and provided a formal outlet to provide feedback.

The Edmonton Waste Management Centre has implemented several community based relation programs. The facility is a diverse waste management centre with 12 processing facilities on 550 acres of land. Throughout its development, the facility has dealt with odour impacts and established community relations by organizing a community liaison committee, offering facility tours, soliciting odour feedback and developing an odour complaint protocol. The facility is also a member of the Strathcona Industrial Association, which engages the community on environmental management issues. The association also operates an air monitoring network and publicly publishes the results. Several other prevention and mitigation tools are used at the facility and more detail can be found in the case studies.

4.6 Real-time Downwind Monitoring

Downwind monitoring can be considered a prevention and mitigation tool, if the monitored parameters are representative of the odour, frequently monitored (real-time), and if appropriate action levels are established. 'Real-time' refers to continuous and near instant reporting of monitoring results and can be used with any of the previous downwind monitoring examples. Monitoring at the source or at the fence line provides better opportunities to catch potential odour episodes before they reach the community. With near instantaneous knowledge of odorants, alerts can be provided and corrective actions can be quickly taken to reduce the potential for the odour effect to become more significant. Corrective actions can be built into operating procedures and further automated to interact with the facility processes.

Downwind monitoring and sampling is traditionally used in odour assessments and odour monitoring programs to gather information. Results are used to determine the presence of odorants, probability of adverse effects and determine the effectiveness of prevention and mitigation techniques. Monitoring can be part of odour screening and assessments. Some example types of downwind monitoring include:

- Fence-line monitoring at or near the property line of the facility.
- Permanent ambient monitoring stations established within a community or area of interest. List of monitored odorants are typically smaller or only indicator odorants are monitored.
- Single event ambient odorant sampling at specific receptors. Larger quantity and specific odorants can usually be sampled.
- Long-term odour diaries within the surrounding areas which collect qualitative data, but can provide information on the actual odour effects on the community.

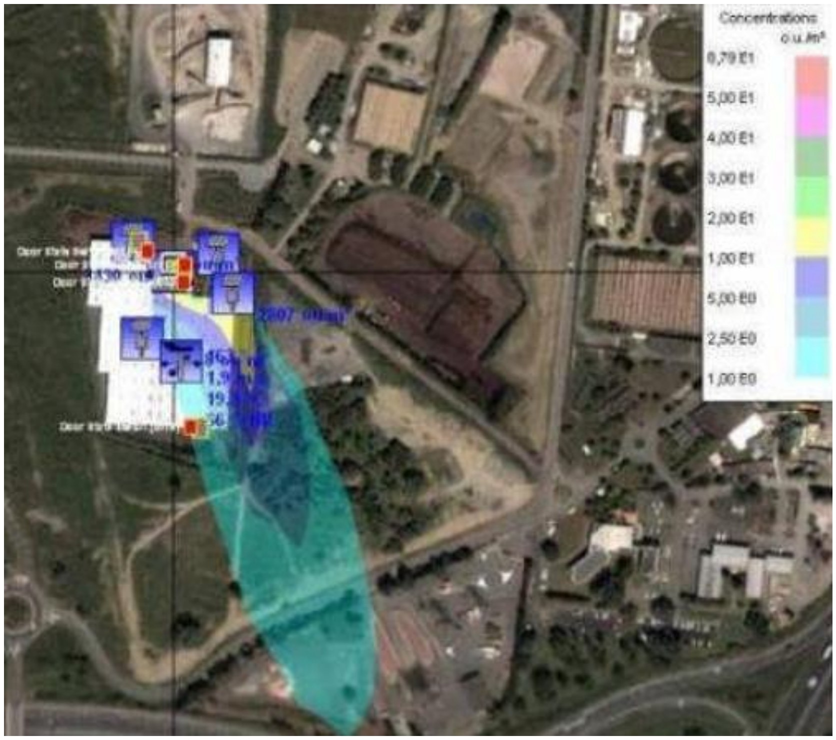


Figure 6: Sample Graphic of Real Time Plume Prediction (Felske *et al.*, 2013)

Real time fence-line and ambient community monitoring is more applicable for low level area, volume, line and multi-sources since monitoring techniques and equipment are typically used near ground level. Near source monitoring systems are easier to implement for point sources since the odour is released from a small point and may not have dispersed into a large area. The monitoring data can be shared with the community or regulators to help develop community relations. Information can also be developed to form an odour quality index, similar to the Alberta Air Quality Health Index. Some of the benefits and considerations are listed below.

Benefits	**Considerations**
• Provides early warning alerts and allows economic use of other prevention and mitigation tools	• Requires site specific calibration and odour assessment
• Can be implemented as part of an odour assessment or monitoring program	• May requires specialized knowledge to operate and maintain
• Can provide additional qualitative data for other prevention and mitigation tools	• Does not directly prevent or reduce the odorants and can be costly to implement & maintain

Alberta currently has an ambient air monitoring system which consists of approximately 48 continuous monitoring stations providing information to an online database (CASA, 2014c.). The stations are operated by ESRD, various airshed management groups, Environment Canada or industry. Odour concentration is not monitored; however several common odorants are monitored, such as ammonia, hydrogen sulfide, total reduced sulphur, volatile organic compounds and hydrocarbons. In addition to the network of established monitoring stations, facilities often install fence-line or ambient monitoring equipment as part of monitoring plans, establishing good neighbour relations and meeting environmental permit requirements.

Traditionally ambient monitoring has been used in most jurisdictions in a reactive manner after potential adverse effects have occurred. To better utilize this tool as a prevention and mitigation tool, quicker reporting, analysis, feedback and corrective actions are required. An innovative technique being used is the combination of real-time monitoring with atmospheric dispersion modelling. Odorant and weather sampling or sensors are placed at several strategic locations and the results are uploaded in real time to a computer system. The results are then used by air dispersion models to predict and visualize the odour plume and movement. Some examples of this innovative use include:

- As part of the prevention, mitigation and monitoring plan, the Edmonton Waste Management Centre uses predictive real time odour monitoring. The sensors are placed near the sources on site and uploaded to a central processing system.
- Fish Creek Wastewater Treatment plant in Calgary, has recently awarded a project for the supply and installation of real time odour monitoring, to complement their odour prevention and mitigation options.

Users of these systems can benefit from near instantaneous prediction of potential odour effects and act accordingly to prevent or mitigate the root causes.

4.7 Atmospheric Dispersion Optimization and Pathway Buffering

4.7.1 Atmospheric Dispersion and Source Optimization

When released into the environment, odour will travel through a pathway before reaching a receptor. Optimizing discharge parameters is a mitigation technique used at the source that will affect the pathway while the odour disperses and dilutes. Since most receptors are near the ground, adverse odour impacts can be mitigated by increasing the distance or time the odour must travel. The most obvious way to accomplish this is by erecting a taller stack which allows the odour to disperse more effectively before reaching a potential low level receptor. Improved dispersion measures are most often implemented to reduce impacts of wind induced turbulence caused by buildings and structures in the vicinity of the odorous discharge. These wind induced turbulence zones frequently cause the odorous plume to remain at or near ground level with minimal dilution.

Figure 7: Stack Plume (Syncrude, 2014)

In general, optimizing the odour release can be accomplished by:

- Adjusting the discharge orientation. Vertically upward discharges are preferred and provide the better opportunity for dispersion and dilution.
- Increasing the exit velocity. Imparting a faster exit velocity typically provides more energy for dispersion and dilution.
- Raising the release height. Typically, this is the most common adjustment towards minimizing negative influences (downwash effects, air wake zones).
- Increasing the bulk momentum. Combined gas streams with increased overall flow will increase the kinetic energy and height of the plume prior to dispersion
- Elevating the discharge temperature. Higher discharge temperatures will allow the odour to better rise in the atmosphere, increasing dispersion and dilution.

The most common and effective methods are to ensure that odour releases have a vertical discharge, sufficient vertical velocity and adequate elevation. Good engineering practices will typically define a range of acceptable exit velocities and elevations. In some cases combining odour sources into a larger collective source will reap benefits in both improved dispersion and costs. Combining sources is also conducive towards applying engineering controls. One hybrid solution is to combine a stack with thermal treatment in the form of a stack incinerator or flare, which is commonly used at wastewater, industrial and oil and gas facilities (additional details are provided in Section 4.8.4). In other cases it is not technically or economically feasible to increase the temperature of an odour release. Depending on the situation, consideration should be provided for increasing temperature, increasing stack height, or both.

Optimizing release characteristics is a mitigation tool that is used at the source. It is most easily implemented for point sources because the source is already collected in a common space or stack. Since most area, volume and line sources are near ground elevation and contain a large working area, it is typically not economical or feasible to optimize their release characteristics. Potential solutions would be to convert or modify the area/volume/line source into a point source and optimize the release characteristics or use some of the other prevention and mitigation tools. Tools that are implemented within the pathway and can also affect dispersion are covered in the next section on Shelterbelts and Artificial Windbreaks (Section 4.7.2).

The benefits of reducing odour concentration can be predicted using a variety of engineering tools to model the expected impact. Under favourable conditions, concentrations of odorants can be reduced by several orders of magnitude in ambient air (Petrov, 2008). This tool is typically combined with other engineering controls (Section 4.8), however can still be effective if used alone. Some of the benefits and considerations of this tool are listed as follows.

Benefits	**Considerations**
• Straightforward, low maintenance and effective tool for point sources	• Typically not economical or feasible for area, volume and line sources
• Typically more economical than other engineering control tools	• Potential negative visual perception and reaction from surrounding land users
• Applicable for proposed and existing facilities	

Alberta has a 183 metre tall dispersion stack located at an industrial facility (Environment Canada, 2014). This stack combines several different processes and source types into a single point source with greatly improved dispersion and dilution. Several other types of tools are implemented on the individual processes prior to entering the stack.

Figure 8: Example of Elevated Stack (Globe and Mail, 2013)

Selecting a proper stack height, through the use of engineering and dispersion models, to ensure air quality objectives are met is listed as a general air management practice by Alberta ESRD (ESRD, 2009). Many other jurisdictions have listed this tool as part of good engineering practices or part of legislative requirements (USEPA, 1985; RSO 419/05, s 15.; Anderson *et al*., 2003, ASHRAE, 2013).

4.7.2 Shelterbelts and Artificial Windbreaks

Shelterbelts and artificial windbreaks are environmental barriers or restrictions that modify the pathway and change the amount of dispersion and dilution as the air moves. Shelterbelts typically comprise of specially selected series of tree plantings in a predefined pattern (See Figure 9). Trees and shrubs contained within multiple rows with varying heights provide erosion & snow protection, wildlife habitat, reduce wind related energy losses and enhanced landscapes. Artificial windbreaks are non-vegetative barriers such as wind screens, engineered berms and hills that provide similar effects as shelterbelts, however they typically do not provide significant habitat or enhance the natural landscape.

Using similar principles of source optimization, dispersion and dilution, shelterbelts and windbreaks are used after the release of odours. By modifying air pathways, forcing air mixing and raising the elevation of air movement, shelterbelts can help disperse and dilute odour effects. In some cases odorants can be filtered through impacting the leaves or needles or absorbed and converted by the vegetation itself (Adrizal, 2008). Existing studies or literature on the reduction of odorant concentrations after implementation of shelterbelts is sparse and inconclusive (Edeogu, I., 2011), but shows potential and should be considered as part of an overall prevention and mitigation plan.

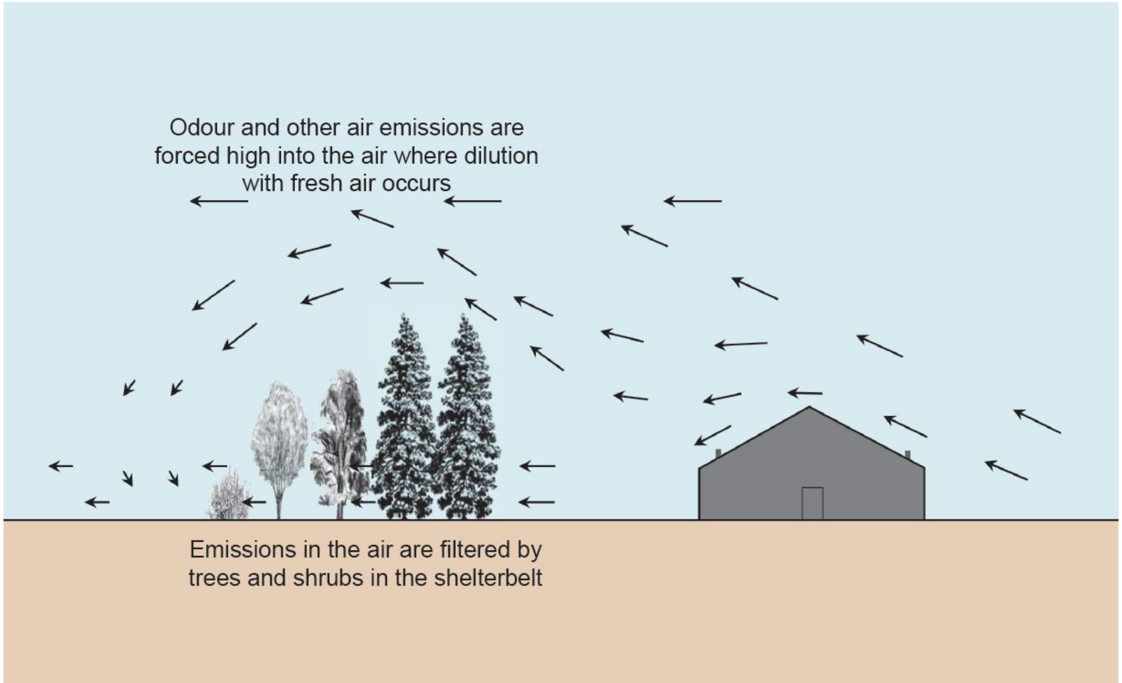


Figure 9: Shelterbelt Schematic (provided by CASA)

Shelterbelts and artificial windbreaks are considered pathway tools that help filter, disperse and dilute the potential odours along the route, but it is not necessary to implement these tools on intermediary lands. They can be installed directly at facility lands or outer boundaries of potential receptors. Lower elevation odour sources such as area, volume and line sources can benefit the most from implementing shelterbelts and windbreaks. It is typically not feasible or economical to implement tall shelterbelts or windbreaks for elevated sources, especially point sources. Some of the benefits and considerations of this tool are listed as follows.

Benefits	Considerations
• Simple and natural solution	• Can require large area to properly implement (length and width)
• Several additional benefits; energy conservation, wildlife habitat, reduced erosion, landscape enhancement	• Shelterbelts can take a long time to fully develop and become effective
• Can implemented with permanent or temporary (portable) installations	• Only practical for low level sources

Figure 10: Sample of a 3-row Shelterbelt (Photo courtesy of Agriculture and Agri-Food Canada)

In Alberta, shelterbelts are promoted by the ARD and the agricultural industry. Guidance is provided on effective species selection, density, setbacks, growth strategies and maintenance (ARD, 2014a). The use of shelterbelts and wind barriers are a recommended practice for confined feeding operations and additional studies have been recommended (CASA, 2008; Edeogu, I., 2011). The Federal Prairie Shelterbelt Program provided technical assistance, and tree and shrub seedlings for shelterbelts projects in Manitoba, Saskatchewan, Alberta and British Columbia until 2013. A number of third party companies in Alberta continue to offer shelterbelt seedlings and plants. In addition to Alberta government and non-governmental organizations, the use of shelterbelts is promoted by the U.S. Department of Agriculture, Agriculture and Agri-Food Canada, and Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), and New Zealand Ministry of the Environment. Since shelterbelts and wind breaks are easier to implement in less populated areas with sufficient land area, they have traditionally been used for agriculture related activities, however they have potential use in any type of remote natural resource development.

4.8 Engineering Controls

Engineering controls are put in place at the source of the SPR model in order to mitigate odour emissions before they are released to the atmosphere or travel towards receptors. Since there are many odorous substances, a variety of different types of engineering controls are available which use physical, chemical and biological principles to mitigate odours. Engineering source controls are sometimes referred to as 'end of pipe' or 'back end' solutions, signifying their implementation at the end of the process.

Engineering controls are divided into five broad categories and include (but are not limited to):

- Absorption systems – Absorption scrubbers, sometimes referred as wet scrubbers, use a scrubbing liquid that is sprayed or showered within the gaseous odour. The odorous compounds then dissolve or react with the liquid and are removed from the liquid agent (Anderson et al., 2003). Types of absorption equipment and wet scrubbers include plate absorbers, venture absorbers, packed towers, tray towers and spray towers (DEFRA, 2010; Davis, 2000).

- Adsorption systems – Contaminants get attached to the adsorption component through the pores of the material and then are removed. Some common adsorption scrubbers use activated carbon or aluminium pellets due to their highly porous surfaces (DEFRA, 2010). Some adsorbents can be desorbed and reused (Anderson *et al.*, 2003).
- Biological – Treatment systems with biological components use micro-organisms to break down odorous compounds and reduce odour releases. Biological components can be sprayed into the odorous air stream, however the most common systems pass the air stream through a porous support media where the micro-organisms establish a population. This self-sustaining system allows for many different species and support media as long as this media does not degrade. Support materials include soil, wood chips, inorganic porous minerals, and calcified seaweed (DEFRA, 2010).
- Thermal – Thermal systems consist of several different methods aimed at oxidizing odorous compounds with the addition of heat and combustion. Thermal oxidation converts odorous compounds into water and carbon dioxide Anderson *et al.*, 2003). Thermal systems can include thermal oxidizers, catalytic thermal oxidizers, recuperative thermal oxidizers and regenerative thermal oxidizers (Rafson, 1998; Davis, 2000).
- Condensation – A somewhat special technique applicable to innately hot gases, where odorants are removed and transferred into a liquid stream by lowering temperatures. Typically used as part of hydrocarbon systems within petroleum applications, but applicable to other hot high VOC sources.

Engineering controls are used as mitigation tools once odour has been generated and prior to its release. By applying specialized and targeted control methods and systems, engineering controls typically can provide large reductions in potential odour releases. This focused mitigation tool is most applicable for point sources that have concentrated and collected odorants. If applicable, volume, area and line sources can be modified to a point source through the use of process and operation modification tools (Section 4.3), such as covering and collecting odorous air. Hybrid systems are also commonly used which incorporate more than one system to achieve better mitigation. Due to the complex nature and principles of engineering controls it is recommended that options are selected with the assistance of specialized expertise and consultation with appropriate guides such as those published by DEFRA, 2006; Jacobs, 2007; DEC, 2006; Stoaling, 2013; AER, 2014a; Davis 2000; Rafson, 1998.

A comparison of the application use of various engineering controls is provided below. These represent the current trend and use observed in the different odour emitting processes. Associated benefits and considerations for each engineering control are provided in the remainder of the section.

Table 1: Comparison of Engineering Controls (adapted from DEFRA, 2010)

Odour emitting Process	Absorption	Adsorption	Biological	Thermal Oxidation	Condensation
Sewage treatment	✓✓	✓✓	✓✓✓	✓	-
Food processing and kitchens	✓✓✓	✓	✓✓✓	✓	✓
Paints and solvents	✓✓	✓✓	✓	✓✓✓	✓✓
Animals and livestock	✓✓	✓	✓✓✓	-	-
Industrial/chemical processes	✓✓	✓✓	✓	✓✓✓	✓✓
Oil and gas	✓✓	✓✓	✓	✓✓✓	✓✓✓
Storage & spills	✓✓✓	✓✓✓	✓	✓	-

✓✓✓ - Common, typically used and established

✓✓ - Use may be limited to specific process and scale

✓ - Rare usage and limited research

4.8.1 Absorption Systems

Through different systems and arrangements, absorption scrubbers allow for the contact of odorous gases to react with or transfer to a specific absorbing material to remove odorous compounds. The absorbing material is typically a liquid mixture which is sprayed, atomised or 'showered' into the gas stream. Due to liquid nature of absorption scrubbers they are sometimes referred to as 'wet-scrubbers'. Example liquid solutions used include chlorine, sodium hypochlorite, diluted sulphuric acid, and sodium hydroxide (DEFRA, 2010; Davis 2000). Wet scrubbers can destroy odorants, however the liquid used is typically another waste product requiring treatment or disposal. The following are a few benefits and considerations for this engineering control:

Benefits	Considerations
• Proven and effective for soluble odorous contaminants and within certain sectors	• Creates a liquid waste stream, which must be treated and disposed
• Can handle a wide concentration range of odorous contaminants	• Requires ongoing maintenance and expertise to properly operate
• Are suitable for humid applications	• Some liquid solutions themselves have undesirable odours
• Can handle gas streams with particulate matter	• Not suited for high temperature sources

4.8.2 Adsorption Systems

Instead of a liquid, adsorption systems use a solid media to filter or scrub the odorants and sometimes are referred to as 'dry scrubbers'. Highly porous materials are used for the media to maximize the surface area, which is where the filtering takes place. Examples of materials used as porous adsorbent media include carbon, zeolite, bentonite, polymers, alumina, activated clay, and silica gel (Anderson *et al.*, 2003). Adsorption media becomes saturated with contaminants over time and requires replacement and off- or on-site regeneration. Regeneration produces a secondary waste stream that must be treated.

Activated carbon is one of the main materials used for adsorption within this engineering control and is best used for organic vapours and gases, as well as some inorganic gases and metallic vapours. Optimal conditions of the gases occur when the air stream is dry with a relative humidity less than 75% and a temperature less than 40ºC (DEFRA 2010). Other systems can combine different medium in separate compartments to target specific odorants. A few benefits and considerations for this engineering control are listed as follows.

Benefits	Considerations
• Proven & effective over a wide range of contaminants	• Media becomes loaded and has to be replaced or regenerated periodically
• Particularly suited for low temperature, low contaminant concentration or mass loading gas streams	• Not suitable for odour streams containing excess water, grease, oil or particulate matter since surfaces of the media can become clogged.
• Media can be specifically chosen for the odorants and multimedia systems are available	• May not be suitable for high contaminant concentration applications due to high replacement or regeneration requirements, unless used as a

Benefits	Considerations
	concentrator ahead of other control technologies
• Equipment and components are simpler and the systems are easier to operate	• Not suitable for high temperature application
• Can be used as a concentrator ahead of thermal oxidation or condensation solvent recovery	• Regeneration stream requires further treatment

4.8.3 Biological Treatment Systems

Biological treatment systems have a wide range of application in the treatment of odours due to their reliability and self-sustaining properties. Biological treatments systems generally fall into two categories of bio-filters and bio-scrubbers. All systems use self-sustaining micro-organisms that reside either on a porous material (bio-filter) or in solution (bio-scrubber). Contaminates need to be biodegradable and must be removed from the gas stream through absorption into water. In bio-filters, the odorous gas passes through the material and the odorants dissolve within the water layer of the material, allowing microbes to metabolise the compounds (Jacobs *et al.,* 2007).

Biological treatment systems are best used on sources with reasonably constant odour streams containing water soluble contaminants (DEFRA, 2010). Since the odorants are used as food, the efficiency of biological treatment can drop when the concentration of odorants is low. Bio-filters also have an earthy type residual odour that typically blends in with odours from the natural environment. See below for a few benefits and considerations for this engineering control.

Benefits	Considerations
• Self-sustaining system over an extended period of time	• May not respond quickly to frequent or wide fluctuations in contaminant concentrations
• Applicable to water soluble bio-degradable contaminants	• Not effective with high contaminant concentration streams
• Has the potential for high removal efficiencies	• Requires higher residence time, large areas and competent workers to maintain
• Relatively low operating costs	• Requires watering to maintain moist environment for bacterial growth.
	• Not tolerant to high temperatures, pesticides, insecticides and other poisons

4.8.4 Thermal Treatment Systems

In thermal treatment systems, organic odorous compounds are dissociated and converted to carbon dioxide and water at high temperature over a sufficient residence time. Catalysts can be added to aid the conversion process at lower temperatures (DEFRA, 2010; Rafson 1998). Types of thermal oxidizers include straight thermal, recuperative, catalytic, and regenerative (Anderson *et al.*, 2003). In the oil and gas industry, thermal treatment can also take the form of stack incineration and flaring. The heat generated by these systems can be recuperated for use elsewhere at the facility.

Energy inputs for thermal systems can be costly. Thermal treatment is best applied to odorants that have higher concentrations of hydrocarbons. Therefore facilities that have high VOCs or landfill gas are better suited to use thermal treatment systems. Thermal systems are also well suited for oil and gas processes using incinerator stacks and flaring. AER's Directive 060 has outlined basic requirements for flares and incinerators such as minimum heating value, recommended exit velocities, residence time and exit temperatures (AER, 2014b). Below are some benefits and considerations of thermal treatment systems:

Benefits	**Considerations**
• Highly effective at converting odorous compounds	• High capital costs if energy recovery technology is included
• Odorous compounds are converted within short residence times	• Energy costs are high on low contaminant concentration streams, especially if energy recovery is not employed
• Waste heat can be recovered for pre-heating incoming odorous gas and other uses in the facility	• Catalytic systems can exhibit varying conversion efficiencies on some contaminants and certain contaminants can be a catalyst inhibitor or poison
• Particularly applicable to higher concentration hydrocarbon based streams	• Catalyst requires regeneration or replacement over time
• Applicable to a wide range of contaminants	• Improperly executed thermal system can create more toxic chemicals and/or odorants.

4.8.5 Condensation

The type of condensation technology used is based on the condensing temperatures of the odorous compounds. Typical applications require a refrigerant temperature of -50 ˚C to 85 ˚C to attain 90 to 95 percent recovery (Rafson, 1998). At many facilities condensation may be installed in the middle of the process as part of a vapour recovery system. If used in such a way this tool can also be a process modification tool (Section 4.3). Whether used in the middle or at the end of pipe, the vapours are converted to a liquid with a potential for reuse. If not reused, then the liquids will need to be disposed of. Condensation is often used in conjunction with adsorption for the purposes of solvent recovery. Some of the benefits and considerations are provided in the following table:

Benefits	Considerations
• Potential to reuse recovered product	• Relative small range of use and application
• Mostly applicable to high VOC concentrated gas steams at lower temperatures	• Typically requires special electrical and additional safety considerations due to concentrated VOC levels
• Can be coupled with adsorption technologies	• Requires qualified operating personnel and operating costs can be substantial
• Typically lower to moderate capital cost	• If recovered solvent is not reused then hazardous disposal will be required

4.9 Masking and Neutralizing Agents

Masking and neutralizing agents are sprayed, mixed and applied to odorous liquids, surfaces or gases to mitigate adverse odour effects. Masking and neutralizing agents act in the form of a mitigation tool, or can be used for the prevention of odour releases at the source. Agents that are applied directly to the odorous substance can prevent odour releases from leaving the source. Examples of this can include adding soil or another filtering material to the top surface of a landfill site. Surface treatments are mainly used in livestock facilities, bio-waste facilities and compositing sites where the sources have large surface areas and agents can be applied with ease (Jacobs *et al.*, 2007). Agents that are applied to liquids can mask or inhibit odour production or destroy odours.

When applied to the odorous gases, agents act as mitigation tools to reduce the odour impact. Several different products and methods are used and typically applied by misting or spraying the air (DEFRA, 2010). Some techniques, such as ozone and UV radiation can prevent odours at the surface and mitigate odours in the air.

The following types of products are available for masking and neutralizing odours.

- Masking agents are used to cover up the smell from odour releases. By the use of aromatic oils, more pleasant smells replace the release of objectionable and offensive odours. The aromatic oils are found to have a more intense odour than the offensive odour. Depending on the sensitivity of the receptors and prolonged use of the masking agent, the aromatic oils can arguably make situations worse (Anderson *et al.*,2003). Masking agents are used both at the surface and in the air.

- Chemical agents can contain mixtures of different aromatic and essential oils that are mixed with gaseous odour streams. These mixtures act to neutralize and reduce the intensity of fugitive releases and offensive odours. This is typically more desirable as the resulting odour is reduced in intensity and is less likely to reach sensitive receptors (Stoaling, 2013, 2013).
- Digestive agents use biological processes to treat gaseous odour compounds. With the use of enzymes and bacteria, digestive deodorants eliminate odour through the means of biochemical digestive processes (Stoaling, 2013).
- Chemical scavengers use chemical processes to remove odorous compounds from surfaces and sources. Chemicals are added to the material source of the odour, such as liquids and spills, and through the process of chemical reactions, potentially odorous substances are then removed or destroyed.

Masking and neutralizing agents are considered to be prevention and mitigation tools that are used to reduce or eliminate the odorous compounds either at the source or along the pathway. Agents can be applied to all types of sources (point, volume, area and line). Masking agents are best used for short term odour sources (such as construction and temporary conditions) from large areas, such as landfills (Anderson *et al.*, 2003). These tools are more effective when there are low levels of odorants (Rafson, 1998).

Masking and neutralizing agents have generally have a low capital cost which makes these treatment methods desirable. However, the effectiveness of these treatment agents are not easy to prove, and therefore should not be used as the main or only treatment of odour releases. Masking and neutralizing agents should be combined with other treatment options or should be used as the final treatment after other odour management practices at a particular source have been implemented (Anderson *et al.*, 2003). Used in the right application, there are many accounts in which these agents have aided different industrial locations with odour releases, particularly those associated with organic waste (DEFRA, 2010) and livestock operations (Zhang *et al*., 2002). A study was completed to test 35 different masking and neutralizing agents on solid manure storage pits. The results indicated that four of the additives had a success rate of 75% or greater in mitigating odour releases within the manure pit (Heber *et al.*, 2001). Other tests have been completed to study the effectiveness of other treatment methods, including sprinkling and spraying of oils, such as vegetable or canola oil, in livestock facilities. In animal pens, odour releases were reduced when vegetable oil was sprayed once a day (Kim *et al*., 2008), however, depending on the odour source, there were considerable differences in the odour reductions.

Alberta is continuing to explore and research the uses of different chemicals and treatment agents that can be added to odour sources to remove the odour emissions being released, particularly in the field of compost, manure and livestock operations (ARD, 2004).

Common areas for masking and neutralizing agents include livestock facilities, compost facilities, locations that handle sludge, and industries dealing with organic waste (DEFRA, 2010; Anderson *et al.*, 2003). Some of the benefits and considerations are listed below:

Benefits	Considerations
• Reduces offensive odours and releases a more pleasant smelling odour	• Efficiency of masking and neutralizing agents can vary with meteorological conditions
• Depending on the substance used, this tool is easy to implement and	• After prolonged exposures to treatment agents, some people consider the smells of the deodorizers and agents as offensive.
• Typically applicable to area and volume sources and some selective point sources	• Combining masking agents with certain chemicals can result in more offensive odours.
	• Typically does not work well on sources with low contact residence time, such as point sources

4.10 Receptor Based Tools

When seeking solutions for odour prevention and mitigation, the focus is typically on the source of emissions. In certain situations after other prevention and mitigation tools have been implemented and receptor based tools may become more feasible. Some examples of receptor based tools include;

- Restricting the receptor land uses. Land use zones are typically broad and allow for a variety of specific uses. Restrictions on the land use could limit the density of occupation (low density), restrict the usage to seasonal, and limit the operation (weekends only). These restrictions are intended to lower the likelihood of causing an adverse effect and would in most cases, be assessed on case-by-case basis.
- Erecting warning signage around the community is similar to establishing community relations, in that it adjusts the tolerance of adverse effects.
- Establishing receptor based agreement clauses can take the form of written or acknowledged contract clauses indicating acceptance of potential odour effects.

Receptors that are aware of the potential for odour effects will have an adjusted tolerance. However this ‘agreement’ does not override any provincial or municipal laws dealing with impairment or nuisance.

- Optimizing or modifying receptor arrangements are not common, but would entail using some of the described mitigation tools at the receptor. Some examples include installing engineering controls at air intakes, erecting barriers or shelterbelts and removing operable windows or balconies on certain building sides.

These receptor based tools will likely be used for multi-sources as odours at the receptor are from a variety of sources. Since they are implemented at the receptor, cooperation is required from the source, municipality and receptor. Receptor tools can be used reactively as the “last chance” to resolve odour issues or reactively by progressive planning groups. There are only limited research and case studies on the use of these tools and even less information about their effectiveness.

5.0 CASE STUDIES

Several case studies have been summarized in this section to outline the Prevention and Mitigation Planning process. The context and type of tools used are displayed in the accompanying tables.

5.1 Municipal Waste Management Facility

The facility is located on 550 acres in an industrial area of northeast Edmonton and contains twelve waste processing facilities, two research facilities, a closed landfill, lagoons and sewage biosolids storage. The facility has expanded since first pilot testing in 1986 and has dealt with odour issues using a variety of techniques. In 1998 and 2003, the City of Edmonton initiated an odour monitoring program that involved training City staff and citizen odour observers to perform daily odour surveys at specific locations over a long period of time. The monitoring work provided an extensive inventory of odour sources from the facility as well as identifying the major contributors to off-site odours. The site contains a variety of source types including point, volume and areas sources. The highest frequency of odour detection were from the biosolids lagoons, composting facility, large chemical plant, feed mill and the mushroom farm.

Analyzing all this information, the facility was able to develop an abatement plan to reduce odours from the most significant sources and also plan for future additions to the facility. The facility uses a combination of neutralization agents, process and operational modifications, engineering controls, fence-line monitoring and forecasting, community liaison committee, complaint logging and is part of a multi-stake holder group. The original monitoring program continues to be used to assist compliance monitoring, complaint investigation, comparison and evaluation of prevention & mitigation techniques and verification of dispersion modeling results. The facility is a member of a local industrial association which has installed ambient air quality monitoring stations and regularly publishes reports on the monitoring results.

Municipal Waste Management Facility

Odour Management Plan	Details
Assessment	City of Edmonton odour monitoring program identified the following from the Waste Management Facility: • sources and nature of the odours • facility as a multi-source with variety of source types • key receptor areas and impacted locations • main or largest contributors to adverse effects
Prevention and Mitigation	Land use planning – facility located in a mainly industrial area Process change – improvements in composting aeration Operational change – improvements to reduce turbulence at lagoon discharge Operational change – maintain water cap on lagoon Management group – facility is part of the local industrial association with an established air monitoring network, results are published and publicly shared Management guide – operating procedures and odour management matrix for staff and contractors to manage operations while minimizing odour generation Establishing community relations – community liaison committee to share information with residents and obtain feedback Establishing community relations – Centre of Excellence offers educational and training programs Engineering controls – installation of wet treatment (biofilter) and recent biofilter media change Neutralizing – installation of permanent and mobile odour neutralizing systems Fence line Monitoring – installation of odour monitoring and forecasting system
Evaluation	Continue use of odour monitoring or surveys Formal complaint tracking, logging and response system Feedback from community liaison committee, industrial association and provincial regulator Real-time odour monitoring and forecasting system

Source: Felske, C. Speers, H. Mumby, A. (2013). *Odour Management at the Edmonton Waste Management Centre: Proceedings from the 2013 Alberta Capital Air Shed Odour Management Workshop Presentation, MacEwan University.* Edmonton, Alberta.

5.2 Secondary Food Processing Facility

A pet foods manufacturing facility operating in Alberta was faced with increasing pressure from neighboring communities and municipal officials regarding the odour impact from their operations. The manufacturer produces high quality pet foods using high inclusions of fresh meats from Albertan farms. While the product is very unique in the marketplace, the production processes involved are fairly common for this industrial sector, and generally involve raw materials receiving, blending, extrusion, drying, coating, packaging, warehousing, and shipping.

The facility has been operating for nearly forty years at their current location. A number of industrial facilities operate within the area, which is designated as a "Business and Industrial Park District". Over the last ten years there has been increasing development of sensitive land uses around the established industries. This has been especially challenging for the pet food manufacturer, which by nature has potentially odorous materials and processes.

In 2009, the company embarked on an odour abatement program. Suppliers were engaged to review the processes and operations from which one supplier was engaged to install and test an emerging technology that was intended to post-treat the exhaust streams from a number of processes. Over the next two years several attempts were made to reliably and consistently reduce the odour impact from the facility. Unfortunately, the odour impact continued and complaints persisted.

Through mounting pressures from the community, it was finally decided in 2012 to bring in a reputable engineering firm with odour management experience. Over the next year the following plan was executed.

Secondary Food Processing Facility

Odour Management Plan	Details
Communications	• Meetings were held with municipal government officials to outline the steps towards developing and executing an odour management plan • A peer review process was set up • General communications were issued to the impacted communities through news media and dedicated website postings
Assessment	• Processes and materials were reviewed • Historical data was compiled and reviewed • Mechanisms leading to odour generation and release were reviewed • Additional testing and odour sampling was undertaken • Existing sensitive receptors and future sensitive land uses were identified • Atmospheric dispersion modelling was conducted to determine baseline impacts
Prevention and Mitigation Planning	• Two-tier targets were set towards minimizing impacts beyond the industrial district and at the sensitive receptors/lands • Preliminary mitigation options were investigated and short listed • Technical feasibility and effectiveness of the short list options were assessed • An abatement plan was developed that included process modifications, redesign of process exhaust systems, facility ventilation design and balancing, improved atmospheric dispersion, and enhanced housekeeping. • Backend treatment of specific process gas streams was incorporated into the plan as an incremental add-on in event of facility expansion or further encroachment of sensitive land uses
Communication	• The abatement plan was presented to municipality officials • A facility tour and presentation was extended to the community • Communications via news media and online postings continued
Implementation	• Tenders were issued to equipment manufacturers and contractors. • Purchase orders & contracts were awarded • Installation, commissioning and start-up was completed
Assessment	• Final reviews and acceptance testing was undertaken • Compliance testing was undertaken to ascertain that the initial targets

Odour Management Plan	Details
	were met
Communications	• Compliance testing results were forwarded to municipality officials • Final communications went out to the community • An open house and presentation was extended to the community • Website remained open for continued dialog with the community • Procedures for formal complaints were maintained
Re-Assessment	• Compliance testing is planned at specific intervals or as needed to confirm that initial targets are being met.

5.3 Development of Odour Guidance from Multi Stakeholder Group

In 2005, the Clean Air Strategic Alliance (CASA) Board established the Confined Feeding Operations (CFO) project team to develop a strategic plan to improve the management of air emissions from the existing and future CFOs in Alberta and to improve relationships between stakeholders. CFOs are generally defined as fenced or enclosed land or buildings where livestock are confined but not grazing or bedding, and not including equestrian stables, auction markets, race tracks and exhibition areas (CASA, 2008). The CASA consensus process was deemed the most beneficial way to address ongoing concerns between the industry, community and regulator.

Developing an understanding of stakeholder concerns, the project team undertook a great deal of work related to pollution prevention, short and long term adverse effects on the environment, and social, economic health effects related to CFO operation. An inventory of priority substance emissions was first established and compared to other industries. Source apportionment was conducted to determine where the emissions are coming from. With a better understanding of the priority substances, management mechanisms were then developed. Other recommendations from the final report (CASA, 2008) included useful guidance documents that pertain to the management of odours and use of prevention and mitigation tools. One of the documents was a study on the potential management mechanisms of biocovers, bottom loading, shelterbelts, composting and dust palliatives. Another document created and published was an Odour Management Plan Template for Livestock Producers in Alberta. This document is an easy to use guide that outlines odour assessment and management principles and outlines various techniques to reduce impacts on neighbours. The template is fashioned in a form of a checklist table listing the process, prevention or mitigation tool, and the resultant qualitative odour potential.

Although this example is not a traditional facility odour management case study, it highlights the benefits of management and multi stakeholder groups as a prevention and mitigation tool and the need for development of guidance documents and research. An additional benefit was that the process fostered good relationships among the various stakeholders and relations were improved.

Development of Odour Guidance from Multi Stakeholder Group

Odour Management Plan	Details
Assessment	• Health questions about ammonia, hydrogen sulfide, VOCs and PM • Public concerns about odour and dust, arising from complaints • CFO emissions generally diffuse • Priority substances inventory and apportionment
Prevention and Mitigation	The working group was a CASA management group consisting of multi stakeholders. It was successful at establishing and fostering community relationships. Guidance Document - Confined Feeding Operations Report promotes the use of: • Land use planning – minimum distance separation • Processing modifications – covers and minimizes discharges and moisture content • Operational modification – frequency of manure removal/application, bottom loading • Shelterbelts Guidance Document – Odour Management Plan for Alberta Livestock Producers promotes the use of: • Land use planning – minimum distance separation • Process modification – lowering discharge points of liquid streams, covers on odorous sources • Operational modification – timing of manure application with time of day and weather, frequency of cleaning and housekeeping, • Engineering controls – mechanical ventilation for indoor facilities • Establishing community relations – speaking and notifying neighbours of potential odour events, establishing a complaint log

Evaluation	• Follow up reports on status of recommendations completed after 4 years • Feedback from publication of guidance documents. • Successes and lessons learned documented and useful for future multi stakeholder projects. • Working group was generally successful and disbanded in 2012.

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7.0 GLOSSARY

Adverse Effect	As defined by the EPEA, "impairment of or damage to the environment, human health or safety or property"
Area Source	A type of odour source with two dimensions, but without a physical height. The odour emission is diffusive and may not be uniform or well understood.
Aerobic	A term to describe processes that require oxygen or conducted in the presence of oxygen.
Anaerobic	A term to describe processes that do not require oxygen or are conducted in the absence of oxygen sources. Some anaerobic processes are known to produce intense offensive odours.
Character (odour)	An odour description which relates the odour to eight general categories and providing a scale on how intensely the odour matches the general category. The different categories include: floral, fruity, vegetable, earthy, offensive, fishy, chemical and medicinal
Collaborative Consensus	A decision making process used by groups seeking to achieve common participation and agreement amongst the group members.
Fugitive Emissions	A term used to describe odour emissions from non-specific, general, unintended or irregular sources.
Hedonic Tone	A characteristic of odour which describes the pleasantness or unpleasantness of the odour. An assessor provides a numerical ranking corresponding to a range from 'very unpleasant' to 'very pleasant'
Hydrocarbon	Chemical term describing an organic compound which contains hydrogen and carbon. These compounds are typically associated with certain processes and industries.
Intensity (odour)	A characteristic of odour that describes the perceived strength and is rated on a numerical ranking system by an odour assessor.

Line Source	An odour source which is long and narrow. This type of source is not common, however vehicle exhaust from roadways can be classified as a line source.
Multi-sources	A type of source which includes different odour sources such as point, area, volume and line. A complex facility with many individual sources can be comprised of roadways, tanks, piping and stacks.
Odorant	A term used to broadly categorize any type of substance which has an odour or causes the sensation of odour.
Odour	A chemical or combination of chemicals resulting in a perceived sensation by the olfactory nerve and the brain.
Odour Assessor	A person who is involved in the analysis of odours by directly inhaling the samples and providing feedback on the various characteristics.
Odour Concentration	A quantitative measure of odour related to the number of dilutions required for an odour to be just detectable or just recognizable. This measure of odour provides a numeric scale and allows for comparison between odours of different characters.
Odour Diary	A tool used for odour assessment, where an observer records the nature of odour and other characteristics on a regular basis and during odorous events.
Point Sources	A type of source which have well defined exhaust parameters (velocity, temperature, odour rate). They are single entity and easily identifiable. They can be elevated or located at ground level.
Prevailing Winds	The predominant wind direction at a certain location over a certain time period.
Nuisance (odour)	A term used to describe an adverse effect or impairment from an odour. The type of impairment is related to circumstances that cause annoyance, loss of enjoyment, and inconvenience.

Residence Time	Describes the duration that a specialized process requires to be completed.
Sensitive Receptor	A high priority odour receptor type, particularly in relation to the potential for adverse effect. Residential and certain institutional land uses (hospitals, care facilities, schools, places of worship) are typically considered as sensitive receptors.
Volume Source	An odour source type similar to area sources, however have a known height dimension. Odour emanating from a volume source can be diffusive, non-uniform and hard to determine.

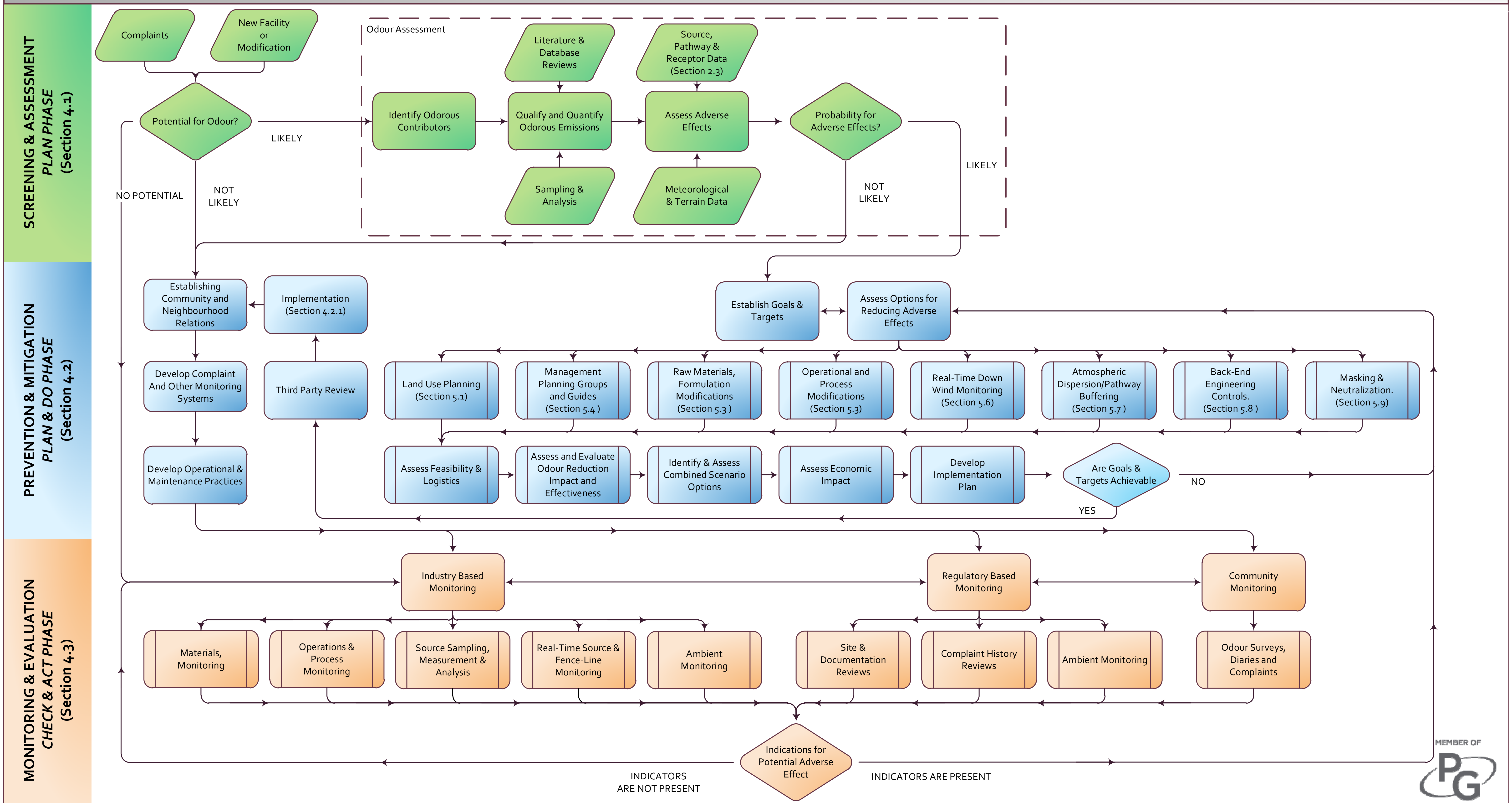
8.0 ABBREVIATIONS AND ACRONYMS

AER	Alberta Energy Regulator
ARD	Alberta Agriculture and Rural Development
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BLIER	Base Level Industrial Emission Requirements
BMP	Best Management Practices
CASA	Clean Air Strategic Alliance
CFO	Confined Feeding Operations
CCME	Canadian Council of Ministers of the Environment
DEC	Department of Environmental and Conservation (Australia)
DEFRA	Department for Environment, Food and Rural Affairs (Alberta)
EC	Environment Canada
EPEA	Environmental Protection and Enhancement Act (Alberta)
ERoRTG	Enforcement and Role of Regulation Task Group
ESRD	Environment and Sustainable Resource Development (Alberta)
FIDOL	Frequency, Intensity, Duration, Odour offensiveness and Location
IAQM	Institute of Air Quality Management
MDS	Minimal Distance Separation
NSW	New South Wales (Australia)
OATG	Odour Assessment Task Group
OMT	Odour Management Team
OMWG	Odour Management Working Group
PDCA	Plan, Do, Check, Act
PM	Particulate Matter
PMP	Pollution and Mitigation Plan
PMTG	Prevention and Mitigation Task Group
RSA	Revised Statues of Alberta
RSO	Revised Statutes of Ontario
SPR	Source - Pathway – Receptor
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound

APPENDIX A - Odour Prevention and Mitigation Charts and Tools

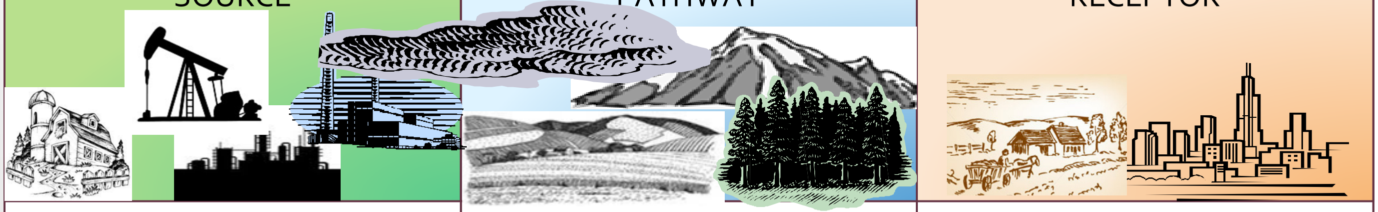
A1 - Guideline for Planners, Regulators and Facility Operators	
Odour Impact Potential	
Source Influence	• Is industry sector known to have odorous emissions? • Are there odorous processes? • Are odorous materials used? • Is there a history of odour complaints from the existing site/facility? • What is the operating schedule of facility, processes & sources?
Pathway Influence	• What is the separation distance between sources and existing/future sensitive receptors? • What is the terrain elevation of the sources and receptors? • What are the terrain features between the sources and receptors? • What are the general meteorological conditions for the local area?
Receptor Influence	• Is there a progression of receptor sensitivity versus distance from odour sources? • What is the receptor sensitivity progression from the odour sources? • Are receptors transient or schedule sensitive (i.e., commercial, offices, places of worship, public spaces, etc.)? • Are receptors housing or places with sleeping quarters? • Are receptors hypersensitive, health vulnerable or otherwise considered more vulnerable? • Are there active community groups, history of complaints or other legacy issues with surrounding neighborhoods?
Odour Prevention and Mitigation Measures	
Source Measures	• Is the site location suitable with respect to surrounding land uses? • Has the site, facilities and sources been strategically located? • Has an odour management plan been adopted or developed for the site, facilities and sources, as applicable? • Are qualified personnel involved with the development, implementation, monitoring and maintenance of the plan? • Have process odours been adequately captured into point sources, where appropriate? • Have point odour sources been controlled and effectively dispersed into the atmosphere, as appropriate? • Have surface, volume & line odour sources been minimized, contained, located, masked or otherwise controlled, as appropriate? • Have fugitive emissions been minimized, contained, located, masked or otherwise controlled, as much as possible? • Is there an ambient odour or odorous compound monitoring system in place for predictive or event monitoring and alarms. • Is there a complaints recording and reporting system in place? • Whom are the personnel responsible for monitoring, recording and reporting complaints, events and alarms? • Are there mechanisms in place for community and regulator communications?
Pathway Measures	• Who is involved with the local land use planning? • Is there an opportunity to address the planning process with respect to separation distance between: existing or future odour source(s); and existing or future sensitive receptors? • Can the pathway between odour sources and receptors be altered or buffered, i.e., berms, trees, foliage, masking application, etc.
Receptor Measures	• Are there current land use plans in place? • Is there an opportunity to address the permitting & licensing process with respect to types of sensitive land uses surrounding existing or future industrial facilities? • Are there community liaison groups or representatives to provide feedback on the planning, permitting & licensing process, on the impact of existing odour sources or on the perceived impact of future odour sources?

A2 - Prevention and Mitigation Planning and Implementation



A3 - Prevention & Mitigation Tools

SOURCE	PATHWAY	RECEPTOR



Community, Industrial & Regulatory Relations

Land Use Planning

- Staged Industrial Zoning, Negotiated & Restricted Uses
- Increased/Dedicated Buffer Zones
- Staged Receptor Zoning, Negotiated & Restricted Uses

SOURCE

- Management Planning & Best Practice Guides
- Product Reformulation & Materials Substitution
- Administrative & Operational Modifications
- Process Modifications
- Back-End Engineering Controls
- Source Masking & Neutralizing

PATHWAY

- Improved Atmospheric Dispersion
- Shelterbelts and Artificial Windbreaks
- Fenceline Masking & Neutralizing

RECEPTOR

- Warning Signage, Agreement Clauses
- Engineering Controls, Receptor Arrangements