MANAGING AIR EMISSIONS FROM CONFINED FEEDING OPERATIONS IN ALBERTA

A Review of Beneficial Management Practices for Managing Undesirable Air Emissions from Confined Feeding Operations

Government of Alberta

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Alberta Agriculture and Rural Development

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Preface

Air quality related to livestock confined feeding operations (CFOs) is an important consideration in the growth and sustainability of Alberta's livestock industry. Emissions of concern include ammonia, bioaerosols (including pathogens), hydrogen sulphide, odour, particulate matter (dust), and volatile organic compounds. Questions have arisen about the impact of these emissions on human health and quality of life, air and environmental quality, and animal health. The Government of Alberta and Alberta CFO industry are taking steps to proactively address CFO air emissions. This comprehensive review of beneficial management practices (BMPs) for managing CFO air emissions is one component of these efforts.

This report stems from a strategic plan entitled *Managing Air Emissions from Confined Feeding Operations in Alberta* that was prepared by the Clean Air Strategic Alliance CFO Project Team in 2008. The report provided 10 recommendations related to improving the management of air emissions from CFOs in Alberta. The sixth recommendation in the strategic plan called for Alberta's Ministry of Agriculture and Rural Development to conduct an in-depth review of five BMPs that have the potential to mitigate the impact of undesirable air emissions from CFOs among other benefits. The five BMPs included, permeable covers for manure storage facilities, bottom loading of manure storage facilities, windbreaks, manure and dead animal composting, and dust palliatives for beef cattle feedlots and unpaved roads.

Alberta Agriculture and Rural Development hopes that the information contained in this report will be of significant value to the CFO industry in Alberta. This information could assist the industry in making well-informed decisions about investments in BMPs for mitigating effects of undesirable air emissions from CFOs. It could also guide decision makers, researchers and extension agents regarding future policies, research topics and extension strategies.

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Executive Summary

This report provides a comprehensive review of information pertaining to beneficial management practices (BMPs) that have the potential to mitigate air emissions of undesirable substances from confined feeding operations (CFOs). As one of 10 recommendations in the Clean Air Strategic Alliance (CASA) CFO strategic plan, it aims to document the efficiency with which a select number of BMPs can reduce undesirable emissions associated with typical CFO livestock production activities or reduce the negative socio-environmental impact of these emissions. Equally of interest are the co-benefits and limitations of each BMP and the economic and social implications of implementing the BMPs. Finally, this report identifies knowledge gaps and offers recommendations to guide future efforts related to air emission BMPs for CFOs.

Six emissions-of-concern were outlined in the CASA CFO strategic plan namely, ammonia (NH_3), hydrogen sulphide (H_2S), particulate matter (PM), odour, volatile organic compounds (VOCs) and bioaerosols (including pathogens). This report examines the effectiveness of five BMPs in mitigating the effects of the six emissions-of-concern from CFOs in Alberta. The five BMPs are: permeable covers for manure storage facilities; windbreaks; bottom loading of manure storage facilities; manure and dead animal composting; and dust palliatives for feedlots and unpaved roads.

1. Permeable Covers for Manure Storage Facilities

Manure storage facilities are significant sources of NH_3, H_2S and odour emissions. Permeable covers can be used to reduce or control emissions of these gases from the storage facilities. Assessing the effectiveness of permeable covers for reducing emissions is extremely difficult because there are no standardized, reliable methods for measuring emissions. Based on the available research, straw covers are perhaps the most cost-effective of all permeable covers and the most producer-friendly means of reducing emissions. Most of the permeable covers evaluated in this chapter are capable of reducing emissions to some degree. NH_3 is the gas pollutant that has been most substantially reduced by the use of permeable covers. All permeable covers reviewed have operational problems, and efforts are underway to resolve these problems.

Recommendations to address key knowledge gaps

- Develop standardized, scientifically sound methods to accurately evaluate and compare the effectiveness of permeable cover technologies.
- Conduct scientifically sound, long-term measurement studies to evaluate the overall efficiency of permeable covers in mitigating NH_3, H_2S and odour emissions.
- Develop more complete information about the life expectancy of straw covers and about the impacts of permeable covers on manure quality.
- If the effectiveness of permeable covers can be scientifically proven, then develop and implement programs to encourage Alberta producers to use these covers.
- Conduct surveys to determine the adoption rate of permeable covers by Alberta producers.

- Improve the ease of use and practicality of permeable covers for Alberta producers.

2. Natural and Artificial Windbreaks

Natural windbreaks, typically called shelterbelts, comprise of rows of trees and shrubs. Artificial windbreaks include windbreak walls, windbreak fences or straw walls. Windbreaks are thought to affect CFO air emissions either indirectly by forcing the emissions to rise to higher elevations where they can be diluted or directly by intercepting, filtering, adsorbing or absorbing the emissions.

Limited information was found in the literature on the effects of windbreaks on concentrations of NH_3, H_2S, PM and odour downwind from livestock facilities. No literature was found on their effects on bioaerosols or VOCs. Of the two types of windbreaks, significantly more information was available on the effects of shelterbelts.

A few comprehensive studies on the effects of shelterbelts were reviewed and are discussed in this chapter. Unfortunately, none of the studies provided conclusive evidence to show that shelterbelts can effectively reduce concentrations of NH_3, H_2S, PM and odour downwind from livestock facilities. In some cases, it seemed that the natural effects of the microclimate may have affected the results. In others, experimental designs and procedures used to conduct the studies raised doubts about the results.

Recommendations to address key knowledge gaps

- Although the effects of shelterbelts on CFO air emissions are inconclusive, shelterbelts have many other environmental, social and economic benefits. Thus, it may be worthwhile to further investigate their effects on air emissions despite the challenges of such studies.
- Develop a research plan to study the effectiveness of shelterbelts in mitigating the impact of NH_3, H_2S and PM emissions. Include measurement of source emission concentrations in the plan.
- Due to the complexity, uncertainty and costly nature of odour studies, considerable, detailed planning is required to evaluate the effectiveness of shelterbelts as a mechanism for odour control.
- Consider examining the effect of shelterbelts at the minimum distance separation, as per Alberta's *Agricultural Operation Practices Act* and Regulation.

3. Bottom Loading of Liquid Manure Storage Facilities

Bottom loading and top loading are methods of transferring liquid manure from an animal housing facility to a manure storage facility. Bottom loading involves discharging the manure below the surface of the stored manure, and top loading involves discharging the manure above the surface.

Bottom loading is considered to be a practical, common sense method of transferring manure. Producer experience and limited studies indicate that bottom loading results in lower air emissions from open, outdoor manure storage facilities, than top loading. Top loading causes more emissions because it causes much more splashing and disturbance of stored liquid manure.

Recommendations to address key knowledge gaps

- Quantify and compare the effects of bottom loading and top loading on air emissions from open, outdoor manure storage facilities. Such research will require careful design and planning to minimize costs and complexities.
- If bottom loading can be scientifically proven to significantly decrease air emissions, then conduct a detailed evaluation of the costs and benefits of retrofitting to determine if it might be appropriate to require manure storage facilities with top loading systems be retrofitted with bottom loading systems.

4. Manure and Dead Animal Composting

Composting is the biological decomposition and stabilization of organic materials that occur under conditions that allow temperatures higher than 40°C to develop from biologically produced heat. These conditions produce a final product that is stable and free of viable pathogens and plant seeds, and can be beneficially applied to the land.

Manure and dead livestock are two types of organic material that can be successfully composted. Manure composting systems can be categorized as active or passive. Typical active manure composting methods include turned windrows, in-vessel or reactor systems, and forced aeration systems, while passive methods include natural aeration and passive aeration systems. Due to their inconsistent nature, composting livestock carcasses does not follow the traditional composting process of mixing all the materials thoroughly before establishing compost piles. Instead, a layering technique consisting of carcasses and carbon material is used.

There is limited literature on the effects of manure or mortality composting on air emissions relative to livestock production. Furthermore, emission rates from non-point sources, or area sources, such as compost piles are difficult to determine accurately. There is no standardized sampling or measurement technique, and there are many uncontrollable factors and conditions that affect emission measurements.

Recommendations to address key knowledge gaps

- Develop standardized, efficient methods of measuring air emissions from animal manures and mortalities so the effects of different practices on these emissions can be determined and compared.
- Develop protocols for composting research so that, when a study is designed to determine emissions from what is supposed to be a composting medium, the necessary steps will be taken to control factors such as temperature and oxygen level to ensure that the composting process actually occurs within the medium.
- Determine emissions from composting manure and stockpiled manure under Canadian conditions.

- Determine emissions from traditional animal mortality disposal methods compared to mortality composting.

5. Dust Palliatives for Beef Cattle Feedlots and Unpaved Roads
The main sources of PM, or dust, related to CFOs are unpaved roads and open beef cattle feedlots. Depending on the dust particle size, dust concerns may relate to human and livestock health, the sanitary nuisance caused by dust, and driving risks associated with reduced visibility.

A few techniques have been developed to estimate dust emissions from unpaved roads. Studies have also been conducted to determine dust emissions from feedlots. However, significant variations in emissions have been reported for a variety of reasons, including meteorological influences, inaccuracies in estimation methodologies, etc.

Several types of dust palliatives are used to suppress dust from unpaved roads and feedlots. They include: water; hygroscopic salts and brines; organic non-petroleum products; synthetic polymer products; organic petroleum products; electrochemical products; clay additives; and mulches. In Alberta, the most commonly used dust palliatives are calcium chloride ($CaCl_2$) and lignin sulphonate for unpaved roads, and water for feedlots.

The effectiveness of dust palliatives is highly variable, depending on the product, application method, site conditions and weather. The few studies for unpaved roads reported dust emission reductions ranging from 10% to 92% for different products. Their effectiveness has been reported to last from less than an hour to up to 3 years, depending on the product. $CaCl_2$ and lignin sulphonate have been reported to be effective for 6 to 8 months. Dust palliatives for feedlots appear to be limited to water and mulch. The limited information on their effectiveness suggests reduction efficiencies ranging from 10% to 88%, but the results do not provide any degree of certainty.

Recommendations to address key knowledge gaps
- Investigate and quantify the effectiveness and potential residual effects of various dust palliatives for unpaved roads and feedlots, using sound scientific and statistical principles. This research will likely require significant funds, labour and time.
- Conduct an in-depth review and research of dust emission mitigation mechanisms used by other jurisdictions around the world.

6. Social Considerations of Select Beneficial Management Practices
CFO air emissions present serious social, political and legal challenges. Social conflict is a key theme between livestock operators and their neighbours. Social concerns are often expressed by nuisance or odour complaints, and in some cases, through political and legal venues.

From a social perspective, odour is the key CFO air emission issue. Although odours can be measured objectively, measurement requires sophisticated instrumentation and sampling protocols, and it is extremely difficult to identify whether an odour limit has been exceeded. The level of acceptance of odours is affected by social considerations. For example, one study found that those lacking strong ties to a rural area were more likely to harshly judge air emissions.

This chapter considers eight BMPs, including the five discussed in the preceding chapters as well as manure application techniques, frequent manure removal and solid manure moisture management. For the most part, adequate information to assess the social potential of the eight BMPs was lacking in the literature. The main BMP discussed in the literature was manure application, with liquid manure injection offering the best potential for addressing odour complaints. Covers for manure storage facilities and shelterbelts also showed promise from a social perspective; they are relatively inexpensive for CFO operators and may be more pleasing from a visual or "natural" perspective.

Introducing new BMPs or changing regulations to ensure their implementation presents significant social challenges for communities and the livestock industry. Dialogue and informed opinion were felt to be important for avoiding conflict and reducing complaints.

Recommendations to address key knowledge gaps

- Assess which BMPs work best in terms of providing societal benefits, and under which circumstances.
- Obtain and evaluate the livestock industry's views on the BMPs.
- Test acceptable emission standards and measurement techniques and communicate them to communities.
- Encourage education and dialogue among all stakeholders, and increase understanding of the social effectiveness of the BMPs. For example, CFO operators could notify neighbours when a new or modified BMP is implemented and request their feedback. This would help enhance communication, help evaluate the BMP's social value, and possibly reduce odour complaints.
- Increase knowledge of nuisance substances and their potential social and health impacts.

7. A Review of Potential Costs and Benefits of Select Beneficial Management Practices

This chapter evaluates the same eight BMPs as the preceding chapter in terms of their potential costs and benefits from reducing CFO air emissions. For each BMP, the author attempts to identify the on-farm costs, emission reduction potential and potential public health benefits from implementing the BMP. For bottom loading and moisture management, there was not enough information on costs to conduct the evaluation. Some of the other BMPs lacked sufficient information to allow estimation of emission reduction potential, and some lacked sufficient information to allow estimation of potential health benefits.

Consequently, only four BMPs could be ranked based on their potential net benefits: permeable covers, shelterbelts, dust reduction mechanisms for beef cattle feedlots, and dust reduction mechanisms for unpaved roads. Shelterbelts rank highest in terms of potential net benefits primarily because of their impact on a suite of emissions. They are also one of the lowest cost BMPs. In addition, shelterbelts offer many other benefits not valued in this report, such as carbon offsets, erosion control and habitat for wildlife. Dust reduction mechanisms for unpaved roads have the second highest net benefits, dust reduction mechanisms for feedlots rank third, and permeable covers rank fourth.

Recommendations to address key knowledge gaps

- Determine the costs for manure storage bottom loading systems and solid manure moisture management BMPs.
- Assess the effectiveness of BMPs in reducing specific emissions.
- Evaluate the effects of chronic exposure to low levels of H_2S to determine the value of emission reductions.
- Assess the value of health benefits from reducing bioaerosol emissions.

Chapter 1.0

Permeable Covers for Manure Storage Facilities

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Contents

1.1 Introduction

Manure storage covers are generally placed over liquid storage units to provide a physical barrier between the liquid manure surface and the atmosphere. Effective manure storage covers can play a key role in controlling undesirable air emissions from livestock operations. By reducing gas emissions from confined feeding operations (CFOs), producers will help maintain the quality of the environment, prevent losses of significant portions of nutrients and protect human, animal and ecosystem health and well-being.

When a cover is placed directly over a manure storage surface, the following processes apparently take place (Nicolai et al. 2005):

- Resistance to mass transfer is increased. Mass transfer of gases between the liquid surface and air is driven by a concentration gradient as described by the two-film theory (VanderZaag et al. 2008).

- Gas concentration builds up under the cover.

- A permeable cover acts as a biofilter by providing a large surface area and aerobic zone that hosts and supports microbial populations that degrade compounds that would otherwise contribute to undesirable emissions (Powers 2004).

Manure storage covers can be classified as impermeable or permeable (Nicolai et al. 2005). Impermeable covers do not allow gases to escape from the manure storage to the atmosphere while permeable covers allow slow release of gases from storage. Impermeable covers are very effective in reducing gas emissions from manure storage, but are very expensive and need more management than permeable covers. In this review the focus is on permeable covers only.

1.2 Permeable Covers

Permeable covers on outdoor manure storage facilities have recently gained some popularity in parts of Canada and the United States because they usually work very well, are easy to manage and are affordable (Lorimer et al. 2001). They have also been used with success in other parts of world such as Australia (Hudson et al. 2006a, 2006b, 2008).

Permeable covers provide a temporary alternative solution to expensive, longer lasting impermeable covers (Burns and Moody 2008). Permeable covers include covers made of organic material like straw, peat moss or vegetable oil, geotextiles, light expanded clay aggregates (LECA) or perlites. Zhang et al. (2002) reported that of all permeable covers, straw covers are perhaps the most cost-effective and producer-friendly means of reducing odour and other air pollutants from outdoor manure storage facilities (MSFs).

MSFs are sources of air pollutants such as ammonia (NH_3), hydrogen sulphide (H_2S) and odour. Therefore MSF covers have been widely used to reduce emissions of these pollutants (Funk et al. 2004b; Miner et al. 2003; Zahn et al. 2001; Clanton et al. 1999). Ammonia emissions decrease the nutrient value of manure and represent a significant loss of fertilizer value. The emissions have negative effects on the environment such as soil acidification and eutrophication[1] of surface water. Ammonia that is lost to the atmosphere combines with nitric acid to form aerosol nitrate, which contributes significantly to total particulate matter. Aerosol nitrate particles can have serious effects on human health and can cause the air to become hazy resulting in reduced visibility while driving. Hydrogen sulphide is considered both an odour nuisance and a health hazard. High concentrations of this gas can be deadly to humans. Odour nuisance can impact the growth and expansion of the livestock industry.

A number of comprehensive reviews that focused on the ability of permeable covers to mitigate NH_3, H_2S, odour and greenhouse gas (GHG) emissions were conducted recently (English and Fleming 2006; Burns and Moody 2008; VanderZaag et al. 2008). Similarly this comprehensive review focuses on analyzing and synthesizing the findings of various studies that have examined the effectiveness of permeable covers as a mechanism for controlling gas emissions. It identifies research and extension gaps related to permeable covers and offers recommendations geared towards the advancement and adoption of permeable cover technology. This study focuses on organic permeable covers and geotextile covers because they are popular among producers, globally, and have been frequently studied. It also reviews LECA covers because of their promising prospects.

1.2.1 Straw covers

A permeable organic cover, as the name implies, is composed of organic material (e.g. wheat straw, barley straw, chopped cornstalks, sawdust, wood shavings, rice hulls, etc.) that is blown to cover the surface of stored liquid manure up to a depth of about 0.25 m (Bicudo 1999). Producers prefer to use straw because it is available at a low cost and its waxy coating keeps it floating longer than other materials such as cornstalks (Nicolai et al. 2005). In view of this, only straw covers amongst the organic covers are reviewed here.

Specialized equipment is required to shred and process straw before it can be applied to the manure surface. A straw applicator device is typically required to broadcast the straw uniformly across the entire manure surface. According to Nicolai et al. (2005), straw covers perform best over semi-solid manure storage systems where the manure has a solids content ranging between 4% and 10%.

A supplementary floating system, such as polystyrene sheets, may also be used to support the straw and keep it dry for a longer time. PAMI (1996) tested a number of floatation methods and found most of them increased the longevity of straw covers compared to unsupported straw

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[1] Water is rich in nutrients that support aquatic plants. Excessive plant growth results in oxygen depletion, which kills fish and other aquatic animals.

covers. Floating polystyrene sheets work well to support straw covers that are intended to be used more than once. PAMI (1996) observed that polystyrene sheets helped keep organic permeable covers dry over an entire summer of use. However, with floating polystyrene sheets, some care is required in the choice of pump-out equipment (PAMI 1996).

Floating oil bottles can also support straw covers. However, some oil bottles sink and can cause pump-out problems. PAMI (1996) suggested that floating oil bottles should not be used unless the bottles can be tightly sealed.

In addition, appropriately sized and designed agitation equipment and a pressurized delivery tank are required to prevent plugging of pipelines by straw (Zhang et al. 2002). PAMI (1993) reported that straw covers do not cause unmanageable earthen manure storage (EMS) pump-out times. Where problems exist, a slight change in method or equipment can facilitate pumping activities. Furthermore, agitating and chopping the straw can make mixing and pumping of manure easier.

1.2.1.1 Advantages and disadvantages

Although straw covers are simple to install, are relatively inexpensive, require minimal labour, and are effective in reducing odour and other gases, they have a number of drawbacks and disadvantages (Jacobson et al. 2001a):

- Straw covers work best when the straw is spread evenly and with consistent thickness. However, it is difficult to spread straw evenly during application especially when applying it to large MSFs (Burns and Moody 2008; English and Fleming 2006). Nicolai et al. (2005) stated that it is impractical to use straw covers on MSFs that are over 0.81 ha in area because wave action on these large areas will disturb the straw cover.
- Straw covers cannot be easily installed on earthen MSFs (Nicolai et al. 2005).
- Straw covers are vulnerable to extreme weather conditions such as wind, temperature, humidity and light intensity that can adversely affect their performance (Bicudo et al. 2004; Funk et al. 2004a). They inhibit evaporation but permit precipitation to enter the MSF.
- Straw covers have the potential to sink should the stalks become saturated and as a result, need to be replaced frequently. Normally two applications (spring and fall) are required in most parts of Canada (Zhang et al. 2002). MSF and manure characteristics can also play important roles in determining the frequency of straw application. Applying straw covers to coincide with those seasons when peak emissions occur may be a way to get by with only one application (A. VanderZaag, Postdoctoral Fellow, University of Guelph, Guelph, ON, pers. comm.).
- Additional agitation of the manure prior to pumping is required in MSFs that use straw covers (Williams 2003) because straw adds to sludge build-up, which may be difficult to remove.
- Indirectly, a straw cover can cause an increase in the volume of manure that must be transported by inhibiting evaporation from an MSF but permitting precipitation to enter the

MSF. The extra cost to transport the additional volume during pump-out can be significant (Zhang et al. 2002).

- Straw covers increase the possibility of attaining higher concentrations of nitrogen and volatile organic compounds (VOCs) in manure. This raises the potential for more significant odour events during pump-out compared to odour events from uncovered MSFs (Bicudo et al. 2001).
- In addition, straw covers do not allow for the capture of GHGs (Berg et al. 2006).

1.2.1.2 Durability

According to Nicolai et al. (2005) and Jacobson et al. (1997), straw covers usually last between 2 months and 6 months depending on the amount of straw applied (depth of straw), uniformity of application, size of the MSF, surface area of the MSF, manure characteristics and wind conditions during application. Mannebeck (1985) estimated the lifetime of straw covers to be just 6 months. Powers (1999) cited a study that showed that only 50% of the straw cover remained 4 months after installation. However, a lifespan of at least 1 year can be achieved if the straw cover is supported by a floatation system (Hudson et al. 2006a).

Some factors that affect durability of straw covers include:

- **Straw quality:** The quality of straw is important in prolonging the durability of straw covers. Research conducted by PAMI (1993) proved that good quality straw (longer stalks, relatively dry, fresh, unweathered, and no mould) lasted longer than poor quality straw (shorter stalks, wet and mouldy). PSCI (2004) reported that any type of cereal straw and even poor quality straw might work effectively when a floatation system is used to support the cover.

  When a straw cover is unsupported, PAMI (1993) found that barley straw is preferred compared to wheat straw because its waxy nature prevents it from absorbing moisture, thereby enabling it to last longer than wheat straw. Conversely, Nicolai et al. (2005) emphasized that there is no significant difference between the performances of barley and wheat straw covers.

- **Straw thickness:** The thickness (depth and density) of a straw cover plays an important role in determining the performance and effectiveness of the cover. A minimum of 4 kg of straw per m^2 of manure surface was recommended by Hörnig et al. (1999) to prevent windy conditions from disrupting the even distribution of a chopped straw cover. Kowalewsky and Fübbeker (1998) recommended an application rate of 7 kg of straw per m^2 of manure surface. A higher application rate of 10 kg of straw per m^2 was recommended by Lundgaard et al. (2004) to establish a 20-cm thick floating straw cover.

  A straw cover thickness of 0.2 m is considered to be the lowest effective limit. Alternatively, Clanton et al. (2001) stated that a thickness of 0.3 m is preferable because the latter thickness helps keep straw material afloat by decreasing the density per unit manure surface area. It also helps keep the upper layer of the straw cover sufficiently dry, enabling the straw to absorb gases and act as a biofilter. Other studies have also shown that a depth of 0.3 m is effective for the optimum performance and durability of MSF straw covers (Nicolai et al. 2005; Bicudo et al. 2001; Jacobson et al. 1997). According to PAMI (1996), two or three reapplications would likely be required if the initial straw depth was 0.10 m to 0.15 m.

- **Solids content of manure:** The solids content of manure can affect the lifespan of straw covers. A study by UKMAFF (2000) found that a straw cover on water that was exposed to rainfall sank in less than 7 days, while a straw cover on manure with a total solids content of 8% maintained 80% of surface coverage for 40 days after exposure to rainfall. Even with exposure to rain, Guarino et al. (2006) found wheat straw and maize stalks remained afloat when placed on manure with 4% total solids during the first 3 months of testing.

- **Oil application:** Application of vegetable oil to the first layer of straw spread on the surface of an MSF seems to be the most effective method of extending straw floatation time. Vegetable oil application is estimated to extend the lifetime of straw covers to twice their lifetime without oil (Filson et al. 1996; Schmidt 1997; Clanton et al. 1999). However, it is unclear if the application of oil to a straw cover may have an adverse environmental impact (Clanton et al. 1999; Pahl et al. 2002; Williams 2003).

- **Floatation systems:** Zhang et al. (2002) suggested that the durability of a straw cover can be extended by combining it with geotextile fabric or some other floatation system such as polystyrene pellets. PAMI (1993) investigated the effectiveness of eight straw floatation systems. These included two sizes of bubble packs (plastic shipping packing material), Geogrid™ (polyethylene material often used to help stabilize slopes during road construction), bale wrap, Plastispan™ (expanded polystyrene), two types of plastic bottles and polyurethane foam. In general, the study concluded that floating systems resulted in increased straw cover longevity compared to unsupported covers.

1.2.2 Geotextile covers

These are synthetic fabrics made from woven or spun polypropylene material. Polypropylene filaments have excellent mechanical and hydraulic properties. Polypropylene is resistant to rot, moisture (Clanton et al. 2001; Koerner 2005), and chemical attack, and has a specific gravity of 0.9 that enables the material to float on water (Clanton et al. 2001). Thus, geotextile covers are self-floating and provide a physical barrier to mass transfer of gases from the liquid to the air (Nicolai et al. 2005). Geotextile covers must be properly and securely installed to maintain the integrity of the covers and to keep them afloat as the MSF is filled, agitated, and pumped out (Burns and Moody 2008).

1.2.2.1 Advantages and disadvantages

Bicudo et al. (2004) reported that new generation geotextile covers have properties that protect them from damage that can result from exposure to ultraviolet radiation from the sun.

Furthermore these types of covers comprise of one or more foam layers to improve flotation and performance. Although they have a relatively high initial cost compared to straw covers, geotextile covers provide a better solution than straw covers for MSFs that are not agitated and pumped annually. In addition, because geotextile covers are porous they do not trap gases that could otherwise cause the cover to balloon, ultimately impacting their performance (Lorimer et al. 2001). Furthermore, geotextile covers do not present issues with rain or snow loads.

Along with the disadvantage of a high initial cost, geotextile covers are difficult to install over EMS facilities. As well, geotextile covers have been reported to pose some challenges to manure agitation and pump-out and subsequently raised safety concerns (Bicudo et al. 2004). Depending on the installation and setup of a geotextile cover, the cover may sink to the bottom of the MSF after manure in the facility has been pumped out. Consequently, the cover could become partially submerged as the MSF is filled with manure again. Unless these issues are resolved, geotextile covers are not recommended for MSFs where frequent pumping or rigorous agitation is required (Nicolai et al. 2005). Eventually, when a geotextile cover has outlived its usefulness, its disposal and the associated costs may also be cause for concern (Nicolai et al. 2005).

1.2.2.2 Durability

Generally, geotextile covers typically have a lifespan of 3 years to 5 years, although some new generation covers can last up to 10 years (Bicudo et al. 2004). Some geotextile covers are not protected against UV radiation, which causes material deterioration and reduces the lifespan of the cover (Nicolai et al. 2005). Adding a layer of closed-cell foam between two types of geotextile material can extend the life of this type of cover and prevent it from sinking (Burns and Moody 2008).

1.2.3 Floating clay balls

Light expanded clay aggregate (LECA) is a special type of clay that has been pelletized and fired in a rotary kiln at very high temperatures. During firing, organic compounds in the clay are burnt off forcing the pellets to expand and become honeycombed while the outside surface of each granule melts and is sintered. The resulting ceramic pellets are lightweight, porous and have a high crushing resistance (Clayteck 2008).

One type of LECA (Leca®, Trading and Concessions A/S, Copenhagen, Denmark) is made from clay, as the product name implies, and has multi-purpose uses and applications including, filtration and purification of wastewater and drinking water. Another type of LECA (Macrolite®, Kinetco, Inc., Newbury, OH) is made from processed mineral oxide.

1.2.3.1 Advantages and disadvantages

Compared to straw covers, LECA covers stay afloat longer and are not impacted by the wind (Burns and Moody 2008; Guarino et al. 2006). LECA could be applied without any problem onto irregularly shaped and circular manure tanks (A. VanderZaag, Postdoctoral Fellow, University of Guelph, Guelph, ON, pers. comm.; Williams 2003).

However, unlike straw covers, LECA covers have a high initial capital cost. Williams (2003) reported that LECA covers reduce evaporation rates and hence most rainwater is retained in slurry, so these covers increase slurry handling costs. In addition, care must be taken during manure agitation and pumping, and LECA covers are not recommended for MSFs that require frequent pumping or rigorous agitation (Funk et al. 2004a). For example, LECA covers are not suitable for manure slurries with high solids contents since the pellets have only limited ability to re-establish themselves as a uniformly distributed cover following agitation and pump-out. Furthermore, practical experience using LECA covers is limited. This becomes evident when attempting to distribute the cover uniformly over manure in an MSF with a large surface area.

1.2.3.2 Durability

LECA covers have a relatively long lifetime spanning 10 years (Burns and Moody 2008).

1.3 Impact of Permeable Covers on Gas Emissions

Permeable covers physically inhibit the emission of gases from the surface of manure in MSFs. They create biologically active zones where emitted gases are aerobically decomposed by microorganisms (Powers 1999; Spellman and Whiting 2007). Furthermore, permeable covers reduce gas emissions by reducing the effects of solar radiation and wind velocity on the manure surface (Powers 1999).

According to Jacobson et al. (2007), the reported effectiveness of technologies used to control emissions from CFOs, including MSFs, vary widely. They attributed the variability to inherent differences in the technologies under investigation and to differences in test protocols and methodologies used to evaluate the technologies. Furthermore, Jacobson et al. (2007) noted that because the test protocols and methodologies varied considerably, it was difficult to summarize and compare test results of various studies.

This review focuses on emission reduction values published in scientific journals or presented at technical conferences or seminars. Each publication was ranked based on a set of criteria that included whether or not the publication was peer reviewed, nature of the experimental design, equipment and measurement protocols used, statistical data analysis performed, etc.

1.3.1 Ammonia

Many laboratory and field studies have shown that NH_3 emissions from MSFs can be reduced if the facilities are covered with permeable covers.

1.3.1.1 Straw covers

Straw covers can reduce NH_3 emissions either by increasing surface resistance to NH_3 gas attempting to escape from the manure surface, by reducing the emitting surface area, or by a combination of both (Portejoie et al. 2003). Olesen and Sommer (1993) reported that surface resistance had significant influence if a manure surface was covered by a 0.15-m thick straw layer. Nicolai et al. (2005) and Ndegwa et al. (2008) reported that the effectiveness of straw covers in reducing NH_3 emissions ranged between 37% and 90%. It is not clear what sources of variation existed between the different studies, but it seems that the type and nature of the various experiments and ammonia measurement techniques contributed to the differences. In other words, the confidence and dependability of these results are at best, uncertain.

Xue et al. (1999) conducted a study to quantify the changes in overall mass transfer coefficients of NH_3 as affected by different thicknesses of a wheat straw cover applied to a dairy MSF. NH_3 measurements were conducted based on a method developed by Xue et al. (1998). Xue et al. (1999) used a two-stage two-trap series with each stage consisting of a vacuum trap followed by an adsorbing flask. The first stage contained 1 N (0.5 M) sulphuric acid for selective absorption of ammonia and amines; and the second stage consisted of 0.1 N (0.1 M) zinc acetate in 0.1 N (0.1 M) sodium hydroxide solution to absorb and preserve the evolved hydrogen sulphide. They found that two thicknesses, 0.05 m and 0.10 m, were effective in reducing emission rates of NH_3 by 60% to 95%. The reduction of NH_3 emission by the straw cover was attributed to a decrease in pH of the manure, or possibly biological reactions, in addition to the physical barrier created by the straw.

Hörnig et al. (1999) conducted laboratory and field studies in which straw covers, 0.05 m to 0.15 m thick, were applied to swine manure collected from an MSF or stored in the MSF. Ammonia was measured with a photo-acoustic gas monitor (Brüel and Kjær, Type 1302, Nærum, Denmark) using a chamber placed over the covered or uncovered manure surface. In this study, NH_3 emissions were reduced by 80% when straw covers were used.

Guarino et al. (2006) investigated the effectiveness of five simple floating covers in reducing emissions from pig and cattle slurry. The coverings included vegetable oil (a mixture of canola and soybean oil), expanded clay, chopped maize stalks, chopped wheat straw, and chopped wood chips. Results of this experiment revealed substantial differences in ammonia emission reduction efficiencies, ranging between 1% and 100%.

VanderZaag et al. (2009) conducted a study investigating the effect of floating barley straw covers on emissions from liquid dairy manure during the storage period when the manure remained relatively undisturbed and at the end of the storage period while the manure was being mixed (agitated) prior to pump-out. They found that during the undisturbed storage period (122 days), two straw cover treatments at thicknesses of 0.15 m and 0.30 m reduced NH_3 emissions by 78% and 90%, respectively. After the storage period and while the manure was being agitated, the 0.15-m and 0.30-m straw cover treatments reduced NH_3 emissions by 68% and 76%, respectively.

1.3.1.2 Geotextile covers

Limited literature specifying the effects of geotextile covers on air emissions was found. Rather the literature seemed to focus primarily on the effects of geotextile covers in combination with other types of organic or inorganic permeable covers. According to Clanton et al. (2001), individually, geotextile covers are not as effective at reducing ammonia emissions from MSFs as straw covers.

Bicudo et al. (2002) conducted a 2-year research study evaluating the performance of geotextile covers on earthen MSFs compared to uncovered facilities. Comparatively and on average, NH_3 emissions were reduced by 44% by the geotextile cover.

Based on the results of Clanton et al. (1999), Clanton et al. (2001) conducted a laboratory-scale study to evaluate the effects of four thicknesses of geotextile fabric in combination with four thicknesses of chopped oat straw covers, on reductions in NH_3, H_2S and odour emissions from swine and dairy manure stored in vessels. Two out of the 32 geotextile-straw cover combinations served as control treatments (one dairy manure and one swine manure) with no geotextile cover or straw cover on the surface of the manure in their respective vessels. NH_3 concentrations in air samples collected from the headspace of the vessels were measured using a boric acid trap. Clanton et al. (2001) reported NH_3 emission reductions of 37%, 72% and 86% by straw covers that were 0.10 m, 0.20 m and 0.30 m thick, respectively, regardless of the thickness of the geotextile fabric covering the surface of the dairy or swine manure. In another study, a composite cover comprising of recycled polyethylene and geotextile fabric was observed to reduce NH_3 emissions by 80% (Miner et al. 2003). In the latter study, NH_3 concentrations were measured at a height of 0.30 m above the surface of the MSF using denuder tubes suspended above the MSF for a period of 4 h to 6 h, both before and after the cover was installed.

Seven different kinds of inorganic (geotextile and polyethylene foam) and organic (straw and redwood chips) permeable covers were evaluated by Regmi et al. (2007). These covers were tested on an operating swine MSF. A floating sampling raft was developed and used to simultaneously sample air from the MSF. No statistically significant reduction in NH_3 emissions was observed relative to any of the covers.

1.3.1.3 LECA covers

In comparison to straw covers, LECA covers have been reported to be more effective at reducing NH_3 emissions (de Bode 1990; Miner and Suh 1997; Hörnig et al. 1999). In general LECA covers reduce NH_3 emissions by more than 80% (Balsari et al. 2006; Sommer et al. 1993; Williams 2003; Berg et al. 2006).

Balsari et al. (2006) evaluated Leca® for its ability to reduce losses of NH_3 from the surface of liquid swine manure. NH_3 emission was measured with the aid of a wind tunnel. NH_3 emitted from the covered (Leca® balls) and uncovered slurry, respectively, was measured simultaneously over 24 h for 6 consecutive days. Measurements were conducted in spring, summer, autumn and winter over 1 year. A significant reduction in NH_3 emissions (87%) with the placement of a 0.10-m thick Leca® cover was recorded in this experiment.

Sommer et al. (1993) simultaneously measured NH_3 losses from pig and cattle slurries stored in eight manure storage tanks using wind tunnels. The slurry was either stirred weekly (uncovered), or was allowed to develop a natural surface crust. Oil, peat, chopped cereal straw, PVC foil, Leca® and a lid were tested as additional covers. They found about 85% reduction in NH_3 emissions from the cattle slurry and between 88% and 95% reduction in NH_3 emissions from the swine slurry when covered with Leca® pellets as compared to uncovered slurries. Similarly, research conducted at Iowa State University indicated that covering swine manure with about a 0.04-m thick layer of Leca® pellets reduced NH_3 emissions by about 95% (Bundy et al. 1997).

Williams (2003) conducted lab and field experiments to investigate the effect of different covers on NH_3 emissions from cattle manure. However, Williams (2003) did not describe the NH_3 measurement techniques and methodologies used in the study. NH_3 emissions were reported to be reduced by 82% after the application of Leca® pellets to the surface of the manure in a storage tank. Williams (2003) noted that the effectiveness of the pellets in reducing NH_3 emissions increased with increasing cover depth, up to a depth of about 0.03 m. Beyond 0.03 m, very little was gained in cover effectiveness.

1.3.2 Hydrogen sulphide

Several studies have investigated the reduction of H_2S emissions by straw covers. Xue et al. (1999) conducted a study to quantitatively evaluate the effectiveness of different thicknesses of wheat straw covers for reducing ammonia and hydrogen sulphide. The study is described in more detail in section 1.3.1.1. Xue et al. (1999) found that the combination of a straw cover, applied to dairy manure to a depth of 0.10 m to 0.12 m, and the naturally occurring manure crust, reduced H_2S emissions by 95%.

Clanton et al. (1999) conducted an experiment to evaluate the use of organic and inorganic floating covers to reduce odour and H_2S emissions from swine manure. Seven treatments, including a control treatment (i.e. no cover), a straw cover treatment, vegetable oil cover treatment, combined straw and oil cover treatment, clay ball cover treatment, composite PVC and rubber membrane treatment, and geotextile membrane treatment, were tested on swine manure stored in polyethylene tanks. Air samples were taken from the tanks and tested for H_2S using a Jerome® meter. Clanton et al. (1999*)* concluded that both straw cover treatments and the composite PVC and rubber membrane treatment significantly and consistently reduced H_2S emissions (82% to 94%) when measurements were taken 24 h after the treatment tanks had been filled with fresh batches of manure. The 0.20-m thick clay ball cover treatment appeared to significantly reduce H_2S emissions by 64% to 84%.

In a later study, Clanton et al. (2001) observed reductions of 93%, 98%, and 98% in H_2S emissions from manure with straw covers that were 0.10 m, 0.20 m and 0.30 m thick, respectively. Little additional reduction in H_2S (or NH_3 or odour) was gained by increasing the thickness of the straw cover to 0.30 m. Thus, a minimum straw cover thickness of 0.20 m was recommended.

1.3.3 Odour

A number of studies have been conducted and have shown varying effects of straw covers on reductions in odour emissions from manure. Nicolai et al. (2005) estimated that odour reduction could vary from 90% for a newly applied cover to 40% or less depending on straw cover thickness and uniformity of application.

Li et al. (1997) used steel tanks, measuring 1.8 m in diameter by 1.2 m high and filled with manure to a depth of 0.9 m, to test the effectiveness of straw covers in abating odour emissions. Odour reduction was evaluated by using a dynamic forced-choice olfactometer. Results published by Li et al. (1997) suggested that a 0.25-m thick wheat straw cover reduced odour emissions consistently by more than 86% over a 9-week period. A 0.15-m wheat straw cover was also effective in reducing odour emissions by more than 84% over the 9-week period. Jacobson et al. (2001b) reported that straw covers, 0.10 m, 0.20 m and 0.30 m thick, reduced odour emissions by 60%, 80% and 85%, respectively.

Clanton et al. (1999) concluded that their straw cover treatments significantly and consistently reduced odour emissions from swine manure stored in manure storage tanks, apparently by 61% to 84%. Odour concentration was measured via dynamic forced-choice olfactometer. Tests conducted with the geotextile membrane cover showed a significant reduction of 59% in odour emissions in only one out of three scenarios in which a fresh batch of manure was added to the tanks. In the other two scenarios, no significant difference was observed when the geotextile membrane cover was used. Clanton et al. (2001) supported the findings of Clanton et al. (1999). Clanton et al. (2001) reported that odour levels were reduced by 47% to 63%, 69% to 78%, and 76% to 83% when manure (dairy or swine) was covered with straw 0.10 m, 0.20 m, and 0.3 m thick, respectively. Furthermore, Clanton et al. (2001) concluded that the geotextile fabric cover used in their study was not effective in reducing odour.

Bicudo et al. (2004) conducted a study to evaluate the effects of geotextile fabric covers on odour and other emissions from manure stored in earthen MSFs versus uncovered MSFs. Odour emissions from the covered and uncovered manure surfaces were determined with the aid of a wind tunnel, with odour concentration measured by dynamic forced-choice olfactometry. In the first year, the geotextile cover was reported to reduce odour emissions by 50% to 80%, but its effectiveness decreased in the second year of the study.

Hudson et al. (2006b) assessed the effectiveness of various barley straw cover support structures in reducing odour emissions from swine manure. The supported straw covers were applied to a swine MSF at Wacol Pig Research Centre, near Brisbane, Queensland, Australia. A wind tunnel

designed by Wang et al. (2001) was used to collect odour samples from the MSF. Odour samples collected over a 10-month period (October 2000 to June 2001) were analyzed using an eight-person, triangular forced-choice dynamic olfactometer. Results of this study indicated that the supported straw cover reduced odour emissions by 87% to 90%. Under laboratory conditions using the same floating support system, Hudson et al. (2006a) found that the supported straw cover reduced odour emissions by 84%.
Guarino et al. (2006) investigated the effectiveness of five simple floating covers in reducing emissions from pig and cattle slurry. The coverings included vegetable oil (a mixture of canola and soybean oil), expanded clay, chopped maize stalks, chopped wheat straw, and chopped wood chips. Nine stainless steel airtight cylinders were filled with manure and used to test the covers. Gaseous and odour concentrations in the headspace were monitored using a Brüel and Kjær 1302 multi-gas monitor and a T07 olfactometer. Results of this experiment revealed substantial differences in odour emission reduction efficiencies, ranging between 1% and 100%.

1.3.4 Greenhouse gas emissions

Some studies suggest that straw covers increase emissions of GHGs while other studies suggest the opposite. Berg et al. (2006) observed that straw covers increased methane (CH_4) and nitrous oxide (N_2O) emissions from MSFs. Jungbluth et al. (2001) confirmed the same effect in laboratory scale studies using swine and dairy manure. Amon et al. (2006) also conducted an experiment to quantify NH_3, CH_4 and N_2O emissions from dairy cattle and pig manure. They reported that covering the MSF with a layer of chopped straw instead of a wooden lid increased CH_4 emissions by 21.7%. They also concluded that straw covers had a negative environmental effect and as such were not recommended for mitigating air emissions from manure.

Conversely, in a pilot scale study Sommer et al. (2000) observed that straw covers applied overtop cattle slurry significantly lowered CH_4 emissions, presumably due to enhanced CH_4 oxidation in the interface between the cover and the slurry surface. VanderZaag et al. (2009) conducted a study to assess the effect of floating straw covers on NH_3 and GHG emissions from liquid dairy manure storage. They concluded that simple floating straw covers can provide reductions of GHG emissions from liquid dairy manure.

1.4 Practical Implications

Regardless of the ability of permeable covers to reduce emissions from MSFs, there are other practical implications to consider. These implications are discussed in the following sections.

1.4.1 Straw covers

Despite some limitations, straw covers have been used for a number of years. Straw is readily available in Alberta and easy to apply, but maintaining an intact straw cover throughout the year may be a challenge because the straw is likely to sink over time, especially if a supplementary floatation system is not utilized. Straw covers may separate or sink due to high winds and heavy rain. If a straw cover starts to separate or sink, then additional straw should be applied to re-establish the cover's original effectiveness.

Using straw covers implies that additional input (e.g. time, effort and cost) is required when an MSF is emptied of its contents. The contents of the MSF have to be agitated during pump-out to prevent clogging of pumps by large clusters of straw mixed with other organic material. Thus, it may not be practical to use straw covers if an MSF will be frequently agitated and pumped out (Lorimor and Schmidt 2003).

PAMI (1993) noted that MSFs with unsupported straw covers had to be agitated before and during pump-out to break up the straw. Manure pumps with chopping blades were most effective at blending the contents of the MSF so the slurry could flow through conventional sludge pumps. Similarly, during manure application in the field no problems were encountered with applying the manure using a continuous flow injection system with pressurized tanks and diverter nozzles mounted on a truck. However, in those treatments where agitation was insufficient, wads of straw plugged the sludge pump or the diverter nozzles during manure application.

1.4.1.1 Commercial availability

Equipment that CFO operators can use to chop and apply straw covers is commercially available. Alternatively, some custom manure applicators also have the expertise to apply straw covers or handle the contents of MSFs with straw covers. Table 1.1 provides a listing of straw cover equipment dealers and suppliers in Alberta and Saskatchewan.

Table 1.1 Straw cover equipment suppliers and custom applicators in Western Canada

Company	Contact information	Product type
Highline	Phone: (306) 258-2233 Fax: (306) 258-2010 Toll free: (800) 665-2010 Website: www.highlinemfg.com	Straw cover equipment
Royal Services Inc.	Phone: (403) 782-4731 Fax: (403) 782-7657 Toll free: (866) 782-4731 Website: www.royalservices.ca	Straw shredders, custom application

1.4.2 Geotextile covers

Bicudo et al. (2004) concluded that geotextile covers performed satisfactorily at a reasonable capital cost. They reported that livestock producers who participated in their study were generally satisfied with this type of cover, but found that managing the cover and safety concerns during agitation and pump-out were challenging and time consuming.

Geotextile covers used without a supplementary floatation system may sink after the winter season and may take 1 month or 2 months to re-establish as the MSF is filled again (Nicolai et al.

2005). Likewise, Bicudo et al. (2001) concluded that it is difficult to re-establish a geotextile cover after winter especially if an MSF was completely emptied in the previous season. They also reported that if a straw cover was used in combination with a geotextile cover, then as the snow and ice melted in spring, the straw became wet, increasing the weight on the geotextile cover and increasing the risk of failure of the cover.

It is also proven that it is difficult to agitate MSFs covered with geotextile covers without at least partially removing the cover first. Consequently, the cover is lifted by a cable and winch system and the pumping equipment is positioned beneath the cover. Even the partial removal of a geotextile cover does not favour vigorous agitation of an MSF (Nicolai et al. 2005).

1.4.2.1 Commercial availability

Geotextile fabrics and the supporting technology to cover MSFs are commercially available. The fabric is available in weights ranging from 0.12 kg m^{-2} to 0.61 kg m^{-2}, comes in rolls much like carpet, and is usually stabilized to provide UV protection. A typical roll of non-woven fabric contains about 420 m^2 (range is 230 m^2 to 585 m^2), with dimensions typically ranging between about 3.8 m and 4.6 m in width, and between 37 m and 137 m in length (Ruhl et al. 1997). Table 1.2 provides a listing of geotextile suppliers in Canada and the U.S.A.

Table 1.2 Geotextile cover suppliers in North America

Company	Location	Contact information
Layfield Geosynthetics & Industrial Fabrics	Toronto, ON	Phone: (905) 761-9123 Fax: (905) 761-0035 E-mail: msimpson@layfieldgroup.com Website: layfieldgroup.com
Summergreen Systems Ltd.	Seaforth, ON	Phone: (519) 527-2470 Fax: (519) 527-2560 E-mail: lambert@summergreen.com or summerg@summergreen.com Website: summergreen.com
Industrial & Environmental Concepts, Inc.	Minneapolis, MN, USA	Phone: (952) 829-0731 or (952) 829-9770 Website: ieccovers.com
Environmental Fabrics, Inc.	Gaston, SC, USA	Phone: (800) 910-5280 or (803) 551-5700 Fax: (803) 551-5701 E-mail: dshanklin@environmental fabrics.com Website: info@environmentalfabrics.com
Encon Technologies Inc.	St. Andrews, MB	Phone: (204) 338-2514 or (204) 334-6965 Website: dantony@enconcovers.com

1.4.3 LECA covers

LECA covers have been used on swine MSFs in Iowa for more than 8 years without issues (Burns and Moody 2008).

1.4.3.1 Commercial availability

Table 1.3 provides a listing of LECA manufacturers and suppliers in Canada and Europe.

Table 1.3 LECA manufacturers and suppliers in Canada and Europe

Product	Company	Location	Contact information
Leca®	Leca trading & Concession A/S	Copenhagen, Denmark	Phone: 45 87 61 02 01 Fax: 45 87 61 44 05 Website: www.leca.com
Macrolite®	Kinetico Canada	Caledon, ON	Phone: (519) 927-9500 Toll Free: (866) 351-8722 Fax: (519) 927-5160 E-mail: kfarnsworth@kinetico.com Website: www.thinkclearthinkblue.ca or www.kinetico.com

1.5 Summary of Research

Many research studies have been conducted to evaluate the effectiveness of permeable covers. Table 1.4 summarizes the ranges of effectiveness of these covers, their lifespan and practical challenges of using them. It is evident from this table that straw covers have higher emissions reduction but their durability is limited. Although geotextile covers have a longer lifespan than straw covers, their effectiveness is not as promising as straw covers. Limited research has indicated that LECA covers are capable of reducing gas emissions from MSF; however more research is needed.

Table 1.4 Summary of ranges of effectiveness, lifespan and practical challenges for straw geotextile and LECA covers

MSF type	Cover type	Emission reduction (%)			Lifetime	Practical challenges
		NH_3	H_2S	Odour		
Swine and dairy	Straw	40 - 100	40 - 90	30 - 100	3 - 6 months	Sinking and replacement
	Geotextile	0 - 86	13 - 90	40 - 65	3 - 5 years	Difficult to agitate MSFs
	LECA	14 - 87	60 - 90	60 - 90	10 years	Difficult to agitate MSFs

1.6 Research Gaps and Recommendations

1.6.1 Research gaps related to permeable covers

Assessing the effectiveness of permeable covers as a means of reducing emissions from MSFs is extremely difficult. There are no standardized, reliable methods for measuring emissions. Some of the studies discussed in this review were conducted on a small (laboratory) scale, which raises questions about the transferability and validity of such results when considered on a larger (field) scale, especially given the importance of wind and rain. It is also difficult to compare treatments at a field scale. In some cases it is difficult to find out which is the best approach to compare the effects of various treatments. For example, is it valid to cover one-half of an MSF and compare emissions from the two halves? Or is it better to compare paired MSFs located near each other? Or is it better to compare the same MSF before and after covering (A. VanderZaag, Postdoctoral Fellow, University of Guelph, Guelph, ON, pers. comm.)? The emission reduction values presented in this review vary widely. In some cases, the measurement procedures or equipment used were not outlined in the associated publication.

Therefore, it is imperative to apply scientifically sound methodologies to evaluate permeable covers, quantify their effects on air emissions from MSFs and provide reliable results. It is extremely important to develop standard test methods so that the effectiveness of permeable covers technologies can be fairly evaluated and compared.

In addition, the life expectancy of straw covers is inadequately known at present. Furthermore, the impact of permeable covers on the quality of manure also needs to be fully and thoroughly investigated.

1.6.2 Recommendations for advancement and adoption of permeable cover technologies

No studies have been carried out to determine the readiness of producers to adopt permeable covers as an emissions control technology. A few surveys have been conducted but their results were not conclusive. Therefore, if the ability of permeable covers to reduce emissions from MSFs can be scientifically quantified and validated using sound protocols, then technology transfer and communication programs should be developed to promote the use of permeable covers by livestock producers in Alberta. Surveys should also be conducted by CFO industry groups in collaboration with the government or associated agencies to determine the rate of adoption of permeable covers by producers in the province. Efforts should also be directed to improve the use and practicality of permeable covers so that producers can use them easily.

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Chapter 2.0
Natural and Artificial Windbreaks

I. Edeogu

Alberta Agriculture and Rural Development

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Contents

2.1 Introduction

There are two types of windbreaks common to agricultural production namely, natural and artificial windbreaks (OSUE 2006; Patterson and Adrizal 2005; Ullman 2005; Chastain 2004). Natural windbreaks comprise of rows (single or multiple) of trees and shrubs planted and nurtured to maturity (AAFC 2008; Tyndall and Colletti 2007). Their growth to maturity may take several years depending on the type of species used and their management. Artificial windbreaks on the other hand are man-made structures, constructed out of a variety of materials including wooden fence posts and boards, straw bales, tarpaulin (tarp), etc.

2.1.1 Natural windbreaks

Natural windbreaks are commonly referred to as shelterbelts (AAFC 2008; Tyndall and Colletti 2007, 2000). AAFC (2008) outlined different design principles for shelterbelts intended for agricultural and non-agricultural purposes. For agricultural purposes, the Agroforestry Development Centre (Agriculture and Agri-Food Canada - AAFC) provides information on the design of farmstead shelterbelts, field shelterbelts, forest belts, shelterbelts for dugout management and shelterbelts for snow control. Note that trees or shrubs planted alongside roads to prevent snow drifting onto roadways are referred to as roadside shelterbelts (AAFC 2008; Kulshreshtha and Knopf 2003).

Agricultural shelterbelts may also be designed and planted to provide habitats for wildlife (AAFC 2008; Tyndall and Colletti 2007, 2000); reduce net greenhouse gas emissions via carbon sequestration in the trees, shrubs or soil (Malone et al. 2008; AENV 2007); or function as private on-farm recreational facilities (Tyndall and Colletti 2007).

2.1.1.1 Farmstead shelterbelts

A farmstead shelterbelt generally comprises of multiple rows of trees and shrubs planted around the area of a farm where animal buildings or feedlot pens and major farm roadways exist (AAFC 2008; Kulshreshtha and Knopf 2003; Tyndall and Colletti 2000). Farmstead shelterbelts, also referred to as vegetative environmental buffers or VEBs (Tyndall 2008; DPII 2007; Malone et al. 2006) or vegetative buffers (Sauer et al. 2008), are typically designed to protect livestock from the effects of harsh, cold winter winds; to control snowdrift around buildings and main roadways throughout the farmyard; and to trap snow for the storage of snowmelt in dugouts (AAFC 2008; Sauer et al. 2008; Tyndall and Colletti 2007, 2000).

In addition, according to DPII (2007) the four objectives of a VEB are to foster good relations between neighbours; maximize stewardship of the environment; support biosecurity measures already in place on the farm; and enhance the aesthetic value of the farm (Lin et al. 2006). Malone et al. (2008) further specified that shelterbelts are designed to provide a visual screen of buildings, other infrastructure and daily farm activities on the farmstead; shade livestock and buildings from the direct rays of the sun; and vegetatively filter dust, feathers, odour, noise and airborne pathogens in air emissions from animal buildings, feedlot pens and manure storage facilities (Sauer et al. 2008; Lin et al. 2006; Patterson and Adrizal 2005).

Nicolai et al. (2006) and UMBAE (2005) reported that shelterbelts reduce odour by:

- Forcing odorous air to rise to higher elevations, resulting in dilution as the odorous air mixes with clean air, especially on windy days.

- Intercepting or inducing settlement of airborne particulates that carry and transport odours.

- Microbial breakdown of odorants that are adsorbed and absorbed by the tree and shrub foliage.

Design of farmstead shelterbelts

According to AAFC (2008), a multi-row farmstead shelterbelt designed to protect prairie livestock facilities, including animal housing facilities, manure storage facilities and access roads, from the direct or associated downwind effects of the wind should comprise of a minimum of 3 rows or up to 6 rows of deciduous and coniferous trees and dense shrubs. The notion is that a 3-row shelterbelt will provide basic protection from the effects of the wind with the level of protection increasing with each additional row. In some cases shelterbelts of different sizes may be established on the same farmstead with the larger shelterbelts located to provide protection from prevailing winter winds.

Detailed information, including information on how to handle, plant and care for seedlings, trees and shrubs, and technical support towards the design of farmstead shelterbelts that will meet specific needs of livestock facilities in Alberta, can be obtained from:

Agroforestry Development Centre
Agri-Environment Services Branch
Agriculture and Agri-Food Canada
Box 940
Indian Head, Saskatchewan
S0G 2K0 Canada
Tel: 1-866-766-2284
Fax: 1-306-695-2568
Email: agroforestry@agr.gc.ca

2.1.2 Artificial windbreaks

Artificial windbreaks include solid windbreak walls constructed from wood, steel or tarp, straw walls, fixed and portable windbreak fences, or soil berms (Patterson and Adrizal 2005; CPS 2005; Chastain 2004; ISUE 2004a; ARD 2002; EQB 2002; Bottcher et al. 2001; Jacobson et al. 2001; Johnson 1999; Jones et al. 1983). Similar to natural windbreaks they are designed to serve several purposes, such as protecting animals from harsh winter winds and for snow control (Bottcher et al. 2001), among other functions.

2.1.2.1 Windbreak walls

Windbreak walls are also referred to as dustbreak walls (Bottcher et al. 2000). Just like farmstead shelterbelts, windbreak walls are typically constructed on the farmstead. They may be located upwind of a feedlot pen to protect animals from the negative effects of cold winds, or downwind to immediately deflect emissions from animal buildings (Bottcher et al. 2000; Jacobson et al. 2001) up into the atmosphere thereby facilitating dilution. Windbreak walls may also be used around manure storage facilities.

Design of windbreak walls

According to Bottcher et al. (2000), windbreak walls should typically be designed to withstand failure due to the effects of maximum wind speeds. In addition, it is important to consider and plan for possible failure of the wall in the event of extreme winds in order to minimize damage to property or injury to people. Bottcher et al. (2000) also recommended that windbreak walls used to deflect exhaust emissions from livestock buildings should be located 4 m to 6 m from tunnel ventilation fans while Bottcher et al. (2001) recommended a spacing of up to 10 m from the fans. Other publications (EQB 2002; Jacobson et al. 2001; OSUE 2006) recommended a separation distance of 3 m to 6 m from the fans. Furthermore, the walls should measure over 3 m in height and should use UV-resistant material such as medium density polyethylene, tarp (trampoline-quality) or aluminium roofing sheets. The synthetic or metal sheets should be fastened to posts or steel-pipe frames anchored to the ground.

2.1.2.2 Windbreak fences

Fixed or portable windbreak fences are usually constructed upwind of animal feedlot pens to protect the animals from the negative effects of cold winds (CPS 2005; Johnson 1999); to provide snow protection in areas renowned for heavy snow (CPS 2005); or to supplement natural windbreaks (Johnson 1999). They may be solid fences, open fences or snow fencing (Johnson 1999; Jones et al. 1983). However, the most effective windbreak fences are slatted, open fences with 20% to 25% openings (Johnson 1999), 25% to 33% openings (ARD 2002) or 25% to 50% openings (Jones et al. 1983). Johnson (1999) explained that, unlike open fences, solid fences prevent the wind from filtering through, and therefore enable the wind on the downwind side of the fence boards to flow downwards (downdraft) towards the ground and swirl within the animal pens rather than beyond the pens.

Design of slatted windbreak fences

Literature on the design of slatted windbreak fences suggests that the fences should be 2.4 m to 3.0 m or more in height (CPS 2005; Johnson 1999). Jones et al. (1983) stated that the height of the fence is dependent on the size of the zone it is required to protect on the downwind side of the fence. A fence designed for snow management will enable snow deposits to occur in a zone extending from the fence to a distance of 10 times the height of the fence in the downwind direction. If wind protection is desired then the protective zone extends up to a distance of 20 times the height of the fence. This implies that a 3.0-m high fence would result in snow deposits occurring within 30 m of the fence and protection from wind for livestock up to 60 m from the fence. CPS (2005) reported that a slatted fence with 20% porosity provides protection from the wind up to a distance of 12 times the height of the fence.

Posts pressure-treated with wood preservative are recommended (CPS 2005; Johnson 1999) for windbreak fences. The posts should be buried 1.2 m in the ground and posts for fences over 3.5 m in height should be placed on 3-m centres (Johnson 1999). The holes made in the ground for the posts should be smooth-walled and back-filled with concrete. If the walls are not smooth, then consider backfilling with crushed stone or rubble and then compact adequately afterwards (CPS 2005).

Boards measuring 0.15 m wide may be placed vertically or horizontally and spaced 38 mm apart to provide 20% porosity (CPS 2005; Johnson 1999). Alternatively, spacing between boards may be up to 50 mm (Johnson 1999; Jones et al. 1983) if boards wider than 0.15 m are used (Johnson 1999). However, Johnson (1999) cautioned that such wide spacing between the boards can reduce livestock comfort and ultimately performance. Furthermore, plywood or metal roofing sheets tend to be too wide and the metal sheets can cause injury to animals. Place boards on the inside of the framing to avoid potential damage by the animals following installation; otherwise install a horizontal rub rail along the fence if the animals will have access to both sides of fence. Boards should be fastened with galvanized nails, preferably. If staining is desired then use a pentachlorophenol stain (Johnson 1999). CPS (2005) also suggested the use of sawmill slabs as an alternative low-cost measure. If such boards are used then the bark side of the boards should be placed on the exterior side of the fence.

The fence should be constructed with a 0.10-m to 0.15-m high gap beneath the fence (Johnson 1999). This will permit drainage and help prevent problems that can be caused by pooled water. The space above the ground will also facilitate summer ventilation. Jones et al. (1983) suggested that the space beneath the fence should be up to 0.30 m.

Portable slatted windbreak fences are similar to fixed fences. According to ARD (2002) steel frames are preferable because they can withstand the effects of the wind and the impact of moving them from one location to another. The width of the fence should be greater than its height to help maintain stability. A spacing of 0.30 m above the ground is recommended. The total length of the fence is dependent on the number of livestock to be protected and is calculated based on a rate of 0.30 m per head.

2.1.2.3 Straw walls

Straw walls are constructed out of wood, chicken mesh (wire) and straw. Similar to windbreak walls, straw walls are used to deflect building exhaust air vertically into the upper atmosphere to facilitate dilution and dispersion of emissions. However, since straw walls tend to be more porous than windbreak walls they are also able to filter particulate matter exhausted from buildings (Jacobson et al. 2001).

2.2 Impact of Windbreaks on Air Emissions

Limited literature was found on the effects of natural or artificial windbreaks on emissions of ammonia (NH_3), hydrogen sulphide (H_2S), odour, particulate matter (PM), bioaerosols and volatile organic compounds (VOCs) from livestock facilities. The findings of different field studies (ironically only studies conducted on natural windbreaks were found) were with regard to the impact of shelterbelts on emissions of NH_3, H_2S, odour and PM. It is important to note that some of the literature on shelterbelts addressed the effects of different types of trees on ammonia absorption or the effectiveness of tree leaves in trapping dust particles, etc. However, only those aspects of the literature that pertain to reductions in the emissions of interest are addressed in this section.

2.2.1 Ammonia

Study 1: Effect of multi-row shelterbelt on emissions of ammonia, odour and dust

Malone et al. (2006) conducted a study on the effectiveness of a 3-row shelterbelt in reducing emissions from poultry buildings immediately downwind from the shelterbelt. The shelterbelt was established in spring 2002 and measured 9.1 m in length. It comprised of a row of 4.9-m tall Bald Cypress deciduous trees, a second row of 4.3-m tall Leyland Cypress trees and a third row of 2.4-m tall Eastern Red Cedar trees located approximately 9.1 m, 12.2 m and 14.6 m, respectively, from two 1.2-m diameter tunnel ventilation fans.

According to Malone et al. (2006), the purpose of the arrangement was for the Bald Cypress trees to filter feathers and large particulates out of the exhaust air in the summer months when ventilation rates were high and the trees would have a full crop of leaves. The Bald Cypress trees were also intended to reduce the velocity of the exhaust air while the middle and outer rows served to filter the finer particulates.

Concentrations of NH_3 were measured for 5-h periods over four summers between 2002 and 2006. Measurements were conducted in front of each fan at a height of 1.2 m in years 1 to 3 and at an additional height of 2.4 m in year 4. Measurements were also taken at the same heights at two locations 9.1 m from each fan and two locations 16.8 m from the fans, in the flow path of the exhaust air. Windbreak walls were installed between the edge of the building and the shelterbelt to minimize the effect of crosswinds on the measurements.

Ammonia measurements were conducted with integrated sampling colorimetric tubes (No. 3DL, Gastec Corporation, Ayase-Shi, Japan) over the 5-h sampling period. Since the cumulative NH_3 concentrations at the different measurement locations and heights exceeded the measurement capacity of the tubes (i.e. 10 ppm), multiple tubes were used in series to conduct the measurements. The measurements were then integrated to obtain the 5-h readings.

The tubes had a measurement accuracy of ±10% for concentrations ranging between 1 and 10 ppm-h. According to the manufacturer, the measurement results had to be corrected for temperature and relative humidity. Furthermore, the tubes were susceptible to interference by other gaseous compounds specifically, amines and hydrazine. However, Malone et al. (2006) did not indicate if their data were corrected for temperature or humidity, nor did they specify if, or how, they addressed the potential interference by other substances.

Malone et al. (2006) reported a significant NH_3 concentration reduction of 46±31% ($P < 0.01$) between the measurement locations immediately upwind and downwind of the shelterbelt based on 29 days of NH_3 measurement conducted between 2002 and 2006. In 2008, Malone et al. (2008) reported that the shelterbelt significantly reduced NH_3 by 54%. No margin of variability was provided in the results reported in 2008. Thus, it is uncertain what effect, if any, the maturity of the shelterbelt had on the measurements.

Study 2: Effect of tree foliage on ammonia and particulate matter emissions

Adrizal et al. (2008a) conducted a study involving five poultry operations. Shelterbelts comprising of either 3, 4 or 12 rows were established downwind from the exhaust fans at the five sites between 2003 and 2004. The rows of trees were spaced about 3 m apart while the distance between the exhaust fans and the shelterbelts ranged between 11.4 m and 17.7 m.

Ammonia concentration was measured using passive dosi-tubes (No. 3D, Gastec Corporation, Ayase-Shi, Japan) located immediately in front of the fans (0 m) at each site and then 11.4 m and 15.0 m downwind from the fans. In other words, the measurements were either conducted between the shelterbelts and the fans or within the shelterbelts. Ammonia concentrations were also measured at a control location an offset distance of 30.0 m away from the fans but not downwind of the fans. Samples were collected at a height of 1.5 m above the ground and read after 4 h and 8 h.

The tubes had a measurement accuracy of ±10% for concentrations ranging between 25 and 500 ppm-h with a required correction for temperature. Furthermore, the tubes were susceptible to interference by other gaseous compounds specifically, amines (excluding aromatic amines) and hydrazine. Adrizal et al. (2008a) did not indicate if their data were corrected for temperature, nor did they specify if, or how, they addressed the potential interference by other substances. No indication was given of the number of repeated measurements.

Adrizal et al. (2008a) reported that the mean NH_3 concentration of all five poultry farms, measured at the control location, i.e. 30 m from the exhaust fans, significantly decreased ($P \leq 0.05$) by 97%. While that may have been the case, it is not clear if the significant reduction in NH_3 was wholly due to the effect of the trees or if it was influenced in part by the orientation of the control location relative to the airflow direction. It is equally uncertain what role wind direction, wind speed or distance might have played and to what extent they might have influenced the results. At 11.4 m and 15.0 m immediately downwind from the fans, significant ($P \leq 0.05$) NH_3 reductions of 78% and 83%, respectively, were reported. Again, it is not clear what effect distance from the fans may have had on the results. Furthermore, it is uncertain which measurements at 15.0 m from the fans occurred among the trees and for those that did, what influence the trees at those sites may have had on the measurements.

Study 3: The potential for plants to trap emissions from farms with laying hens. 1. Ammonia
In 2005, Patterson et al. (2008) conducted a study evaluating the effects of a portable 5-row shelterbelt on ammonia emissions downwind of four exhaust fans in a laying hen building. The shelterbelt was classified as portable (potted trees) because it was set up in such a way that the trees could be moved from one location to another. Each row comprised of 10 trees of five different species with a mean tree height ranging between 1.37±0.15 m and 2.25±0.28 m. Furthermore, each row of trees was staggered relative to the next row and split, to an extent, into two sets of trees per row such that each set of five trees was positioned, primarily, downwind of a pair of exhaust fans. Within the shelterbelt, adjacent rows were spaced 1.5 m apart and, within each set of trees per row, the trees were spaced about 1.2 m apart. The first row of trees was located perpendicular to the fans at a distance of approximately 3.5 m from the fans while the fifth row of trees was spaced about 9.5 m from the fans. A sixth row, comprising of two sets (assumption) of the five different tree species, was spaced about 50 m downwind from the fans.

The laying hen building housed only about 600 birds. Thus, due to the low ammonia production by the birds, anhydrous NH_3 was injected into the exhaust air from the building to increase the concentration of NH_3 emitted from the building. Externally, a light-trap hood was placed over each fan and setup in such a way that air from the building was redirected towards the ground from a height of about 1.5 m above the ground.

Ammonia measurements were conducted using two techniques, a photoacoustic detector (Model 1412, IN-NOVA AirTech Instruments, Ballerup, Denmark) and passive dosi-tubes (No. 3D, Gastec Corporation, Fukaya, Japan). Measurements with the detector were taken 1.5 m above the ground at the exhaust surface of each fan hood (distance from fan = 0 m). Sequential measurements were also taken at heights of 0.3 m, 1.5 m and 3 m from the ground at distances of 5.5 m, 10 m and 50 m downwind from each fan hood. No measurements were conducted without the trees at the 50 m distance. The measurements with the photoacoustic detector at each measurement location (defined by height and distance from fan hood) were conducted in ten 30-s intervals on each day over two consecutive days. Measurements were reported in parts per million (ppm).

Conversely, composite measurements were obtained with the passive dosi-tubes over an 8-h period on each day. Tubes were located at a height of 1.5 m at the fan hood exhaust (distance from fan = 0 m) and at the same height at distances of 5.5 m, 10 m and 50 m downwind from each fan hood. Measurements were reported in ppm h^{-1}. Following the 2 days of measurements with the trees in place, the trees were removed and the same measurements were repeated over another 2 days at the various measurement locations using the photoacoustic detector and a new set of passive dosi-tubes.

The results of the study by Patterson et al. (2008) seemed to suggest that the shelterbelt significantly reduced ammonia emissions compared to no shelterbelt. However, other results presented in the publication indicated that there was no significant effect of the presence of trees relative to the absence of trees at the measurement locations 5.5 m and 10 m from the fan hoods. Thus, the approximate mean ammonia reduction of 97% and 100% that occurred 5.5 m and 10 m, respectively, from the fan hood with the trees in place may not have been influenced at all by the presence of the trees. Note that ammonia was reported to be undetectable in the measurements 50 m downwind from the fans with the trees in place so these measurements were not factored into data analyses.

Finally, given the specifics of the experimental setup and methodologies used to conduct the measurements, a degree of uncertainty also exists with regard to the effect of distance from the fan hood on the concentrations of ammonia measured at 5.5 m and 10 m. It is uncertain if the microclimate had a greater dilution effect on the concentration of ammonia measured at the various locations as opposed to the presence of trees.

Study 4: The potential for plants to trap emissions from farms with laying hens. 2. Ammonia and dust

In 2006, Adrizal et al. (2008b) conducted a study quite similar to study 3 above. In the latter study, ammonia measurements were taken at the three heights, i.e. 0.3 m, 1.5 m and 3.0 m from the ground, except at the fan hoods where the measurements were only taken at a height of 1.5 m above the ground. The measurements were initially conducted with both sets of 5 rows of trees in place at distances of about 3.5 m, 5.0 m, 6.5 m, 8.0 m and 9.5 m downwind from the fans, and both sets (assumed) of a sixth row of trees spaced about 50 m downwind from the fans. Measurements were taken at distances of 0 m, 5.5 m, 10 m and 50 m from the fan hoods and duplicated over 2 days. At each measurement location, the photoacoustic detector (Model 1412, IN-NOVA AirTech Instruments, Ballerup, Denmark) from study 3 above was used to measure ammonia repeatedly (seven or more times) over a 5-min period. Composite measurements were also obtained with the passive dosi-tubes over a 6-h to 8-h period on each day. Once again the tubes were located at a height of 1.5 m at the fan hood exhaust (0 m) and at the same height at distances of 5.5 m, 10 m and 50 m downwind from each fan hood.

In order to control the effects of the prevailing wind on the measurements, a 10-m long by 2.5-m tall cloth curtain barrier was mounted on the west side of the fans, perpendicular to the 5 rows of trees, offset by an unknown distance from the southwest corner of the laying hen building and ending just after the fifth row of trees.

In the second series of measurements (day 3), the 6-row set of trees on the right hand side of the building, i.e. southeast side (assumption), was removed. In the third series (day 4), the other 6-row set of trees was removed, and duplicated measurements were conducted without any trees over 2 days. Finally, on day 6, the 6-row set of trees on the right hand side of the building was replaced and measurements were taken once again over a day. Thus, ammonia concentration measurements were conducted at the four distances from the fan hoods, either with all the trees in place, half the trees in place or no trees in place.

Similar to the results presented by Patterson et al. (2008), the study conducted by Adrizal et al. (2008b) did not seem to signify any effect of the trees on reductions in ammonia concentration measured with the photoacoustic detector in comparison to the treatments without trees at distances of 5.5 m, 10 m or 50 m from the fan hoods. In all tree versus no tree scenarios, ammonia reductions were deduced to range between 97% and 100%. Unfortunately, due to what appears to be a typographical error in the data presented in the publication, the results of the ammonia concentration measurements using the passive dosi-tubes could not be assessed. Once again it is uncertain if the effects of the microclimate might have influenced the measurements and subsequently, may have confounded the results reported by Adrizal et al. (2008b).

2.2.2 Hydrogen sulphide

Study 5: Effect of two shelterbelts on hydrogen sulphide emissions

Nicolai et al. (2006) conducted a study on the ability of a large and a small shelterbelt to reduce the concentration of H_2S emissions from a swine housing facility and an outdoor, uncovered manure storage facility. The large shelterbelt measured about 43 m wide by 650 m long and was located 18.2 m to the west of the manure storage facility, also on the west side of the housing facilities, and comprised of 8 rows of large, mature deciduous trees averaging approximately 9.1 m in height. The small shelterbelt comprised of 3 rows of 10-year-old trees and 1 row of 2-year-old trees located 36.6 m north of the manure storage facility. Of the 10-year-old trees, 2 rows comprised of deciduous trees while the third row was of coniferous trees. The two shelterbelts were oriented perpendicular to one another.

Hydrogen sulphide concentration was measured continuously every 17 minutes at 10 different locations using Single Point Monitors – SPM (Model 7100, Zellweger Analytics Inc., Lincolnshire, IL) accurate to within +7% and -10% of the readings of an unspecified H_2S analyzer. Three monitors were located parallel to and west of the large shelterbelt, two of them directly west of the manure storage facility while the third was located northwest of the facility. A second set of three monitors was located parallel to and immediately north of the small shelterbelt, and directly north of the manure storage and swine housing facilities. A third set of three monitors was located parallel to and directly south of the manure storage and swine housing facilities, adjacent to the southern end of the large shelterbelt. The tenth SPM was located immediately southeast of the manure storage facility and south-southwest of the southernmost swine housing facility. No indication was given of the length of the measurement period.

Nicolai et al. (2006) noted that two of the three SPMs located south of the manure storage facility to provide control treatment (no shelterbelt) data malfunctioned during the study. Therefore, only one functional SPM provided H_2S concentration control treatment data for comparison. The three SPMs located west of the large shelterbelt provided H_2S concentration readings that were not significantly different ($P < 0.05$) from each other while readings from the three located north of the small shelterbelt were significantly different signifying the importance of using more than one SPM to conduct measurements at each measurement location.

Wind speed and wind direction were also monitored and recorded every 10 min during the study. A weather station was centred approximately 30.5 m immediately south of the southern-most swine housing facility in what was described as an open area.

Relative to the limited nature of the study, Nicolai et al. (2006) reported no significant difference in the average H_2S concentration between the control treatment (13.4 ppb) and the small shelterbelt treatment (10.9 ppb) under all wind speed conditions ranging between 0 m s^{-1} and 2.2 m s^{-1}, 2.2 m s^{-1} and 4.5 m s^{-1}, and over 4.5 m s^{-1}. In contrast, significant reduction ($P < 0.05$) in H_2S concentration (85%) occurred across the large shelterbelt compared to the control, resulting in an average concentration of 2 ppb. Further analysis of the results showed that at wind speeds within 0 m s^{-1} to 2.2 m s^{-1}, H_2S concentrations were significantly lower ($P < 0.05$) across the small and large shelterbelts resulting in reductions of 66% and 87%, respectively.

For wind speeds between 2.2 m s^{-1} and 4.5 m s^{-1} the results indicated that the readings taken across the small shelterbelt were higher than those of the control and large shelterbelt treatments. However, Nicolai et al. (2006) did not elaborate on these results. No significant difference ($P < 0.05$) in H_2S concentration was observed between the shelterbelt treatments and the control treatment at wind speeds greater than 4.5 m s^{-1}.

2.2.3 Odour

Study 1: Effect of multi-row shelterbelt on emissions of ammonia, odour and dust

In their study on shelterbelts, Malone et al. (2006) reported that odour samples were collected from one location in front of the shelterbelt and a second location behind the shelterbelt, but did not specify their respective distances from the fans or the shelterbelt. Thus, it is assumed that, similar to the ammonia and total dust measurements, odour samples were collected from one height (unspecified) at distances of 9.1 m and 16.8 m from the fans in the flow path of the exhaust air. Odour samples were collected in Tedlar® bags and analyzed by olfactometry within 24 h of sampling.

Malone et al. (2006) reported that odour concentration was reduced by 6±45% (n.s.) based on 13 days of sampling and analysis. This result implies that, at times, the odour concentration downwind (16.8 m from the fans) of the shelterbelt was greater than its concentration immediately upwind (9.1 m from the fans) of the shelterbelt. Malone et al. (2006) suggested that the odour measurements were influenced by the presence of a corn crop 1.2 m downwind of the shelterbelt and by wind direction on the sampling days. In 2008, Malone et al. (2008) reported an increased and significant reduction in odour (26%) across the shelterbelt. However, they did not report the margin of variability or the level of significance of their analysis. Consequently, it is unclear what effect, if any, the maturity of the shelterbelt had on the measurements.

Study 6: Effect of single-row windbreak on odour dispersion

Lin et al. (2007) conducted a study on the effect of four individual single-row shelterbelts, located at different sites, on dispersion of odour in the field compared to a control (no shelterbelt) treatment at a fifth site. The shelterbelts, situated on relatively flat (0.1% slope) farmland, comprised of either, deciduous or coniferous trees, heights less than 10 m or greater than 15 m, and optical porosities (measure of the density of the tree foliage) of 35% or 55%. Lin et al. (2007) did not describe how optical porosity was measured. The control site was also on relatively flat farmland with a 0.1% slope, an open field without a shelterbelt, trees or fences and where a cereal crop had recently been harvested.

A mobile odour generator consisting of a 500-L tank of swine manure, a pump, and a fan, was used to generate odorous air at a rate of 1.65 m^3 s^{-1}. The generator was located a distance of 15 m, 30 m, 49 m or 60 m upwind of the shelterbelts. Samples of odour were collected in Alinfan® bags from the outlet of the generator every 30 min during the tests. No other air samples were collected for analysis at locations downwind from the generator or the shelterbelts. The samples were analyzed by triangular forced-choice dynamic olfactometry with a team of 12 trained panelists.

The team of panelists also rated the hedonic tone (measure of offensiveness) of the bagged odorous air samples based on an 11-point scale as follows: ratings of 0 to -2 implied that the undiluted bagged odour was perceived as tolerable; -2 to -4, unpleasant; -4 to -6, very unpleasant; -6 to -8, terrible; and -8 to -10, intolerable. An empirical relationship between odour concentration and odour perception was developed based on the olfactometry and 11-point categorical scale hedonic tone measurements.

In the field, the team of 12 panelists, in three groups of four, assessed the hedonic tone of the ambient air using the same 11-point categorical scale measurement. Measurements in the field were converted to odour concentration using the empirical relationship established in the laboratory. Each group of four panelists traversed a planned route with specific measurement points downwind of the odour generator. A measurement in the field was qualified as valid if 50% of the group at any given point detected an odour. A weather station was set up at each site prior to conducting the tests. Temperature, wind direction and wind speed were recorded at 1-min intervals.

It appears that a total of 39 tests (odour plumes assessed) were conducted over 18 days between August and December in 2003, i.e. ranging between one and three tests on a given day. Over this period, temperatures ranged between 28^{o}C in August and -9^{o}C in December. Three of the 39 tests were conducted at the control site in August. Based on the results presented by Lin et al. (2007), it seems that the mean estimated area (average product of plume length and plume width) of the odour plumes at sites with shelterbelts (tests 1 to 33 and 35) was approximately

42% smaller than the mean estimated area of three plumes at the control site (tests 37 to 39) and two plumes at sites with shelterbelts, but a wind direction parallel to the shelterbelts (tests 34 and 36).

2.2.4 Particulate matter

Study 1: Effect of multi-row shelterbelt on emissions of ammonia, odour and dust

Similar to the NH_3 measurements, Malone et al. (2006) measured PM in front of each fan at a height of 1.2 m in years 1 to 3 and at an additional height of 2.4 m in year 4. Measurements were also taken at those heights at two locations 9.1 m from each fan and two locations 16.8 m from the fans, in the flow path of the exhaust air.

Total dust samples were collected using an integrated sampling gravimetric technique (NIOSH method 0500 with an accuracy of ±11% and method 0600 with an accuracy dependent on particle size distribution). The samples were shipped to a laboratory for analysis. A continuous measurement aerosol monitor (Dust Trak #8520; TSI Inc., St. Paul, MN) of unspecified accuracy was also used for total dust concentration measurements in 2004.

Total dust concentration was significantly reduced by 49±27% ($P < 0.01$) between the measurement locations immediately upwind (9.1 m from fan) and downwind (16.8 m from fan) of the shelterbelt based on 33 days of measurement during the study. Malone et al. (2006) also reported that in 2004, the gravimetric and aerosol monitor dust measurement techniques resulted in 35% and 39% total dust reduction, respectively. However, the number of measurement days when the aerosol monitor was used was not specified.

In 2008, Malone et al. (2008) reported that total dust reduction across the shelterbelt increased to 56%. No margin of variability was reported in 2008 and so it is not certain what effect, if any, the maturity of the shelterbelt had on the results.

Study 2: Effect of tree foliage on ammonia and particulate matter emissions

Adrizal et al. (2008a) also measured the amount of PM trapped by the foliage of the trees. Foliage samples were collected in June and July 2006 from two locations. At one location the samples were from trees that were between 11.4 m and 17.7 m downwind from the fans. At the second location (control), the samples were from trees at an offset distance of 40.0 m or more from the fans. No samples were collected immediately in front of the fans to provide a reference. The samples were packaged and shipped to a laboratory for analysis of total PM weight per unit area of foliage.

Mean total PM concentrations of all five poultry farms were not significantly different ($P \leq 0.05$) between the sampling location between 11.4 m and 17.7 m downwind from the fans and the control location 40.0 m or more from the fans. Although not significant, it appears that on average the shelterbelts trapped 29% more total PM at the former sampling location compared to the latter. Once again it is uncertain what influence, if any, wind patterns or other external factors may have had on the results.

Study 4: The potential for plants to trap emissions from farms with laying hens. 2. Ammonia and dust

In another investigation, Adrizal et al. (2008b) compared the effects of the trees on dust reduction from the poultry facility used for the ammonia investigation. Approximately 5 to 8 kg of poultry litter (assumed) was released on the upwind side of each fan. Dust concentrations were determined gravimetrically. Dust samples were first collected using personal air sampling pumps (Model AFC-123, BGI Incorporated, Waltham, MA) situated 2.5 m downwind from the fans (i.e. between the fans and the first row of trees); 4.5 m from the fans between the first and second row; 6.0 m from the fans between the second and third rows; and 50 m from the fans. Finally, a microbalance was used to measure the mass of dust captured on filters located inside the pumps at each sampling location. Dust samples were collected only after ammonia measurements were completed to avoid contamination of the photoacoustic ammonia detector.

Adrizal et al. (2008b) reported mean aerial dust emission rates of 530.6, 319, 130.1 and 1.7 mg h^{-1} at distances of 2.5 m, 4.5 m, 6.5 m and 50 m, respectively, for treatments conducted with trees positioned downwind from the fans. These corresponded to dust emission reductions of 40%, 75% and 100% approximately, measured 4.5 m, 6.5 m and 50 m downwind from the fans, respectively. On the other hand, with no trees in place, mean dust emission rates of 381.1, 241.1, 166.8 and 3.1 mg h^{-1} were reported relative to distances of 2.5 m, 4.5 m, 6.5 m and 50 m, respectively, from the fans. Subsequently, the latter results corresponded to approximate mean emission reductions of 55%, 69% and 99% at distances of 4.5 m, 6.5 m and 50 m from the fans, respectively. Overall, the mean percentage dust reduction appeared to be 72% with the trees present and 74% without the trees. However, it is uncertain if the results are a true representation of the effects of the trees on dust emissions or if the results may have been compromised by external factors such as the influence of the microclimate.

2.2.5 Overview of the six studies

The efforts of the various research teams that undertook the tasks of assessing windbreak effectiveness relative to livestock facility emissions are commendable considering the prospective complexities and large variability associated with such measurements, the influence of the weather and sheer scope of such studies. However, there are a few areas of concern that this review hopes to address in order to enhance the outcomes of future studies.

As stated earlier, published information on the effects of natural and artificial windbreaks on emissions is limited. This is not only in terms of the number of studies performed but also with regard to the scope of the information provided by these studies. For most of the studies, it seems that the number of replications were often inadequate to provide significant confidence ($\alpha = 0.95$) in the results relative to the projected variability stemming from the nature of studies of this kind, type of measurements required and scope.

Secondly, the outcomes of some of the studies were affected by malfunctioning measurement equipment. This served to reduce the number of data points available to validly assess the effectiveness of the windbreaks on emissions. Without the verification of the results in other studies or repetition of the studies by the pioneering researchers, it remains unclear as to what the true effect of the windbreaks on emissions might be. In addition, some of the studies did not indicate what the emissions from the fans were in order to provide a true reference for the reductions downwind from the fans that were attributed to the shelterbelts.

A third concern is the lack of clarity provided by the publications in terms of experimental procedures and experimental designs used to conduct the studies. Some publications did not indicate the relative distance and orientation of the measuring locations with respect to the livestock facilities. Even when such information was provided, it remains uncertain if the measurement locations were appropriately chosen to effectively assess the effects of the windbreaks on emissions. Furthermore, in choosing monitoring locations, most studies did not appear to take into account the downwind effects of shelterbelts on wind flow patterns, making it difficult to assess the potential impact of the windbreaks on downwind concentrations of the various substances. As mentioned earlier, the literature suggests that the wind protection zone can extend as far out as 20 times the height of a windbreak (Jones et al. 1983).

2.3 Practicality of Using Windbreaks

Windbreak fences are typically used in Alberta for feedlot management to help minimize the effects of cold winter winds on the animals. Unfortunately, literature on the use of such windbreaks to reduce the downwind impact of air emissions from feedlot facilities was not found.

Similarly, information on the effectiveness of windbreak walls used to mitigate the downwind impact of air emissions from livestock buildings is limited (Tyndall and Colletti 2007). Consequently studies, such as the one conducted by Liang et al. (2010) on the ability of windbreak walls to reduce air velocity downwind from poultry barn tunnel ventilation fans, may be valuable in providing further insight into the potential effectiveness of windbreak walls. However, as noted by UMBAE (2005), windbreak walls are not practical for livestock housing facilities that utilize multiple ventilation fans that are not uniformly distributed around the buildings. In other words, windbreak walls may be better suited to controlling emissions from low, wall-mounted tunnel ventilation fans uncommon to livestock production systems in Alberta. In essence the effectiveness of windbreak walls for mitigating the downwind impact of livestock emissions is still under investigation and it may not be advisable to invest in this type of management mechanism at this time.

Shelterbelts on the other hand seem to hold more promise. First of all, the tree and shrub seedlings can be obtained at no cost from the Prairie Shelterbelt Program (AAFC 2008). CFOs would only be responsible for costs associated with the transportation of seedlings, planting and nurturing the seedlings, and nurturing and maintaining the shelterbelt over the years. Seedlings may be planted and nurtured by the CFO in order to save cost as opposed to contracting the services out. The Agroforestry Development Centre also has a collection of information and staff available to advise CFO operators in planning, establishing and maintaining their shelterbelts.

Although a limited number of field studies have been conducted to assess the effectiveness of shelterbelts for mitigating the downwind impact of air emissions from CFO facilities, including manure storage and livestock housing facilities, natural windbreaks have a number of established co-benefits. Benefits such as the potential to participate in the carbon offset market by planting shelterbelts on CFOs in Alberta (AENV 2007), improvement of farm aesthetics, provision of a visual barrier for the CFO, potential reduction of neighbour and community conflict, among other benefits, outweigh the time and cost demands associated with the transportation, planting, nurturing and maintenance of shelterbelts (Kulshreshtha and Kort 2009; Tyndall and Grala 2008).

A survey of 562 pork producers in Iowa in 2004 (ISUE 2004b) indicated that 38% (approximately 213) of the producers were using or had used windbreaks as an odour control technology. Although the report did not specify what type of windbreak, this management mechanism was classified as one of the four most popular management mechanisms among producers. Of this percentage, approximately 64% were satisfied with the management mechanism, 35% were indifferent and 1% were unsatisfied. The survey also showed that about 1% of the producers had discontinued their use of this management mechanism. No reason was given for the discontinued use of shelterbelts by the producers.

2.4 Limitations of Shelterbelts

The primary limitation of using windbreaks (shelterbelts) as a management mechanism to mitigate the downwind impact of CFO emissions is the fact that it takes time, a minimum of 3 years to 5 years, for the trees to become established and consequently, effective for mitigation purposes (Tyndall and Colletti 2007).

Secondly, existing CFOs that desire to retrofit shelterbelts on their farmsteads may be limited by the lack of available space to establish shelterbelts that will be effective for mitigating the downwind impact of CFO emissions. Often the issue is the presence and locations of pre-existing buildings and roads as well as boundary and land use restrictions (Malone et al. 2008; Tyndall and Colletti 2007). Malone et al. (2008) suggested that such a limitation does not often apply when shelterbelts are taken into consideration in the planning and construction of new CFOs.

Farmstead shelterbelts may interfere with the function of naturally ventilated buildings. Sauer et al. (2008) noted that even a properly designed shelterbelt can lead to airflow restrictions around buildings on the farmstead. This may have a subsequent impact on heat exchange between livestock buildings and ambient air especially during the hot summer season. Ultimately, reduced heat exchange implies a warmer, uncomfortable building with a direct impact on animal performance. Furthermore, sites where manure storage and livestock facilities exist may cover extensive areas of land signifying the need for large shelterbelts.

Another consideration is the need for increased knowledge about tree and shrub growth and maintenance requirements. It appears that a common error is to assume that knowledge of crop production is directly transferable to shelterbelt establishment and nurturing. Specific design, planting and maintenance knowledge is important in order to maximize tree and shrub health, prevent premature mortality and ultimately, prevent shelterbelt failure. Consequently, time and effort have to be put into maintaining the shelterbelt by mowing the grass around the trees and shrubs, spraying for weed control, irrigating and occasionally replacing dead trees or shrubs (Malone et al. 2008; Tyndall and Colletti 2007).

2.5 Conclusions

There appears to be limited information on the potential effectiveness of artificial or natural windbreaks as management mechanisms for mitigating the downwind impact of air emissions from livestock facilities. Of the two types of windbreaks, natural windbreaks, or shelterbelts, seem to hold more promise for the CFO industry in Alberta because of the numerous other benefits that can be derived through the establishment of shelterbelts, such as improving the aesthetics of the farm.

In Canada, prairie farmers can establish shelterbelts at no initial cost for the supply of tree and shrub seedlings. The Canadian government provides these seedlings to prairie farmers free of charge through its Prairie Shelterbelt Program (AAFC 2008). Furthermore, a more recent development is the ability to use shelterbelts to generate supplementary farming income through the provincially established carbon offset trading market. Alberta recognizes and has approved quantification protocols for afforestation projects like shelterbelt establishment on farmland.

Although shelterbelts have several benefits associated with them, implementing this potential management mechanism should not be taken for granted. Any CFO intending to establish a shelterbelt on its property should invest the time to develop a proper plan to meet its desired needs. Thankfully, the Agroforestry Development Centre has the resources to provide knowledge-based technical assistance to farmers.

2.6 Recommendations

The following recommendations are made with regard to the quantification of CFO air emission reductions due to shelterbelts:

1. Develop a research plan for a study that will assess the effectiveness of shelterbelts used to mitigate the downwind impact of emissions of ammonia, hydrogen sulphide and particulate matter from CFOs. The number of substances under consideration may be decreased

depending on the outcome of the baseline ambient air quality study being conducted currently by Alberta Agriculture and Rural Development.

2. Odour may be considered as a fourth substance of interest. However, due to the complexity, degree of uncertainty and exorbitant nature of odour studies, alternative performance metrics may need to be adopted. For example, the effectiveness of the shelterbelt may have to be measured by the number of odour events perceived or valid complaints registered by neighbouring residents. Such a study would require very careful planning.

3. The downwind effect of the shelterbelt on concentration or perception of the substances of concern at the minimum distance separation (MDS), as per Alberta's *Agricultural Operation Practices Act* and regulation (AOPA), should be given due consideration. In addition, the measurement of source emission concentrations should be included in the plan.

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Chapter 3.0

Bottom Loading of Liquid Manure Storage Facilities

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Contents

3.1 Introduction

Open storage of liquid manure from confined feeding operations (CFOs) can be a source of emissions of concern such as gases (e.g. hydrogen sulphide, odour) and particulate matter (e.g. dust). As CFOs become larger, the potential for emitting substances of concern is even greater because of the increased number of animals and therefore, volume of manure that has to be handled.

3.1.1 Background

Over the past 40 to 50 years with the increasing size of livestock operations, the handling of manure has become a major problem for producers. Best management practices suggest that manure be applied to land when it is appropriate and not when the ground is frozen or covered with snow. This necessitates a long storage period to allow CFO operators to time manure application to fit cropping practices and climatic conditions of the area. Storage in excess of 6 months is usually required in Alberta.

Several storage methods have been used including, in-barn deep pits, covered concrete storage tanks, above-ground metal and concrete structures (MAFRI 1995; MWPS 1985; CAST 1996). However, when large volumes of manure are involved, such structures can become cost-prohibitive. Therefore producers generally choose the lower cost option of storing manure in open, clay-lined earthen manure storage facilities (MSFs).

Manure in MSFs exists primarily in an anaerobic state (Wilkie 2000), thereby creating the potential to produce gases of concern. Since earthen MSFs usually have large exposed surface areas, they provide avenues for gaseous emissions into the atmosphere. CFO operators have to consider how to manage these large storage facilities to minimize the emission of gases of concern. Some of the techniques used to minimize air movement and emissions from MSFs today include permeable and impermeable covers, additives, biological treatment systems (lagoons), and natural and artificial windbreaks. Several of these options are discussed in other chapters in this report.

The process of transferring manure from animal housing facilities to MSFs may also contribute to release of air emissions. Many MSFs are filled by gravity from the animal housing facility or mechanically by pump, if the elevation does not permit gravitational flow. These manure handling systems move manure into the storage facility either by discharging manure above the surface of the stored manure, called top loading, or below the surface of manure in the MSF, called bottom loading.

3.1.2 Objectives

The purpose of this study is to evaluate the effectiveness of bottom loading in comparison to top loading of MSFs, with the intention of reducing gaseous emissions of concern.

3.2 Effects of Top and Bottom Loading on Air Emissions

It is generally known by CFO operators that air emissions of concern, primarily odour, from stored manure increase when manure is disturbed or agitated. This effect, along with hazards associated with the release of high concentrations of certain gases, has been documented relative to indoor MSFs (McQuitty and MacLean 1983). In enclosed, inadequately ventilated spaces, the consequences can be fatal, for instance, following the release of high concentrations of hydrogen sulphide (NIOSH 1990). Therefore, CFO operators must take extreme care when agitating stored liquid manure, especially inside buildings or enclosed spaces.

Although there is little direct scientific evidence, it can be inferred that reducing the disturbance of outdoor earthen MSFs will likely result in lower air emissions. Since top loading results in more disturbance (splashing at the manure surface), it is therefore presumed to increase emissions. Bottom loading avoids splashing and minimizes agitation, so it is presumed to reduce emissions. Furthermore, bottom loading can allow an undisturbed crust of dried manure and bedding material to form on the manure surface (Knowlton and Herbein 2008). This crust greatly restricts volatile nitrogen (N) loss into the atmosphere (Muck and Richards 1983). A well-developed crust will reduce ammonia emissions by about 70%. If the manure solids content is low and a surface crust does not form, then little difference in gaseous emissions could be expected between top and bottom loading systems (C. Rotz, Agricultural Engineer, United States Department of Agriculture, University Park, PA, pers. comm.).

Limited studies have been conducted to compare emission losses from bottom-loaded and top-loaded facilities. Muck and Steenhuis (1982) developed a model to simulate N losses from a dairy manure storage facility and validated this model using data obtained from the laboratory and from published literature. They compared N losses from bottom-loaded and top-loaded MSFs under different environmental and management regimes. Nitrogen losses from the bottom-loaded MSF were less than 10% whereas N losses from the top-loaded facility were as high as 25 to 30%. Due to the lack of scientific data, validation of the model developed by Muck and Steenhuis (1982) was limited. Therefore, Muck et al. (1984) conducted another study to perform N balance analysis on two MSFs, one bottom-loaded by gravity and another top-loaded from a push ramp. They found losses from the top-loaded MSF ranged between 29 and 39% whereas the losses from the bottom-loaded MSF ranged between 3 and 8%. They concluded that bottom-loaded MSFs, be they earthen, concrete or metal, provided similar levels of N conservation.

Dou et al. (1996) developed a computer worksheet that integrated information from different disciplines to quantify N flow throughout any given dairy enterprise. This model estimated that N losses from a watertight manure storage structure were 60% when the facility was top-loaded compared to 30% when bottom-loaded. On the other hand, Rotz (2004), in a review paper, reported that N losses from a top-loaded dairy manure slurry tank were 30%, while losses from a bottom-loaded tank were only 5%. Note that Rotz (2004), Dou et al. (1996), Muck et al. (1984) and Muck and Steenhuis (1982) did not specify the nitrogen compounds measured.

3.3 Practical Implications

Bottom loading is a manure handling practice recommended by various best management practice manuals (e.g. CPS 1986, 1996) and extension specialists (D. Ward, Poultry & Other Livestock Housing & Equipment Engineer, Ontario Ministry of Agriculture, Food and Rural Affairs, Stratford, ON, pers. comm.; B. English, Business Development Specialist - Engineering, Manitoba Ministry of Agriculture, Food and Rural Initiatives, Brandon, MB, pers. comm.). In some jurisdictions it forms part of the legislative policy. For example, Alberta's *Agricultural Operation Practices Act* and *Regulations* (GOA 2005) requires new or expanding CFOs to construct outdoor MSFs with a bottom-loaded manure delivery system from the livestock building to the MSF.

Feddes and Edeogu (2001) provided some design specifications for bottom-loaded manure delivery systems. They recommended that the discharge outlet should be located at least 0.91 m below the surface of the manure and at least 0.31 to 0.61 m from the bed of solids at the bottom of the MSF. Furthermore, the discharge flow rate at the outlet should be low to minimize the zone of disturbance within the stored manure. However, their specifications were experiential and not based on any scientific studies.

If bottom loading could be scientifically proven to significantly reduce emissions, then retrofitting top-loaded MSFs with bottom loading systems could be an option. DGH Engineering Ltd., a Canadian company experienced in the design and construction of livestock facilities, estimated the cost of such a retrofit to be about $5000. Obviously, this is only a broad estimate and the actual cost would depend on the specifics of the CFO site including, distance from the livestock building to the MSF, elevations of the building and MSF, storage volume (single or multiple storages) and other factors.

3.4 Research Gaps and Recommendations

Without specific, scientific emission reduction data to verify the inference that bottom loading significantly reduces air emissions from MSFs, it is difficult to suggest that bottom loading should be a required practice for all open, outdoor MSFs at this time. Therefore, it is recommended that, as a first step, the effects of bottom loading and top loading on air emissions from open, outdoor MSFs should be investigated and quantified. Subsequently, if bottom loading is scientifically proven to significantly decrease air emissions from MSFs as compared to top loading, then a detailed evaluation of the costs and benefits of retrofitting should be conducted to determine if MSFs can be retrofitted with bottom loading systems.

Setting up a controlled experiment to compare the effects of bottom loading and top loading on air emissions may be complicated (S. Lemay, Directeur Scientifique, Institut de Recherche et de Développement en Agroenvironnement, Québec city, QC, pers. comm.). This probably explains the lack of research efforts on this topic. The variabilities in storage configurations, layouts, discharge frequencies, manure quality and management introduce many difficulties in scientific studies of the effectiveness of bottom loading compared to top loading. Such research will require careful design and planning to minimize difficulties and costs.

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Chapter 4.0

Manure and Dead Animal Composting

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Contents

4.1 Introduction

Intensive livestock production is always associated with the production of large quantities of manure and the need for responsible management of inevitable mortalities. Composting can help alleviate some of the manure and mortality management problems and concerns related to intensive livestock production, while providing many other benefits to producers. It has routinely and successfully been used as a livestock production management practice in many parts of the United States (Baldwin and Ranells 2002; TAMU 2003) and Canada, including Alberta (Larney et al. 2000).

Composting is the biological decomposition and stabilization of organic substrates under conditions that allow development of temperatures above 40°C from biologically produced heat. It results in a final product that is stable, free of viable pathogens and plant seeds, and can be beneficially applied to the land (Haug 1993). Under controlled conditions, manure composting is accomplished in two main stages: an active stage and a curing stage (ARD 2005). Composting mortalities is achieved via a different management process involving a primary, secondary, and potentially, a tertiary phase of composting (ARD 2002a).

In the active manure composting stage, microorganisms consume oxygen (O_2) while feeding on organic matter, and produce heat, carbon dioxide (CO_2) and water vapour. During this stage, most of the degradable organic matter is decomposed. A management plan is needed to maintain proper temperature, oxygen and moisture levels in order to provide an environment that is conducive for microorganisms to thrive (ARD 2005).

During the curing stage, microbial activity slows down, and as the process nears completion, the material approaches ambient air temperature. Finished compost takes on many of the characteristics of humus, the organic fraction of soil. Composting is reported to result in a 20% to 60% reduction in volume, 40% reduction in moisture content and 50% reduction in weight at the end of the process (ARD 2005).

Although it may appear similar, the traditional solid manure management practice of stockpiling manure is not equivalent to composting. Stockpiled manure does not undergo the same type of transformation that composted manure does, and as such, does not produce a homogeneous, stable product at the end of the storage period (NACI 2008).

Fundamentally, composting livestock mortalities aims to achieve the same outcomes as manure composting by following similar principles. However, strict application of manure composting methods can only be done when dealing with a consistent, thoroughly mixed pile. A pile containing livestock mortalities is an inconsistent mixture; the mortality has a low carbon to nitrogen ratio (C:N), high moisture content, and nearly zero porosity, and must be surrounded by a material with a high C:N, moderate moisture levels, and good porosity (ARD 2002b). The carcasses and amendments are layered into the pile, and no mixing is done until after the high-rate phase (primary phase) of composting has occurred. It is important to note that even though manure and dead livestock are two types of organic material that can be successfully composted, in order to be successful, both feedstocks typically need to be mixed with other organic material to provide a substrate with suitable properties.

Alberta's *Destruction and Disposal of Dead Animals Regulation* under the *Animal Health Act* requires the owner of a dead animal to dispose of that animal within 48 h of death. Mortality composting is an approved and viable option for disposing of dead animals on the farm. There are three generally accepted approaches to mortality composting namely, enclosed or bin systems, open pile or windrow systems, and reactor systems. Currently cattle producers do not require a permit to dispose of their cattle mortalities provided the animals have not died from a reportable disease. However, the Canadian Food Inspection Agency (CFIA) considers composted cattle mortalities to be specified risk material (SRM) even though the animals may have died from natural causes. Thus, composted cattle mortalities cannot be sold, but in some instances may be used with restrictions under permit (CFIA 2009).

4.1.1 Factors that influence the composting process

Composting is a complex yet natural process. Factors (parameters) affecting the process, including C:N ratio, temperature, aeration and oxygen content, moisture content, porosity, and pH, i.e. acidity or alkalinity (ARD 2005), can be measured during composting to determine the stage or phase of the process. These factors can also be controlled to accelerate and enhance the overall composting process.

4.1.1.1 C:N ratio

Some types of livestock manure are referred to as highly bedded manure, which means that they contain a large amount of bedding material such as straw or wood shavings. Highly bedded manure has a high C:N ratio. Composting uses the high C:N ratio to its advantage by reducing the amount of ammonia loss to the atmosphere. The carbon causes the nitrogen to become temporarily unavailable but this does not affect the stability of the final composted product (Martins and Dewes 1991). Typically, raw materials should provide a C:N ratio ranging between 25:1 and 30:1 (Rynk et al. 1992). C:N ratios greater than 30:1 will result in slower and, perhaps, incomplete decomposition of the bedding material. After the composting process is complete, the C:N ratio of the composted product can measure approximately 12:1, which is reported to approach the C:N ratio of soil (Carcamo et al. 1997).

An animal carcass is generally a mass with a low C:N ratio, high moisture content, and relatively low oxygen content (Looper 2001). Keener et al. (2000) reported cattle carcasses to have a C:N ratio as low as 5:1. Therefore, livestock carcasses must be layered with an adequate amount of sawdust, wood chips, or straw in order to raise the C:N ratio to 25:1 or greater (Keener et al. 2000). Because of its ability to shed rain water from the pile, sawdust is recommended as the carbon amendment for composting mortalities. For example, the recipe for composting poultry mortalities by weight is 1 part poultry carcass to 1.5 parts manure litter and 0.1 parts straw (Adams et al. 1994).

4.1.1.2 Temperature

Temperature is a very good indicator of how well the composting process is progressing. When the process is functioning normally, temperature within the compost mix is expected to increase with increasing microbial activity. Keener et al. (2005) stated that the composting process is capable of generating and regulating its own temperature. According to Larney et al. (2000), composting essentially takes place within two temperature ranges defined as mesophilic (10°C to 40°C) and thermophilic (higher than 40°C).

Temperature increases are noticeable within a few hours of forming manure compost mixtures, because easily degradable compounds are consumed by microbes that generate heat early on in the composting process (Rynk et al. 1992; Haug 1993). The heat generated raises the temperature of the compost mix from the mesophilic range to the thermophilic range. The temperature of the mix usually increases rapidly up to 50°C to 60°C, where it can be maintained for several weeks during the active stage of the composting process. As the active composting process slows down, the temperature of the composting material gradually drops to 40°C and the curing stage begins. Eventually the temperature within the compost mix will approach the ambient air temperature.

Thermophilic temperatures are desirable in the compost mix because pathogens, weed seeds and fly larvae in the manure are destroyed over this range of temperatures. However, Rynk et al. (1992) noted that when the temperature in a composting mix approaches 60°C, heat loss should be accelerated either by forced aeration or by turning the mix. At temperatures above 60°C, fewer microorganisms responsible for composting can survive.

Initially, the temperature in mortality compost piles rises to between 55°C and 65°C. Once the pile reaches 55°C it ought to remain at that temperature for at least 1 week. Even under cold weather conditions, mortality compost piles composed of cattle carcasses were noted to maintain temperatures of up to 55°C for 1 week (Stanford et al. 2007). Both the Canadian Council of Ministers of the Environment (CCME) and the United States Environmental Protection Agency (USEPA) follow the same processes to further reduce human and plant pathogens and kill parasites. These processes include maintaining temperatures above 55°C either for 3 days within reactors and aerated static piles or for 15 days within mechanically turned windrows (CCME 2005; USEPA 2003).

4.1.1.3 Aeration and oxygen content

Air must be supplied to composting material for three basic purposes. First, it is needed to satisfy the oxygen demand (minimum of 5% oxygen) necessary to facilitate the aerobic microbial decomposition of organic matter (Rynk et al. 1992; Haug 1993). If the supply of oxygen drops below 5%, the microbes responsible for the composting process become inactive, and anaerobic bacteria flourish. Should this occur, the heat generated within the composting material will decline and the benefits of achieving thermophilic temperatures within the material will not be attained.

Second, air may be required to remove excess water from wet substrates. The heat generated in the composting material helps achieve this purpose because it heats the air and increases its capacity to remove moisture from excessively wet material (Haug 1993).

Third, air must be supplied to remove excess heat generated by microbial decomposition in order to control the composting process and maintain temperatures within the desired range (Haug 1993).

4.1.1.4 Moisture content

Moisture is important to sustain the metabolic processes of microorganisms (primarily actinomycetes, fungi, and bacteria) responsible for composting. It fosters chemical reactions, transports nutrients, and allows microorganisms to migrate through the composting material (Rynk et al. 1992). Moisture content is defined as the percentage weight of moisture in the mixture. If moisture levels are allowed to fall below 40%, the composting process slows down. When the moisture level is above 70%, water fills the pore spaces in the material and displaces oxygen essential to the process.

The ideal moisture content for composting manure ranges between 40% and 70% on a wet basis (WB) depending upon the source of information, composting materials used, and time of year. In dry climates, such as southern Alberta, the optimum moisture content appears to range between 50% and 60% WB (Nelson 2003).

Similarly, the desirable moisture content for mortality composting piles ranges between 40% and 60% (Merka et al. 1997). Nelson (2003) observed that at moisture contents higher than 60%, temperature within the piles failed to reach 55ºC. High moisture contents above 60% can occur in mortality composting piles because of the inconsistent nature of the material. On one hand, the carcasses are large masses with a low C:N ratio, high moisture content, and nearly zero porosity, while the surrounding carbon amendment has a high C:N ratio, moderate moisture levels, and good porosity. Thus careful consideration should be given to the properties of the carbon amendments used to surround the carcasses (ARD 2002b). Note however that once mortality composting piles have completed the primary composting phase, the moisture content of the piles may need to be increased when the piles are turned or mixed.

4.1.1.5 Porosity

Porosity refers to the percentage of pore spaces between particles in the compost material. These spaces can be partially or wholly filled with air that supplies oxygen to the composting microorganisms and provide a path for air circulation. As the material becomes saturated with water, the pore spaces fill with water so the amount of air in the compost mix decreases ultimately slowing down the composting process in favour of anaerobic, malodorous conditions (ARD 2005).

Compacting the composting material reduces its porosity while turning the material increases its porosity. Excessive shredding can also impede air circulation by creating smaller particles which can pack together more tightly so the pore spaces are smaller. Adding coarse materials such as straw or woodchips can increase the overall porosity of the compost mix. However, one disadvantage of using coarser materials is that they decompose more slowly (Rynk et al. 1992).

In mortality compost piles, 35% to 45% of the volume should comprise of small pore spaces (Keener et al. 2005). Optimum porosity is achieved by balancing the particle sizes, water content of the mix, and pile size. According to Looper (2001), the particle size of the materials should range between 3 mm and 13 mm to ensure the piles are adequately aerated.

4.1.1.6 Acidity versus alkalinity

A neutral pH of 7 is desirable throughout the composting process, but composting can occur at pH levels ranging between 5.5 (acidic) and 9 (alkaline). A high pH, above 8.5, encourages the conversion of nitrogen compounds to ammonia, which further adds to the alkalinity of the composting material (Rynk et al. 1992). A pH below 8 reduces ammonia loss and reduces the production of noxious odours (Tablante et al. 2003).

4.1.1.7 Animal species

The size of the animal carcass affects the characteristics of the composting process. Small to moderately sized animals generally require less than 3 months to complete both the primary and secondary phases of composting (Keener et al. 2005). For larger animals, primary composting requires more than 3 months for each phase and may require a total of three phases in order to achieve complete decomposition of large bones.

4.1.2 Composting livestock manure

Manure can be composted in a variety of ways distinguished by the technique used to supply air to the microorganisms. Typical active manure composting methods include turned windrows, in-vessel or reactor systems, and forced aeration, while passive methods include natural aeration and passive aeration systems (Sartaj et al. 1997). Larney et al. (2000) noted that active composting performed better than passive composting on the basis of mass, volume and water content reduction. The induced aeration achieved in active composting systems helps enhance the composting process.

4.1.2.1 Windrow composting

Windrow composting is achieved by piling mixed organic matter or biodegradable waste, like animal manure and crop residues, in long rows called windrows. Windrows may be formed outdoors, on covered concrete pads, or indoors.

Windrows are often turned with specialized equipment as part of the procedure for managing temperature, replenishing oxygen and improving porosity of the piles. The physical aeration mechanisms, unique to various windrow turners, affect the biological processes and composting efficiency differently. This is apparent in the amount of power consumed, labour requirement and quality of compost produced. Turners vary from conveyors to rotating drums with flails (Nelson 2003). Many commercially available windrow turners can accommodate compost windrows measuring 4 m wide by 2 m high, but some require modification to the windrow size.

An important feature of any windrow is its cross-sectional dimension. Windrows with larger cross-sectional areas may not allow sufficient oxygen to reach material at the centre of the piles, thereby creating zones within the piles that become anaerobic (ADEQ 2007). On the other hand, smaller cross-sectional areas may not be able to generate and maintain desirable temperatures within the windrows

4.1.2.2 Natural aeration composting

Natural aeration occurs simply by diffusion and convection and does not include a mechanical means of supplying air to the composting media. Its effectiveness is governed by the nature and size of the exposed surface area, the temperature difference between the ambient air and the interior of the compost pile, and the bulk properties of the composting material (Fernandes and Zhan 1994). Since aeration occurs naturally, this method of composting is typically slow and the material used must be carefully selected to ensure the porosity of the mix is optimal. Natural aeration is not recommended for organic matter of high moisture content (Sartaj et al. 1997).

4.1.2.3 Passive aeration composting

Passive aeration composting is a variation of natural aeration composting whereby perforated ducts are installed under a compost pile to facilitate air delivery to the composting material. An alternative is to place the compost on a bed of high porosity material such as wood chips. Air is drawn into the perforated pipes by convective currents that develop via thermal buoyancy in the warm, decomposing composting mass (Sartaj et al. 1997). However, Larney et al. (2000) discovered that large portions of composting material at the centre of passively aerated windrows had the appearance of raw manure at the end of the thermophilic phase of the active composting stage.

4.1.2.4 Forced aeration composting

Forced aeration utilizes fans or blowers to push air through ducts buried under compost windrows (Rynk et al. 1992). The rate of aeration is often dictated by monitored levels of temperature, oxygen or both, at various locations within the composting media while the optimum aeration rate is influenced by a number of additional factors, including moisture content and porosity of the material (Sartaj et al. 1997).

4.1.2.5 Reactor composting

Reactor composting is commonly referred to as in-vessel or enclosed system composting. Such reactors may either be oriented horizontally or vertically. Reactor composting technologies are often used to help get the material through the early stages of composting when odours and process control are most critical, and the material is moved into a windrow or static pile system for the later stages of decomposition and curing (Richard 1998).

Vertical reactor composting: According to Richard (1998), vertical reactors are generally over 4 m high, and can be housed in silos or other large structures. Organic material is typically fed into this type of reactor from the top through a distribution mechanism, and then flows by gravity into an unloading mechanism located at the bottom of the reactor. These reactors are usually actively aerated via a pressure-induced (forced airflow) system such that air flows upwards from the bottom of the reactors, counter to the flow of the composting material. Although vertical reactors are typically actively aerated, the sheer height of the vessels does not permit air to flow uniformly through the composting material; consequently, neither temperature nor oxygen can be maintained at optimal levels throughout the reactor, leading to zones of non-optimal microbial activity. Some vertical reactors are fed on a continuous basis or an intermittent basis, and may allow for mechanical agitation of the material (Haug 1993).

Horizontal reactor composting: Again, according to Richard (1998), horizontal reactors avoid the high temperatures, oxygen deficiency, and moisture gradients of vertical reactors by maintaining a short airflow pathway. They come in a wide range of configurations, including static systems, agitated systems, pressure-induced aeration systems, vacuum-induced aeration systems, or combinations of the latter two (Richard 1998). Horizontal reactors may either employ a rotating drum system or a bin structure.

Agitated bin systems are the most common types. These systems usually time the movement of material through the reactor and combine controlled aeration, either pressure-induced or vacuum-induced, and periodic turning processes. Composting takes place between the walls of long, narrow channels. A track installed on top of each wall supports and guides a compost turner. As the turner moves, the compost is moved a set distance towards the discharge end of the channel (Rynk et al. 1992).

Rotating drum reactors, another form of agitated system, are designed to speed up the composting process. These reactors retain the material for only a few hours or days. The tumbling rotating action of the drum helps homogenize and shred material within the reactor (Smårs et al. 2001). However, because of the short residence time, the process is primarily physical rather than biological, so the material discharged from the reactor has to be subjected to additional processing (biological) in an in-vessel reactor, static reactor, windrow, or a combination of systems (Richard 1998).

4.1.3 Composting livestock mortalities

The process of composting dead animals uses microorganisms, including bacteria and fungi, to decompose animal carcasses in an aerobic environment. If sufficient oxygen is available, the microbes are able to decompose the animal without the production of objectionable odours and gases (Mescher et al. 1997). As mentioned earlier, due to the inconsistent nature of livestock carcasses compared to manure, composting animal carcasses does not follow the traditional composting process of mixing all the materials thoroughly before establishing compost piles (Fonstad et al. 2000).

4.1.3.1 Windrow composting

Windrow mortality composting uses a constructed pad on which the windrows are built. Site preparation and runoff control structures are desirable for all windrow composting systems but are especially important for mortality composting (Mescher et al. 1997). The base of the windrow is prepared following applicable legislation and best management practices. Once the windrow has been built according to established guidelines, the length of the primary composting phase will depend on the size of the animal carcasses. Furthermore, once a windrow has reached its primary composting phase, a new windrow may be started to accept new carcasses. Note that mortality compost windrows are sized relative to the daily mortality rate of respective livestock operations.

4.1.3.2 Bin composting

Bin composting is carried out in bins typically constructed on concrete floors with concrete or treated lumber walls (ARD 2002a). Installing a roof is highly recommended with the use of bins to help minimize leachate and runoff concerns (Mescher et al. 1997). Building the right number and right size of bins is extremely important (Harper and Estienne 2003). Again, the number of bins required depends on the mortality rate of the operation (Harper and Estienne 2003).

4.1.3.3 Reactor composting

Reactor or in-vessel composting systems are controlled, high flow rate aeration systems which are designed to provide optimal mortality composting conditions (BCMAFF 1996b). The in-vessel composting technique can present numerous advantages with regard to short processing times (10 days to 14 days for the initial phase), controlled temperatures, automated aeration, mixing of the compost mass, and prevention of access by rodents and other disease vectors (Choinière 2006). Compared to bin composting or windrow composting systems that can take up to 6 months to transform mortalities into compost, in-vessel composting can speed up the process by a factor of 30 (Kains 2005).

4.1.3.4 Small and moderate size animals

Poultry and swine are classified as small or moderate size animals. Composting poultry carcasses in bins can be accomplished by placing a 0.3-m layer of dry poultry litter or other carbon amendments such as straw or sawdust in the bottom of the bin (Carter et al. 1996). A layer of carcasses is placed on top of this bottom layer. Carcasses should be placed at least 0.23 m from bin walls and should not touch each other. Except for the uppermost layer of carcasses, the first layer and subsequent layers of carcasses are covered with poultry litter 0.15 m thick up to a height of about 1.2 m. Finally, the uppermost layer of carcasses is capped with dry poultry litter 0.3 m thick (Keener et al. 2005). After the bin is completely full it undergoes primary heating which lasts 10 days to 14 days; the total length of this first phase should take 3 weeks to 4 weeks (Ritz and Worley 2005). Upon completing the first phase, the partially composted waste is removed and placed in a secondary bin for another 3 weeks to 4 weeks. Large birds weighing 7 kg or more may need a third heating phase to achieve complete decay (Ritz and Worley 2005).

Windrow composting is especially useful when significant losses occur in poultry flocks following a disease outbreak or when entire flocks of spent layer hens are culled. Although similar layering techniques are used in windrow composting as in bin composting, some differences exist based primarily on geometrical differences between the two methods. In windrow composting, a layer of poultry litter or carbon amendments 0.3 m thick is spread 3 m to 5 m wide to form the base of the windrow (Ritz 2008). Carcasses should be placed at least 0.25 m from the edges of the windrow and should not touch each other (Carr et al. 1996). The first layer of poultry carcasses should be covered with composting substrate 0.1 m to 0.15 m thick, for instance, a mixture of 1.5 parts layer manure to 1 part carbon amendment (Carr et al. 1996). Subsequent layers of poultry carcasses and composting substrate are added in a similar fashion until the windrow is completely formed, keeping in mind that the uppermost layer of poultry carcasses should be covered with composting substrate 0.3 m thick. Once a windrow is formed it should be left undisturbed for 4 weeks to 6 weeks as it goes through the primary composting phase (Nelson 2003). Once the primary phase is complete, the windrow should be turned with a front-end loader and then covered again with composting substrate, especially in areas where bird parts are visible. Once again, the windrow should be left undisturbed for another 4 weeks to 6 weeks as it goes though the secondary phase of composting. Large birds may be required to undergo a third composting phase or a curing stage prior to land application.

Swine mortality composting can be achieved either in a bin or windrow system. Either system follows a similar procedure to ensure the composting process proceeds efficiently. Primary composting begins with a 0.3-m layer of sawdust followed by a layer of carcasses placed 0.23 m from the edge. It is important to ensure that the carcasses do not touch each other (ARD 2004). Each carcass must be covered with 0.15 m of sawdust before adding the next layer of mortalities. A final layer of sawdust 0.3 m thick is placed over the uppermost layer of mortalities to minimize odours and rodent problems (BCMAFF 1996a). It takes at least 3 months to complete the primary composting phase. Subsequently, the composting material is moved into a secondary bin or the windrow is rolled over, and then is left to undergo a secondary phase of composting (Harper and Estienne 2003). Once the secondary composting phase is complete, the composted material can be used as a carbon amendment to reduce the sawdust requirements for a new composting process or it can be land applied. Usually the two phases are sufficient, but if the carcasses have not composted entirely by the end of the second phase, then a tertiary composting phase will be required.

4.1.3.5 Large animals

Large animals include cattle, bison, horses, and elk (MAFRI 2007). Initially, a 0.60-m thick layer of absorbent carbon amendment such as wood chips should be placed at the base of the pile to provide sufficient clearance from the ground for the carcasses. For ruminants it is often recommended to lance the rumen to prevent bloating and the potential for it to burst. The first layer of carcasses should be covered with a second and final layer of carbon amendment that is 0.60 m thick.

The first phase is the primary composting phase and it lasts for a minimum of 3 months after which the pile is turned, and a carbon amendment, such as sawdust, straw, or wood chips, may need to be added. During the secondary composting phase the pile should be left undisturbed for another 3 months. At the end of the secondary composting phase the pile should be turned again and left undisturbed for a minimum of 3 months during the tertiary composting phase (BCMAFF 2005). At the end of the composting process, the compost may be used as an inoculant for a new composting process or it may be applied on land.

4.2 Impact of Composting on Air Emissions

There is limited literature on the effects of manure composting or mortality composting on the reduction of air emissions of concern from livestock operations. The main focus of the literature has been on ammonia (NH_3) emissions, but very few of those NH_3 emission studies have compared composting with conventional manure or mortality management practices. A few studies have focused, directly or indirectly, on the effects of composting on hydrogen sulphide (H_2S), volatile organic compound (VOC) and odour emissions (Edeogu et al. 2006; Elwell et al. 2003; Smet et al. 1999; Homans and Fischer 1992). Extremely limited work has been done on pathogen and bioaerosol emissions from composting livestock manure or mortalities, although such emissions from composting various other types of organic material have been studied quite extensively (Taha et al. 2006; Hryhorczuk et al. 2001; Nielsen et al. 1997).

4.2.1 Ammonia

Due to their high nitrogen content, composting livestock manure or mortalities is invariably associated with NH_3 emissions. Again, because of the limited number of studies comparing emissions of manure or mortality composting systems to emissions from other livestock manure or mortality management systems, it remains uncertain if some reduction in NH_3 emissions is actually achieved via composting.

4.2.1.1 Manure composting

Studies have shown that NH_3 volatilization increases during windrow composting with increasing pH, moisture content, and temperature but decreasing C:N ratio (Saludes et al. 2008; Cáceres et al. 2006; Parkinson et al. 2004; Kuroda et al. 1996; Martins and Dewes 1991; Witter and Lopez-Real 1988; Bishop and Godfrey 1983). Martins and Dewes (1991) reported that between 46.8% and 77.4% of the initial nitrogen content of poultry, pig, and cattle manure mixed with straw was lost though gaseous emissions in the form of NH_3.

Several studies have investigated NH_3 losses from liquid manure storages, livestock buildings, and manure applied on land (Xue et al. 1998; Xue and Chen 1999; Zhang et al. 2005; Heber et al. 2000; Misselbrook et al. 2004; Amon et al. 2006). Ironically, NH_3 emissions from stockpiled manure, a traditional solid manure storage practice, have not been widely investigated. Sommer et al. (1999) reported cumulative NH_3 emissions from stockpiled dairy cattle litter totalled 100 g

N ton^{-1} of manure over a period of 80 days; however the NH_3 emissions were only present on the day the stockpile was created and quickly decreased to zero by the following day. Parkinson et al. (2004) and Peterson et al. (1998) observed a similar trend in NH_3 emissions from stockpiled cattle manure. Parkinson et al. (2004) reported cumulative NH_3 emission rates of 10 g N m^{-2} of stockpiled manure within the first few days of forming the pile.

NH_3 losses from composting systems were studied by Saludes et al. (2008) for dairy manure; Hellebrand and Kalk (2001) and Martins and Dewes (1991) for mixed livestock manure; Keener et al. (2002) for poultry manure; and Fukumoto et al. (2003) and Kuroda et al. (1996) for swine manure. In the study conducted by Saludes et al. (2008), the effect of a mixture of a gypsum product and fresh dairy manure on NH_3 losses from a reactor composting system was investigated. From the results presented by Saludes et al. (2008), it appears that a maximum NH_3 loss of 8000 ppm was recorded on the second day after the reactor was filled with the composting material but rapidly declined to zero (0 ppm) by day 7. Saludes et al. (2008) believed the high temperature and pH conditions that prevailed during the thermophilic phase probably promoted intense NH_3 emissions within the first 7 days. Furthermore, it seems that a slight increase in NH_3 emissions (about 450 ppm) occurred on day 9, i.e. 2 days after the composting material was first turned, then quickly decreased to zero (0 ppm) by day 13, with no further emissions recorded up until day 28.

Hellebrand and Kalk (2001) measured NH_3 emissions from compost windrows comprised of straw bedding, cattle manure, and pig manure. The windrows, each measuring 40 m long by 4 m wide and up to a maximum height of 1.2 m, were created in layers. Initially, the first layer of composting material in each windrow, presumably a mixture of the two types of livestock manure and the carbon amendment, was placed on the ground to a height of 0.5 m. Each day an additional 1000 kg of manure (presumably) about 4 m in length was continuously spread on top of the first layer of composting material until the entire length of the windrow (40 m) was covered. It is assumed that this process took 10 days to complete. It appears that the first layer of composting material was left undisturbed to compost for about 50 days to 70 days after which a second layer of composting material, presumably 0.5 m high, was added to the entire windrow (again presumably). It also appears that the layering and composting processes may have been repeated up to a maximum windrow height of 1.2 m. Immediately after windrow set-up the NH_3 emission rates, derived with the aid of a static flux chamber, ranged between 0.3 g m^{-2} h^{-1} and 0.7 g m^{-2} h^{-1}. After 2 weeks to 3 weeks the levels dropped to below 10% of the initial values.

Keener et al. (2002) reported that composting poultry manure resulted in 25% to 35% less NH_3 emissions compared to manure stored in a deep pit manure storage system. Losses of NH_3 measured in July were 0.376 kg N bird^{-1} year^{-1} for the deep pit storage system and 0.136 kg N bird^{-1} year^{-1} for the composting system. In addition, the total amount of nitrogen conserved in the composted manure was twice as much as that in the untreated manure.

Fukumoto et al. (2003) investigated the effects of pile size on NH_3 emissions from composting material comprised of swine manure and sawdust. Cumulative NH_3 emissions from a small pile weighing about 320 kg and measuring 1.4 m in diameter and 0.7 m high, initially, were compared to cumulative NH_3 emissions from a larger pile with about 780 kg of composting material and measuring 2 m in diameter by 0.9 m high. It appears that after 21 days, the temperature of the two treatments began to differ with the temperature of the smaller pile decreasing at a faster rate. Similarly, the concentration of NH_3 emissions from the smaller pile seemed to decrease from as high as about 35.5 mg m^{-3} to about 2.2 mg m^{-3} after 28 days, compared to the larger pile where the concentrations seemed to decrease from as high as about 75.5 mg m^{-3} to about 2.2 mg m^{-3} after almost 39 days. The total amount of NH_3 released from the small and large composting piles were 350.3 g NH_3-N and 960.4 g NH_3-N, respectively, corresponding to emission rates of 112.8 g NH_3-N per kilogram of total nitrogen (TN) and 127.4 g NH_3-N per kilogram of TN, respectively. Thus, it was suggested that the NH_3 emission rate was directly proportional to the size of the composting pile.

In a somewhat related study, Parkinson et al. (2004) reported that the proportion of initial TN lost as NH_3 was low during colder periods and was an order of magnitude greater under warmer ambient conditions. Similar NH_3 emission trends relative to temperature increases and decreases within the composting mix were also observed by Kuroda et al. (1996) using laboratory-scale apparatus and swine manure.

Other studies have shown that NH_3 volatilization increases during reactor composting with increasing pH, aeration and temperature but decreasing C:N ratio (Guardia et al. 2008; Liang et al. 2006; Pecchia et al. 2002; Witter and Lopez-Real 1988; Hansen et al. 1989; Li et al. 2008). Liang et al. (2006) reported 90% of NH_3 emissions from composting dairy manure occurred within the first 100 h. Hansen et al. (1989) reported that over 85% of total NH_3 emissions occurred within the first 4 days of composting poultry manure.

Li et al. (2008) reported that cumulative NH_3 emissions increased from about 3.5 g to 10 g to 26 g with aeration rates increasing from 0.125 L min^{-1} kg^{-1} of volatile solid content (VS) to 0.25 L min^{-1} kg^{-1} of VS to 0.5 L min^{-1} kg^{-1} of VS, respectively. According to Liang et al. (2006), NH_3 volatilization during reactor composting of dairy manure accounted for 78% of N losses. In the latter study, the average NH_3-N loss was 2.5 g kg^{-1} of the initial dry solids content. Furthermore, increasing the C:N ratio from 25:1 to 30:1 reduced N losses by half, i.e. from 24.6% to 12.1%, respectively. A small scale study conducted by Pecchia et al. (2002) also showed that NH_3 losses decreased significantly with increasing C:N ratio. Similar results were reported by Hansen et al. (1989).

4.2.1.2 Mortality composting

NH_3 emissions were measured from a cattle mortality bin composting system by Thomson and Van Heyst (2008). Three bins were filled with composting material comprised of different proportions of animal carcasses and carbon amendments. Maximum NH_3 emission rates from the bins were 4.20 g h^{-1}, 1.14 g h^{-1}, and 0.86 g h^{-1}.

4.2.2 Hydrogen sulphide

Since H_2S is the produced under anaerobic conditions, it is not surprising that the effects of composting on H_2S emissions appear to relate to the inability to provide sufficient oxygen to facilitate the composting process. Smet et al. (1999) and Homans and Fischer (1992) stated that anaerobic conditions that exist in manure composting piles, due to incomplete or insufficient aeration, will produce sulphur compounds of intensive smell. In a laboratory scale study of composting dairy manure, Li et al. (2008) recorded higher H_2S emissions at lower aeration rates. Similarly, Elwell et al. (2003) observed that H_2S emissions were higher from intermittently aerated composting vessels compared to vessels that were continuously aerated. No reports were found on H_2S emissions from mortality composting.

4.2.3 Volatile organic compounds

According to USCC (2002), volatile organic compounds (VOCs) in compost include aliphatics (e.g. acetone), aromatics (e.g. benzene) and halogen-containing organic compounds (e.g. carbon tetrachloride).

Emissions of many VOCs have been associated with manure including, volatile fatty acids (VFAs), indolics, phenolics, and sulphur compounds (Elwell et al. 2003). Among the VFAs, Elwell et al. (2003) identified the following VOCs to be of interest to their study: acetate, propionate, isobutyrate, butyrate, isovalerate, valerate, phenol, p-cresol, indole and skatole. Part of their study included a comparison between the VOC content and emissions from a composting process using aged 12-day-old dairy manure and a composting process using fresh dairy manure. The results showed the process using the aged manure had a higher VOC content in the composting material and higher VOC emissions compared to the process using fresh manure. Furthermore, composting either the aged or fresh manure seemed to reduce emissions (losses) of VOCs from the composting material by over 90% and by over 99% for some of the VOCs. However, since no comparison was made to VOC emissions from stockpiled or undisturbed dairy manure, it is uncertain if the low emissions associated with the study were truly due to the effect of composting on the emissions.

In another study, Akdeniz et al. (2007) investigated the effects of aeration on VOC emissions from shredded pig mortalities mixed with corn silage and placed in 450-mL glass jars. The number of VOCs detected under anaerobic, undisturbed conditions was twice as many as detected under intermittently aerobic, passively aerated conditions.

4.2.4 Odour

Edeogu et al. (2006) studied the effects of beef cattle manure windrow composting and the composted manure on odour emission rates compared to the rates from stockpiled manure. Flux chambers vented with filtered air at 0.5 L s^{-1} were used to collect odour samples. The samples were analyzed by dynamic triangular forced-choice olfactometry within 24 h of sample collection. The results indicated that the mean odour emission rate from the composting treatment was significantly higher during the active composting stage (day 1 to day 78) by about 28% compared to the emission rates from the stockpiled manure treatment over the same length of time. At the end of the composting period (day 106), the mean odour emission rate of air samples taken after disturbing the windrow was 28% lower than the mean emission rate associated with the disturbed stockpiled manure. However, the difference in the means was not statistically significant ($p = 0.14$).

Despite the results, Edeogu et al. (2006) were unable to conclude if composting beef cattle feedlot manure reduced or did not reduce odour emissions. Their inability to draw a conclusion following their study stemmed from their lack of confidence in the results, citing concerns such as the potential dilution effect of excessive airflow through the vented flux chamber. In addition, the effect of background odours that may not have been effectively filtered despite the use of an activated carbon filter also raised some doubts about the results. Background odours were perceived a number of times during the study with a distinctive odour presumed to be from a distillery perceived on day 106 during air sample collection. Furthermore, although Edeogu et al. (2006) stratified their measurements across the surfaces of the windrow and stockpiled manure, their study was conducted using only one compost windrow and one manure stockpile. This strongly suggests a lack of sufficient replication and possible autocorrelation effects in their data.

Similar to manure composting, limited information was available on the effects of mortality composting on odour emissions. In a study conducted by Glanville et al. (2005), odour concentrations of sampled emissions from composting cattle carcasses with corn silage, ground cornstalks or ground straw were typically less than 1500 dilutions to odour threshold levels. Ironically, according to Glanville et al. (2005), these concentrations were often similar to the concentration of emissions from the stockpiled carbon amendments without the cattle carcasses.

4.3 Regulatory Requirements for Composting

Effective on-farm composting of livestock manure and mortalities is achievable but requires a dedicated site that meets regulated requirements, careful process management, proper equipment and manpower availability. Alberta has several regulatory requirements that apply to manure and mortality composting.

4.3.1 Manure composting

GOA (2005) requires livestock producers in Alberta who compost their own manure to comply with the *Agricultural Operation Practices Act and Regulations* (AOPA). Should a producer consent to accept any municipal or industrial waste then that producer must comply with Alberta's *Environmental Protection and Enhancement Act* (EPEA) and associated Codes and Regulations (D. Chaw, Waste Policy Advisor, Alberta Environment, Edmonton, AB, pers. comm.). Some of the requirements producers need to satisfy to compost their livestock manure under AOPA include siting the composting facility according to standards with respect to minimizing odour issues and meeting liner requirements during compost pad construction.

Similarly, the Code of Practice for Composting Facilities under EPEA outlines minimum requirements for siting, design, construction, operation, and closure of composting facilities (AENV 2001). These requirements were established to ensure composting facilities are designed and operated in a manner that is protective of air, land, water, biodiversity, human health, and human quality of life. A producer accepting waste other than manure for composting should consult Alberta Environment prior to commencing the construction and operation of a composting facility.

4.3.2 Mortality composting

Livestock producers composting their own animal mortalities must comply with the *Animal Health Act* and the *Destruction and Disposal of Dead Animals Regulation* (GOA 2007). Some of the requirements producers need to satisfy to compost their animal mortalities under these regulations include: identifying a suitable location for the composting facility; managing the volume of mortalities composted in each batch or continuously; and managing the amount of organic carbon material used to cover the mortalities (ARD 2002a).

4.4 Non-Air Emission Related Benefits and Limitations of Composting

Many studies have been conducted to define the benefits, feasibility, influences, effectiveness, and so on, of composting livestock manure and mortalities. Composting manure has become a common feature and an integral part of livestock production best management practice (BMP) manuals and extension portfolios (ARD 2005). Mortality composting is an accepted option for dealing with carcasses.

4.4.1 Benefits of composting

There are several documented benefits of composting and compost.

4.4.1.1 Nutrient retention

The composting process stabilizes the volatile N in raw manure, consequently reducing nitrogen loss (Tiquia and Tam 2000). Compost returns N, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and micronutrients to the soil. Although the amounts vary, well-prepared, mature compost can contain 7.5 kg t^{-1} to 15 kg t^{-1} of N, 2.5 kg t^{-1} to 5 kg t^{-1} of phosphate and 15 kg t^{-1} of potassium oxide (COG 1992). The nutrients retained in mature compost are released to plants slowly and steadily, and the benefits tend to last for more than one season.

4.4.1.2 Weed control

Composting reduces the viability of weed seeds by a combination of factors including, high temperatures, rotting and premature germination within the composting pile. Tompkins et al. (1998) reported that of the 12 common weed seeds investigated, 11 of them had 0% viability after 2 weeks of composting. The only exception was *Amaranthus retroflexus* (red root pigweed), which had a viability of 3.5%.

4.4.1.3 Disease control

Plant and animal pathogens are reduced because of high temperatures achieved during the composting process. Some regulations have deemed livestock mortality compost to be sufficiently biosecure to be used as a soil amendment or fertilizer (Spencer and Guan 2004).

Pathogen elimination during composting various substrates has been studied extensively. The United States Department of Agriculture (USDA) conducted numerous studies on pathogen survival in windrow and aerated static pile composting systems. Epstein (1996) showed that the salmonellae populations in unspecified composting material increased initially but were destroyed within 10 days of composting in a static pile and 15 days in a windrow. Walke (1975) monitored *Escherichia coli, Salmonella eidlebert*, and *Candia albicans* during windrow composting of bark and biosolids and detected no organisms after 36 h. Pereira-Neto et al. (1986) evaluated the efficiency of aerated static piles of refuse and biosolids in destroying *Escherichia coli,* fecal streptococci, and salmonellae. Salmonellae were destroyed in 7 days to 15 days; *Escherichia coli* decreased from 10^7 org g^{-1} wet weight (WW) to $<10^2$ org g^{-1} WW in 15 days; and fecal streptococci decreased from 10^7 org g^{-1} WW to $<10^2$ org g^{-1} WW in 30 days. Krogstad and Gudding (1975) inoculated solid waste and biosolids with *Salmonella typhimurium* and *Bacillus cereus* and made periodic measurements to determine the die-off rate. *Salmonella typhimurium* could not be detected after 4 days in a horizontal drum composter when the temperature was kept at 65°C. The researchers concluded that within 3 days to 5 days, a reactor vessel with temperatures ranging between 60°C and 65°C would destroy pathogens.

4.4.1.4 Greenhouse gases

Emission of methane (CH_4) during the composting process has been raised as a concern regarding the net benefit of composting in relation to carbon sequestration. Singh (2005) reported that composting beef cattle feedlot manure produced 33% less greenhouse gas (GHG) emissions compared to stockpiled manure, and estimated composting to have the potential to reduce carbon emissions in Canada by as much as 1.6 Mt annually. However, the study by Singh (2005) seemed to lack sufficient replication to enable such conclusions to be drawn. Ultimately, further study is needed to fully evaluate the impact of composting livestock manure and mortalities on overall GHG emissions (Hao et al. 2004).

4.4.1.5 Biodiversity

Compost supports and encourages the growth of earthworms, bacteria, fungi and other microorganisms and adds organic matter to the soil. In this way, compost improves the biological, physical and chemical properties of the soil (Cooperband 2002). In comparison, raw manure also adds organic matter to the soil but can cause a period of disruption to soil life by creating an imbalance of nutrients (COG 1992).

4.4.1.6 Soil integrity

Compost helps improve soil structure by binding soil particles into aggregates. This binding ability is due to the nature of composted material, the fungal/actinomycete mycelia in compost and the stimulation of mycelia growth in the soil by compost application. The aggregated structure greatly increases the ability of the soil to resist wind and water erosion (Chen and Wu 2005). It also protects the surface soil by reducing the disintegrating action of rain drop impacts, increasing infiltration, reducing water runoff, and increasing surface wetness.

4.4.1.7 Manure volume reduction

Compost has a higher bulk density compared to untreated raw manure on a dry matter basis. SAF (2006) reported that raw cattle manure had a bulk density of 500 kg m^{-3} while composted cattle manure had a bulk density of 650 kg m^{-3}. Larney et al. (2000) reported the ability of composting to substantially reduce the mass, volume and water content of manure. Ultimately the transformation results in fewer trips to the field to apply manure.

4.4.1.8 Mortality management

Composting turns mortalities into biologically stable, heat-treated soil amendments that can be applied to cropland with little risk of air or water pollution (Glanville and Richard 2001). It allows producers to manage their animal mortalities promptly without waiting for scheduled rendering service pick-up and with no rendering service fee payments, or without waiting for the ground to dry or thaw so that the carcasses can be buried (Glanville et al. 2008). Prompt and careful disposal of mortalities reduces the potential for disease transmission, air and water pollution, and attraction of insects and scavenging animals (Glanville and Richard 2001). Mortality composting is a well-established technology for the reduction of: bacterial, viral and fungal pathogens (Wilkinson 2007); internal parasites (Kalbasi et al. 2005); and weed seeds (Larney and Blackshaw 2003).

4.4.2 Limitations

The rate of aeration has a significant impact on the composting process. A lower aeration rate was shown to reduce emissions but also slowed down biodegradation therefore prolonging the process (Pagans et al. 2006; Li et al. 2008).

Application of untreated raw manure or composted manure can result in the increased concentration of nutrients in the soil (Eghball 2002). Increased plant-available P in soil following N-based manure or compost applications can provide sufficient P for up to 10 years without the need for additional P (Eghball 2003). Eghball et al. (2004) reported that one year after applying untreated and composted manure on land, an increase in P concentration was measured at soil depths ranging between 0.15 m and 0.30 m. Three years later, increased P levels had reached depths ranging between 0.45 m and 0.60 m.

Compost made from cattle carcasses is considered SRM. The CFIA requires a permit every time cattle producers are handling, transporting or disposing of SRM (CFIA 2007). As stated earlier, SRM compost cannot be sold but may be permitted to be used under certain circumstances (CFIA 2009).

4.5 Research Gaps and Recommendations

Emission rates from non-point sources or area sources on livestock operations are difficult to determine or compare. Part of the problem is the lack of standardized measurement or air sampling techniques and the many uncontrollable factors and conditions that can influence the measurements or sampling (Bicudo et al. 2002). In an evaluation of direct measurement techniques, Smith and Watts (1994) concluded that the wind tunnel (WT) technique was the preferred method for determining emission rates from area sources relative to the vented flux chamber (VFC) technique. Conversely, in a comparison of mean n-butanol emission rates determined with the aid of a WT and a VFC versus theoretically calculated emission rates, Navaratnasamy et al. (2009) reported a closer relationship between the VFC-related emission rates and the theoretical values. While the VFC-related emission rates were 1.2 to 1.3 times the theoretical values, the WT-related emission rates were 3.2 to 3.5 times the theoretical values. Obviously, these relationships will require further investigation.

Another concern, particularly with composting studies completed in the past, is the uncertainty about whether or not the composting material actually underwent the complete composting process, i.e. from the active thermophilic stage to the curing stage, and whether or not anaerobic conditions might have occurred and influenced the results. Thus, it is important that factors such as temperature are adequately monitored for the duration of each composting process and the measured values are reflected in any publications.

As stated earlier, data and information on emissions of H_2S, odour, air-borne pathogens, particulate matter and VOCs from livestock manure or mortality composting systems are lacking. Therefore it is important to investigate the ability of livestock manure and mortality composting systems to reduce emissions of these substances of interest from CFOs. Although more studies have been conducted relative to NH_3 emissions from composting livestock manure or mortalities, further investigation is still required to determine if composting can be used as a mechanism to reduce NH_3 emissions from untreated livestock manure or mortalities.

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Chapter 5.0

Dust Palliatives for Unpaved Roads and Beef Cattle Feedlots

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Contents

5.1 Introduction

An increasing rural population alongside an expanding livestock industry has triggered many conflicts associated with particulate matter (PM) emissions, also commonly referred to as dust emissions (Ferguson et al. 1999; USNRC 2002a; Sanders and Addo 1993). Studies by the United States Environmental Protection Agency (USEPA) report that unpaved roads are the single largest source of dust emissions, producing up to 40% of total dust emissions into the atmosphere (Ferguson et al. 1999).

In agricultural areas, dust sources are primarily attributed to increased road traffic to and from livestock operations. Heavy truck traffic is required to supply the feed, bring in livestock, removed “finished” market-ready animals and haul away large quantities of manure. In addition, open feedlots, e.g. beef cattle feedlots and associated unpaved alleyways, can also be sources of wind-borne dust (Schmidt et al. 2008; USEPA 2001).

Rural residents living in the vicinity of these feedlot operations or adjacent to heavily travelled unpaved roads are well acquainted with the nuisance created by dust from these sources (Ferguson et al. 1999). Although all types of livestock operations may be sources of air emissions, this technical review is limited to a review of information pertaining to the remediation of dust specifically from open beef cattle feedlots and roads servicing different types of livestock operations.

5.1.1 Background

PM in the broad sense includes all solid and liquid droplets suspended in the air. Dust, a constituent of PM, is produced primarily via the breakdown of solids into finely divided particles that become airborne; these particles are also referred to as primary particulates. Therefore, dust can originate from any source in which solid particles are physically reduced in size including, agricultural production sites and vehicle traffic on unpaved roads. This size reduction provides the opportunity for such particles to become suspended in the air (WRAP 2006; USEPA 2001; Sanders and Addo 1993). In addition to primary particulates, secondary particulates are produced by the chemical transformation of atmospheric nitrogen and sulphur compounds into particulates (Stantec 2009; USEPA 2008).

USEPA (2007) defined fugitive dust as ambient airborne dust particles lifted into the air as a result of human or natural activities including, soil movement, effect of vehicle tires on roads, wind action, blasting, etc. However, it excludes dust emissions that are created from internal combustion engine exhausts (e.g. vehicles), brazing, soldering or welding equipment and pile drivers. WRAP (2006), on the other hand, defined fugitive dust, as dust that cannot "reasonably" pass through an opening such as a stack or vent. Several other definitions similar to either of the two definitions given above also exist; however, for purposes of simplicity and level of detail, the definition by USEPA (2007) will serve as the reference for this review.

Dust is typically categorized by size. It is commonly referred to in relation to its equivalent aerodynamic diameter such as PM_{10} or $PM_{2.5}$. PM_{10} refers to dust particles with an equivalent aerodynamic diameter of 10 microns (µm) or less, and $PM_{2.5}$ refers to particles with an equivalent aerodynamic diameter of 2.5 µm or less (USNRC 2002b). According to CAAQES (2005a, b, c) a new "coarse dust" category was under development by USEPA as part of the National Ambient Air Quality Standards (NAAQS). Another common term for classifying dust particles is total suspended particulate (TSP) in reference to the sum of all particles ranging in size up to 25 µm to 45 µm (USEPA 2010). Particle size can be significant in determining suspension times in the air, dispersion patterns and the resulting health effects on people. The silica content of dust is also a factor in determining the degree of health hazard posed to humans (Hicks 2009).

Dust emissions from open beef cattle feedlots are largely the result of short-term weather conditions and cattle activity. Fines from the soil and manure in the feedlot pens are created through the movement of livestock within the confined area and the action of their hooves on the pen surface. Furthermore, the combination of soil and manure can produce a low density particle that can be rapidly launched and suspended in the air by the action of the wind on the pen surface, by the level of livestock activity within the pen, or by a combination of both (Auvermann 2001). Razote et al. (2007) found PM_{10} concentrations to vary greatly with time of day and time of year. Concentrations were usually higher during the evening hours and during summer months. Alleyways subject to vehicle traffic and feedlot pens may also be sources of wind-driven dust and feed particulates, respectively (Auvermann 2001).

Unpaved roads undergo a similar physical process as open beef cattle feedlots except the breakdown of soil particles is facilitated specifically by vehicle traffic. Unpaved roadway dust may be considered to represent the consequential loss of the road surface with subsequent deterioration and a requirement for maintenance. As mentioned earlier, livestock operations require considerable vehicle traffic to and from their facilities, creating dust problems that originate from the farm and local roads leading to the facilities. Thus, unpaved roads can be a significant source of fugitive dust in and around livestock operations.

5.1.2 Concerns about dust

There are several concerns associated with dust.

Human and livestock health

Dust can impact human and livestock health in a variety of ways that are dependent on its particle size distribution and the region of the respiratory system most significantly affected (CAAQES 2005a). Thus, dust is classified into three categories namely, respirable dust, thoracic dust and inhalable dust, in order of decreasing health risk.

Respirable dust is dust that penetrates the lower respiratory system, the alveolar (gas-exchange) region deep inside the lungs. It breaches the natural filtering mechanisms of the body and becomes trapped in the lungs (ASHRAE 2005; USEPA 1996). Dust particles with a median cut size of 2.5 μm ($PM_{2.5}$) are generally classified as respirable dust (ASHRAE 2005; CAAQES 2005a; USNRC 2002a).

Thoracic dust is the fraction of dust that penetrates the lower thoracic region, i.e. the airways in the tracheobronchial region of the lungs (ASHRAE 2005; CAAQES 2005a; USEPA 1996). Dust particles with a median cut size of 10 μm (PM_{10}) are typically classified as thoracic dust (ASHRAE 2005; CAAQES 2005a).

Inhalable dust is made up of dust particles that can be deposited anywhere in the respiratory system. However, most of the particles inhaled are trapped in the extrathoracic airways such as the nasal passage, mouth or larynx (ASHRAE 2005; CAAQES 2005a; USEPA 1996). Inhalable dust constitutes particles with a median cut size of 100 μm (ASHRAE 2005).

Human health effects associated with dust include allergies, bronchitis, emphysema, hay fever, asthma or other chronic long-term ailments (Sanders and Addo 1993; ASHRAE 2005). In a beef cattle feedlot, the incidence of pneumonia was found to increase with increasing concentration of PM ranging in size between 2.0 μm and 3.3 μm. Conversely, there was no significant correlation found between TSP concentration and the incidence of pneumonia in the cattle (MacVean et al. 1986).

Nuisance

Dust can infiltrate homes, offices, and other buildings creating increased sanitation and cleaning requirements. In extreme cases, property values may be affected as well as the quality of life. It can also coat vegetation, degrading the quality of crops grown in neighbouring gardens or fields or lowering the aesthetic value of horticultural plants (Sanders and Addo 1993).

Roads and vehicles

As stated earlier, roadway dust is literally road material that is separated from the bulk of the road surface. As the road gradually wears away, it can ultimately result in the overall degradation of the road, creation of potholes, removal of the road surface, increased maintenance costs and increased damage to vehicle traffic caused by the degradation (Sanders and Addo 1993; Bolander and Yamada 1999; FCM and NRC 2005). Excessive dust in the air can also cause hazy conditions to prevail resulting in reduced visibility and serious driving hazards especially at road intersections and corners (FCM and NRC 2005).

5.1.3 Estimating fugitive dust emissions

5.1.3.1 Roadway dust

Equations 5.1 and 5.2 are used to estimate fugitive dust emissions from unpaved surfaces on industrial sites and public roads accessed predominantly by light-duty vehicles, respectively (WRAP 2006).

$$E = 423\left(\frac{s}{12}\right)^{0.9}\left(\frac{W}{3}\right)^{0.45} \quad (5.1)$$

$$E = \left[\frac{507\left(\frac{s}{12}\right)^{1.8}\left(\frac{S}{30}\right)^{0.5}}{\left(\frac{M}{0.5}\right)^{0.2}}\right] - C \quad (5.2)$$

where

E = PM_{10} emission factor (g VKT^{-1}, i.e. grams per vehicle kilometres travelled)
s = surface material silt content (%)
W = mean vehicle weight (tonnes or megagrams)
M = surface material moisture content (%)[2]
S = mean vehicle speed (km h^{-1})
C = emission factor for 1980 vehicles - exhaust, brake and tire wear = 0.133 g VKT^{-1}

The parameters *s*, *M* and *W* are corrective factors used to adjust the emission estimates relative to local conditions. Values for the various parameters are presented in Table 5.1.

Table 5.1 Range of input values for roadway fugitive dust emission estimates (WRAP 2006)

Emission source	Surface silt content (%)	Mean vehicle weight (tonnes)	Mean vehicle speed (km h^{-1})	Mean number of wheels	Surface moisture content (%)
Industrial roads[a]	1.8 - 25.2	1.8 - 260	8 - 69	4 – 17	0.03 – 13
Public roads[b]	1.8 - 35	1.4 - 2.7	16 - 88	4 - 4.8	0.03 – 13

a See Equation 5.1
b See Equation 5.2

Equation 5.3 below is used to further modify unpaved road dust emission factors.

$$E_{ext} = E\left(\frac{365 - P}{365}\right) \quad (5.3)$$

where

E_{ext} = annual size-specific emission factor extrapolated for natural mitigation (g VKT^{-1})

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[2] WRAP (2006) does not indicate if moisture content is calculated on a wet or dry basis.

E = emission factor from Equation 5.1 or 5.2
P = number of days in a year with at least 0.254 mm of precipitation

Equation 5.3 factors in the natural ability of precipitation events to mitigate emissions. However, note that the factor P does not account for the amount of rain in each event nor the temporal distribution of rain events but rather is a measure of the number of days of precipitation.

According to WRAP (2006), the state-wide predictive PM_{10} and $PM_{2.5}$ fugitive dust emission factors used for all unpaved roads in California are 640 g VKT^{-1} and 64 g VKT^{-1}, respectively.

5.1.3.2 Feedlot dust

Kharrat et al. (2003) reported dust emission rates from two open beef cattle feedlots in Alberta. Emissions of PM_{10} and $PM_{2.5}$ corresponding to three sampling periods at one feedlot, each approximately 4 h in duration, and a fourth sampling period about 22.5 h in duration at the other feedlot, were estimated using a Lagrangian stochastic dispersion model. All samples were collected on different days, two in August and two in October. Concentrations of PM_{10} and $PM_{2.5}$ used in the model were measured at predetermined distances upwind and downwind from the feedlots. Wind speed and direction, and ambient temperature were also measured and used in the model. From the results presented by Kharrat et al. (2003) the emission rates per thousand head of cattle in the feedlots were deduced and ranged between 3.9 kg d^{-1} 1000-hd^{-1} and 69.2 kg d^{-1} 1000-hd^{-1} for PM_{10} and between 0.7 kg d^{-1} 1000-hd^{-1} and 5.4 kg d^{-1} 1000-hd^{-1} for $PM_{2.5}$ (Table 5.2).

Table 5.2 Estimated emissions in kg d^{-1} 1000-hd^{-1} from open beef cattle feedlots in Alberta

Sampling period	Reference sampling location (distance downwind from feedlot)			
	PM_{10}		$PM_{2.5}$	
	100 m	200 m	100 m	200 m
Period #1[a,b]	3.9	7.1	2.7[e]	2.5[e]
Period #2[b,c]	21.0	16.5	3.6	1.4
Period #3[c,d]	6.0[e]	4.0[e]	5.4[e]	0.7[e]
Period #4[c,d]	34.3[e]	69.2[e]	2.2[e]	4.0[e]

a Sampling conducted over 22.5 h
b Sampling conducted in Aug. 2002
c Sampling conducted over 4 h
d Sampling conducted in Oct. 2002
e Data based on upwind concentrations adjusted to 0 g m^{-3} prior to calculation of net concentration

Kharrat et al. (2003) expressed concerns about those emission rates that corresponded to negative net concentrations, i.e. negative differences in concentration between the downwind and upwind sampling points, citing a few possible reasons for the occurrence. Apparently, PM_{10}

and $PM_{2.5}$ concentrations at the upwind sampling points were always expected to be lower than the downwind concentrations by the researchers. Thus, in order to deal with the perceived anomalies in the data (negative net concentrations), Kharrat et al. (2003) determined the net concentrations by using an upwind concentration of 0 g m^{-3} in those specific cases.

In the United States (U.S.), USEPA utilizes an emission factor of 127 kg d^{-1} 1000-hd^{-1} capacity for TSP emissions from open beef cattle feedlots (USEPA 1985, 1988). Based on the latter factor, PM_{10} emissions were estimated to be 70 [sic 81] kg d^{-1} 1000-hd^{-1} capacity (USEPA 1988). The estimation was based on the empirical relationship between PM30 and PM_{10} in mechanically disturbed loose soils with an 18% silt fraction. However, it is not clear if these values were still considered valid by USEPA (1995) since no TSP or PM_{10} emission factors were reported in that edition of its air pollution emission factors standards.

In a later publication, USEPA (2005) reported the PM_{10} emission factor to be approximately 15 tonnes yr^{-1} 1000-hd^{-1} throughput, equivalent to the value estimated by USEPA (1988). No indication was given of the length of a throughput (as measured in days) but it appears to be less than 365 days. Furthermore, USEPA (2005) reported that the $PM_{2.5}$ emission factor for open beef cattle feedlots could be estimated from the PM_{10} emission factor by multiplying the latter by 0.15. Thus, by multiplying 0.15 by the daily PM_{10} emission factor (i.e. 81 kg d^{-1} 1000-hd^{-1} capacity) estimated by USEPA (1988), it can be presumed that the daily $PM_{2.5}$ emission factor for open beef cattle feedlots in the U.S. is 12 kg d^{-1} 1000-hd^{-1} capacity.

Other sources in the U.S. also reported PM_{10} emission factors related to open beef cattle feedlots. Bonifacio (2009) reported a PM_{10} emission factor of 29 kg d^{-1} 1000-hd^{-1} capacity corresponding to measurements taken over 2 years (Jan. 2007 to Dec. 2008) at a feedlot in Kansas. To control dust, the pens at this feedlot were cleaned relatively frequently compared to two other Kansas feedlots where water-based dust control systems were used. According to Bonifacio (2009), emission factors related to the latter two feedlots were 21 kg d^{-1} 1000-hd^{-1} capacity and 48 kg d^{-1} 1000-hd^{-1} capacity, respectively. The smaller of the two emission factors was determined based on measurements conducted over a 2-year period (Jan. 2007 to Dec. 2008) at a feedlot where water was applied only to the pen surfaces. On the other hand, the larger factor was determined based on measurements taken over a 6-month period (Jun. to Nov. 2008) at the other feedlot where water was applied on pen surfaces and unpaved alley surfaces surrounding the pens.

CARB (2004) reported a PM_{10} emission factor of 13 kg d^{-1} 1000-hd^{-1} capacity based on research conducted by Flocchini et al. (2001). In Texas, PM_{10} emissions were reported to range between 7.7 kg d^{-1} 1000-hd^{-1} capacity and 9.1 kg d^{-1} 1000-hd^{-1} capacity (B. Auvermann, Professor, Texas A&M University, Amarillo, TX, pers. comm.).

Variations in the dust emission factors cited above may reflect the effect of external factors on the measurements. These factors may include the impact of dust control techniques, climatic influences such as incidence and frequency of precipitation, length of dust measurement periods and accuracy of estimation methodologies.

5.1.4 Dust reduction techniques

There are many techniques that can be used to reduce dust emissions from unpaved road and feedlot surfaces either individually or in conjunction with other techniques.

5.1.4.1 Proper road engineering

According to FCM and NRC (2005), unpaved roads should be designed to handle anticipated traffic volumes and loads and adequately graded and maintained to facilitate drainage. Furthermore, unpaved road surfaces should comprise of 40% to 60% coarse aggregates and 8% to 10% fines to help stabilize the surface.

5.1.4.2 Restricted road use

Restrictions placed on the type and speed of vehicle traffic on unpaved roads can help reduce traffic volume and subsequently PM emissions. According to WRAP (2006), lowering the maximum permissible vehicle speed from 72 km h^{-1} to 40 km h^{-1} can result in a 44% decrease in PM_{10} emissions.

Incentives to use alternative means, methods and rules of transportation also need to be explored. For example, traffic agreements may be considered as conditions for issuing confined feeding operation (CFO) development permits in order to regulate traffic. Interestingly, such a policy was attempted in Southern Alberta with limited success owing primarily to the inability to enforce it (O. Kenzie, Approvals Officer, Natural Resources Conservation Board, Lethbridge, AB, pers. comm.).

5.1.4.3 Source surface improvements

Although not always economical, paving is the most effective way to minimize the emission of road dust (WRAP 2006). However, in order to remain a feasible alternative the total vehicle traffic volume has to be taken into consideration. A traffic volume between 300 vehicles per day (vpd) and 500 vpd is the suggested threshold at which an upgrade to a paved road may be given due consideration (FCM and NRC 2005). Even with a paved road in place there are still maintenance requirements such as keeping the pavement clean by minimizing trackout (VCAPCD 2008). Trackout is dirt, mud or other debris that is transported by a vehicle on to a paved road from an unpaved road or some other site. The deposits may be disintegrated into fine particles with time by regular traffic flow and subsequently launched into the atmosphere as particulate matter (COT 2008).

If paving is not possible, the use of large aggregates on the road and aggregates with less silt content may help reduce dust emission. Off the road, planting vegetative covers in storage yards and parking areas is an option (Auvermann 2001).

Dust emissions from open beef cattle feedlots are primarily a function of the moisture content of the pen surface layer (Razote et al. 2007; Auvermann 2001). Pen surface layer moisture content should range between 25% and 40% to enable reasonable control of dust and odour (ISUE 2004; Auvermann 2001). This may be achieved either via water application to the pens or frequent removal of manure from the pens. In Texas, frequent manure harvesting is recommended in order to maintain a 2-cm to 5-cm layer of compacted manure on the surface of the lot. This is best accomplished with a pull-type box scraper (B. Auvermann, Professor, Texas A&M University, Amarillo, TX, pers. comm.).

5.1.4.4 Windbreaks

Planting trees and shrubs, installing windbreak fences, or a combination of both, can help mitigate dust emissions by reducing the effects of the wind at the ground level (Auvermann 2001; ISUE 2004). Unfortunately, there is limited information on the effectiveness of windbreaks in mitigating dust emissions from feedlot surfaces and unpaved roads.

5.1.4.5 Dust palliatives

Dust palliatives are categorized as wet suppression, chemical stabilization or physical amendments. They control the release of PM either by agglomerating fine particles or inhibiting the disintegration of coarse particles (WRAP 2006; Lohnes and Coree 2002). Wet suppression agglomerates fine particles in the surface layer of unpaved roads or feedlot pens and alleys. Agglomeration occurs via the capillary action (tension) of water or brine (salt solutions) in the pore spaces between the surface aggregates. On the other hand, dust palliatives that prevent the breakdown of coarse aggregates into fines do so by physically or chemically binding clay particles together, e.g. cements, resins, and asphalt products.

Other than water, most dust palliatives are not typically used on feedlot surfaces. Most dust suppressants, except the salts and brines, are applied at prescribed rates and mixed in place. Efficient suppressant use requires consideration of the type of suppressant, recommended application rate, frequency of application, type, speed and amount of traffic between applications, weather conditions and road design.

5.1.5 Types of dust palliatives

The following sections outline the specifics of commonly used, commercially available dust palliatives (Tables 5.3, 5.4 and 5.5).

5.1.5.1 Water

Water is effective for short-term suppression of dust emissions (USEPA 2002; Sanders and Addo 1993; Bolander and Yamada 1999). Its effect is classified as short term because as soon as water evaporates its effectiveness is lost. Consequently, the effective period for a water application treatment is measured in hours. The length of each effective period will depend on the weather. Dust suppression using water will likely require frequent reapplication in order to sustain its effectiveness. Instances where water might be an effective dust suppression option include during seasonal short-term operations such as silage production and storage or manure hauling.

Maintaining a feedlot pen surface moisture content between 25% and 40% is the most effective way to prevent dust emissions from open beef cattle feedlots (Lorimor 2005). Water may be applied to feedlot pen and alley surfaces via irrigation or truck-mounted sprinklers. Either system should be capable of applying up to 6 mm of water over dust-emitting surfaces (Auvermann 2001). Water application is recommended to combat daily, short-duration, peak dust events, such as when the animals are most active in the evening (Auvermann 2001).

5.1.5.2 Hygroscopic salts and brines

Common products in this category include calcium chloride ($CaCl_2$) brine and flakes, magnesium chloride ($MgCl_2$) brine and sodium chloride (NaCl). These products possess hygroscopic or deliquescent properties that help stabilize unpaved road surfaces by absorbing moisture from the air (Jones and Emery 2003; Lohnes and Coree 2002; Foley et al. 1996; Sanders and Addo 1993). Thus, they tend to be more effective when there is sufficient humidity in the air. Hygroscopic dust suppressants are usually surface-applied and are not mixed in place (Sanders and Addo 1993). Lohnes and Coree (2002) suggested that such products are best applied to soils of moderate fine content.

Hygroscopic dust suppressants can extend the stability of unpaved road surfaces by weeks or months depending on the level of capillary tension achieved in the surface layer. Most agencies using these products in Alberta reported an effective lifespan of about 6 months (F. Peck, Supervisor, County of Red Deer Public Works, Red Deer, AB, pers. comm.; R. Johnson, Supervisor, Town of Claresholm Public Works, Claresholm, AB, pers. comm.; N. Minchou, Supervisor, Town of Pincher Creek Public Works, Pincher Creek, AB, pers. comm.; B. Oulton, Supervisor, MD of Ranchland Public Works, Nanton, AB, pers. comm.).

Table 5.3 Dust control mechanisms of various dust palliatives (Bolander and Yamada 1999)

Dust suppressant	Mechanism	Other attributes
Clay	Agglomerates with fine dust particles	High strength when dry
Polymers	Adhesively binds surface particles	
Electrochemical	Changes characteristics of clay-sized particles	Effective regardless of climate
Tall oil	Causes adhesion of surface particles	High strength when dry
Vegetable oils	Agglomerates surface particles	
Lignin sulphonate	Binds surface particles	High strength when dry; Effective even during long dry spells; Well suited to surfaces with high clay content

Dust suppressant	Mechanism	Other attributes
Petroleum	Binds and/or agglomerates surface particles	Acts as waterproofing agent
Magnesium chloride	Absorbs water from air at a minimum relative humidity (RH) of 32% independent of temperature	More effective than $CaCl_2$ solutions; Helps sustain surface integrity following surface maintenance
Calcium chloride	Absorbs water from air depending on temperature and RH, e.g. at temperature of 38°C and a minimum RH of 20%, or at 25°C and minimum RH of 29%	Significantly increases surface water tension inhibiting evaporation; Helps sustain surface integrity following surface maintenance
Water	Agglomerates surface particles	Readily available
Molasses	Temporarily binds surface particles	

5.1.5.3 Organic non-petroleum products

Organic non-petroleum products are also referred to as natural polymers. They include lignin sulphonate, pine oil, vegetable derivatives, animal fat derivatives, tall oil emulsions and molasses (USEPA 2002). These products bind or cement fine particles together (Sanders and Addo 1993; Bolander and Yamada 1999; Jones and Mitchley 2001).

Similar to hygroscopic products, the effectiveness of natural polymers generally lasts for 6 months to 8 months depending on product solubility and climatic factors (N. Minchou, Supervisor, Town of Pincher Creek Public Works, Pincher Creek, AB, pers. comm.; B. Oulton, Supervisor, MD of Ranchland Public Works, Nanton, AB, pers. comm.). Although these products do not exhibit the same level of effectiveness in the second year as in the first, they still provide a residual benefit by reducing the amount of product that has to be reapplied in subsequent years (FCM and NRC 2005).

5.1.5.4 Synthetic polymer products

These include compounds such as polyvinyl acetate and vinyl acrylic that bind soil particles together (USEPA 2002). They function by conglomerating fine particles into larger particles to form a mat and provide the added benefit of protecting coarse aggregates from disintegration via attrition (Sanders and Addo 1993).

5.1.5.5 Organic petroleum products

Organic petroleum products include used oil, solvents, asphalt emulsions, dust oils and tars (USEPA 2002). They perform similarly to synthetic polymers by binding or cementing fine particles together (Sanders and Addo 1993).

Table 5.4 Dust suppressants ranked by duration of effectiveness (Bolander and Yamada 1999)

Suppressant	Longevity	Dosage	Limitations	Treatment method
Clay	1 - 5 years	1 - 3% by dry weight	Rutting or slippery when wet	Mix clay and water; Distribute uniformly
Polymers	1+ years	2.3 L m^{-2}	Hard surface difficult to maintain	Mix into surface or spray followed by light compaction
Electrochemical	Not reported	1 part product to 100 to 600 parts water	Depends on surface fine clay content mineralogy; Limited lifespan; Needs time to set	Mix into surface or spray and compact surface.
Tall oil	1+ years	2.3 L m^{-2}	Reduced surface binding action due to long-term exposure to rain; Hard surface difficult to maintain	Mix and/or compact after spray application
Vegetable oil	Seasonal	1.1 - 2.3 L m^{-2}	Limited availability; Prone to oxidation then becomes brittle	Loosen top 2.5 to 5 cm of surface; Mix into surface or spray and compact surface
Lignin sulphonate	Seasonal	2.3 L m^{-2} (once or twice)	Corrosive tendencies; Reduced surface binding action due to long-term exposure to rain; Slippery when wet; Brittle when dry; Hard surface difficult to maintain; Potential pollution from leaching	Mix and/or compact after spray application
Petroleum	Seasonal	0.5 - 4.5 L m^{-2} (once or twice)	May not maintain form under dry conditions; Can form crust and fragment under traffic or in wet weather	Spray
Magnesium chloride	Seasonal	2.3 L m^{-2} @ 30% residual conc. (once or twice)	Corrosive tendencies; Requires minimum humidity level to absorb moisture from air; More suitable in drier climate; Susceptible to leaching by rainwater; Slippery when wet	Spray and compact lightly

Suppressant	Longevity	Dosage	Limitations	Treatment method
Calcium chloride	Seasonal	1.6 L m^{-2} @ 30% residual conc. (once or twice)	Corrosive tendencies; Requires minimum humidity level to absorb moisture from air; Does not tolerate long dry spells; Susceptible to leaching by rainwater; Slippery when wet	Spray and compact lightly
Water	12 hours maximum	Regular, light watering	Evaporates readily; Short effective duration; Most expensive and labour intensive among inorganic suppressants	Spray
Molasses	Not reported	Not reported	Limited availability	Uncertain

Bitumen products, such as SC250 (pre-asphalt), have reportedly been used in Alberta and have an effective lifespan of 2 years to 3 years. (L. Read, Owner, AB Road Management, Okotoks, AB, pers. comm.). On the other hand, the application of used oil for dust control is prohibited in most areas since used oil can contain polycyclic aromatic hydrocarbons and various metals that are considered to be carcinogenic (FCM and NRC 2005).

5.1.5.6 Electrochemical products

These suppressants are derived from sulphonated petroleum and highly ionic products such as sulphonated oils, enzymes and ammonium chloride (USEPA 2002). Their effectiveness is reported to be soil dependent (Sanders and Addo 1993).

5.1.5.7 Clay additives

Clay additives include silica oxide tetrahedral (SiO_4), alumina hydroxide octahedra ($Al(OH)_6$) and bentonite. According to Lohnes and Coree (2002), bentonite can be effective up to 2 years, and it is best applied where the road surface consists of a low percentage of fines and has a low plasticity index.

5.1.5.8 Mulch and fibre mixtures

Products such as waste wood fibres, recycled newspapers, shredded shingles, and manure are also classified as dust palliatives (USEPA 2002). The fibrous nature of these suppressants provides a cushioning effect that helps protect soil aggregates from degradation (Auvermann 2001). Furthermore, mulch and fibre mixtures are resistant to the effects of the wind and do not easily become airborne because of their structure and shape.

Table 5.5 Product selection chart† (adapted from Bolander and Yamada 1999)

Dust suppressant	Traffic volumes (average daily traffic)			Surface material								Climate type		
	Light (<100)	Medium (100-250)	Heavy[a] (>250)	Plasticity index			% Fines‡					Wet to rainy	Damp to dry	Dry[b]
				(<3)	(3-8)	(>8)	(<5)	(5-10)	(10-20)	(20-30)	(>30)			
$CaCl_2$	✓✓	✓✓	✓	x	✓	✓✓	x	✓	✓✓	✓	x[c]	x[c,d]	✓✓	x
$MgCl_2$	✓✓	✓✓	✓	x	✓	✓✓	x	✓	✓✓	✓	x[c]	x[c,d]	✓✓	✓
Petroleum	✓	✓	✓	✓✓	✓	x	✓	✓	✓[e]	x	x	✓[c]	✓✓	✓
Lignin sulphonate	✓✓	✓✓	✓	X	✓✓	✓✓[e]	x	✓	✓✓	✓✓	✓✓[c,e]	x[d]	✓✓	✓✓
Tall oil	✓✓	✓	x	✓✓	✓	x	x	✓	✓✓	✓✓[e]	x	✓	✓✓	✓✓
Vegetable oil	✓	x	x	✓	✓	✓	x	✓	✓	x	x	x	x	✓
Electrochemical	✓✓	✓	✓	x	✓	✓✓	x	✓	✓✓	✓✓	✓✓	✓✓[c,d]	✓	✓
Synthetic polymer	✓✓	✓	x	✓✓	✓	x	x	✓✓	✓✓[e]	x	x	✓	✓✓	✓✓
Clay additives	✓✓	✓	x	✓✓	✓✓	✓	✓✓	✓	✓	x	x	x[c]	✓	✓✓

† Legend: ✓✓= Good ✓= Fair x = Poor

‡ Particles pass through 75 µm, No. 200 sieve openings

a. May require higher or more frequent application rates, especially with high truck volumes.

b. Greater than 20 days with less than 40% relative humidity - assumed to be per year.

c. May become slippery in wet weather.

d. SS-1 or CSS-1 with only clean, open-graded aggregate. SS-1 and CSS-1 refer to anionic and cationic slow set emulsion products, respectively (Telfer Oil 2009).

e. Road mix for best results.

5.2 Effect of Dust Palliatives on Dust Emissions

There is limited information on the effectiveness of dust palliatives on PM emissions from unpaved roads and open beef cattle feedlots. Where sufficient information is available, emission reduction efficiencies reported or deduced from the literature are presented in the following sections.

5.2.1 Unpaved roads

According to WRAP (2006), the use of dust palliatives, excluding water, on unpaved roads can reduce PM_{10} emissions by up to 84%. Alternatively, the use of water on unpaved road surfaces was reported to reduce PM_{10} emissions by 10% to 74%. USEPA (2002) reported initial, short-term emission reductions of up to 85% following the application of water on unpaved roads. Pechan and Associates (2006) reported a reduction of 37.5% in PM_{10} and $PM_{2.5}$ emissions from unpaved roads following the use of chemical stabilization to control emissions.

In laboratory-scale experiments to determine PM_{10} emissions from unpaved roadways and feedlot surfaces, Razote et al. (2005) actually used simulated feedlot surfaces and simulated cattle hoof impacts to determine emissions from both surfaces. Note that they did not use simulated unpaved road surfaces and vehicle impacts to determine PM_{10} emissions from unpaved roadways. The simulated feedlot surfaces comprised of a 0.91-m deep, compacted soil base overlaid with sieved feedlot manure to a depth of 0.10 m. The simulated surfaces were treated with X-hesion (an organic-based substance), water and $MgCl_2$ to an application depth of 6.4 mm. To simulate cattle hoof action, they used a weight-drop procedure.

In one experiment, Razote et al. (2005) used a weight-drop energy of 27 J. PM_{10} emissions associated with the X-hesion, water and $MgCl_2$ treatments were reported to range between 1.50 mg and 2.19 mg, 2.93 mg and 4.47 mg, and 9.29 mg and 13.59 mg, respectively. The reported emissions seem to be the absolute emissions associated with each dust palliative treatment. It does not appear that Razote et al. (2005) included a control treatment in this experiment. The inclusion of a control treatment would have enabled the calculation of emission reductions associated with each dust palliative treatment as a function of the emissions from the control treatment.

A control treatment was included in a second experiment conducted by Razote et al. (2005). They used the simulated feedlot surfaces described above and a weight-drop energy of 54 J on the control treatment surface resulting in a mean PM_{10} emission of 19.2 mg. Thus, if it is assumed that the latter emission was equivalent to a control treatment emission in the previous experiment, then it may be inferred that the relative reductions in emissions associated with the X-hesion, water and $MgCl_2$ dust palliative treatments might have ranged between 89% and 92%, 77% and 85%, and 29% and 52%, respectively. The deduced range of emission reduction for the $MgCl_2$ treatment appears to be in close agreement with the percentage reduction reported by

Pechan and Associates (2006). Similarly, the range deduced for the water treatment appears to be in close agreement with the percentage reported by USEPA (2002).

5.2.2 Open beef cattle feedlots

WRAP (2006) reported that dust emissions could be reduced by over 10% following daily water application or the use of wood chips or other types of mulch products on feedlot surfaces. Pechan and Associates (2006) reported a reduction of 50% in PM_{10} and $PM_{2.5}$ emissions could be achieved by watering beef cattle feedlots.

In the laboratory-scale study conducted by Razote et al. (2005, 2006), different simulated feedlot surfaces were treated with wheat straw, sawdust and water. The effects of three wheat straw treatments, three sawdust treatments and two water treatments on PM_{10} emissions were investigated and compared to a control treatment. Wheat straw and sawdust were applied at rates of 242 g m^{-2}, 484 g m^{-2} and 726 g m^{-2}, while 3.2 mm and 6.4 mm of water were applied to both water treatment surfaces. A weight-drop energy of 54 J was used to simulate the action of cattle hooves on all treatment surfaces. Relative to the control treatment, the three wheat straw treatments appear to have resulted in immediate PM_{10} emission reductions of 36%, 44% and 77%, respectively. On the other hand, the sawdust treatments seem to have resulted in immediate PM_{10} emission reductions of 14%, 43% and 69%, respectively. Thus, for both fibrous amendments the reductions in PM_{10} emissions increased with increasing quantities of material per unit area.

With the water application treatments, Razote et al. (2005, 2006) reported that 3.2 mm of water applied to the simulated feedlot surface resulted in a PM_{10} emission reduction of about 82%, 30 min after water application. When the amount of water applied was doubled to 6.4 mm in the second water treatment, the reduction in PM_{10} emissions increased to 88%. Both reductions in PM_{10} emissions appear to be in close agreement to the deduced range of reductions (77% to 85%) from the previous experiment by Razote et al. (2005) where 6.4 mm of water was applied, measurements were taken 60 min, rather than 30 min, after water application, and a drop energy of 27 J, rather than 54 J, was applied.

In a subsequent experiment by Razote et al. (2005, 2006), the dust emission reduction potentials of the 726-g m^{-2} wheat straw treatment and both water application treatments were assessed following five successive weight drops on the same spot. A weight-drop energy of 54 J was used in this experiment. After each successive drop the simulated feedlot surfaces were not restored to their original (leveled) states. Furthermore, after each water application treatment, the simulated feedlot surfaces were left undisturbed for 30 min prior to taking initial measurements.

In the results of the latter experiment, Razote et al. (2005, 2006) reported a decrease in the dust emission reduction efficiency with increasing number of drops following the 6.4-mm water application treatment. Similarly, a decreasing emission reduction efficiency was observed with each successive drop following the 3.2-mm water application treatment and the wheat straw treatment, except that the decrease peaked after the fourth drop and then increased after the fifth and final drop. No mention was made of what depth of the simulated feedlot surface was displaced with each successive weight drop. It is likely that with each drop a certain percentage of dislodged particles were displaced. In the case of the 3.2-mm water application treatment and wheat straw treatment, particle displacement may have reached a maximum after the fourth drop leaving a smaller percentage of particles available for displacement after the fifth drop. Ultimately this may have led to less dust emissions after the fifth and final drop.

In another study conducted by Razote et al. (2007), field measurements of PM_{10} emissions were taken from a 30,000-hd beef cattle feedlot with and without the use of a water sprinkler to control dust emissions. Ironically, the use of the sprinkler appeared to result in significantly higher dust emissions compared to periods when the sprinkler was not used. Razote et al. (2007) suggested that the results may have reflected conditions that prevailed at the time the water sprinkler was used, e.g. either after the onset of a dust event or when atmospheric conditions favoured the onset of a dust event.

As an alternative to the procedure used by Razote et al. (2007), Razote et al. (2008) conducted a comparison between continuously measured net dust concentrations from two open beef cattle feedlots, one with a 30,000-hd capacity and the other with a 25,000-hd capacity. The feedlots were located about 40 km apart. Dust control at the 30,000-hd capacity feedlot was achieved using a water sprinkler system. In contrast, at the 25,000-hd capacity feedlot, dust control was achieved by scraping manure from the pens year-round and hauling manure out of the feedlot five or six times annually. Furthermore, the 30,000-hd capacity feedlot was surrounded by agricultural fields, while the 25,000-hd capacity feedlot was surrounded by trees and fields.

According to Razote et al. (2008), average monthly upwind, average monthly downwind and net PM_{10} concentrations, not emissions, at the 30,000-hd capacity feedlot ranged between 12 $\mu g\ m^{-3}$ and 256 $\mu g\ m^{-3}$, 21 $\mu g\ m^{-3}$ and 317 $\mu g\ m^{-3}$, and 7 $\mu g\ m^{-3}$ and 298 $\mu g\ m^{-3}$, respectively. At the 25,000-hd capacity feedlot the average monthly upwind, average monthly downwind and net PM_{10} concentrations ranged between 9 $\mu g\ m^{-3}$ and 79 $\mu g\ m^{-3}$, 16 $\mu g\ m^{-3}$ and 434 $\mu g\ m^{-3}$, and 9 $\mu g\ m^{-3}$ and 203 $\mu g\ m^{-3}$, respectively. While the reported concentrations may reflect site-specific conditions that prevailed at each measurement location, they do not give a true indication of the differences in the effects of the water treatment system and manure removal treatment system on the normalized feedlot dust emission rates.

Bonaficio (2009) also conducted a dust emission field study at the 30,000-hd capacity feedlot used by Razote et al. (2008). Due to differences in the stocking densities, pen cleaning frequencies and rainfall events, among other reasons, at the two feedlots in the study by Razote et al. (2008), Bonaficio (2009) decided to use only one feedlot to assess the effectiveness of a water sprinkling system on PM_{10} emissions. Bonaficio (2009) compared dust concentrations measured on days the sprinkler system was in operation to the concentrations on days the sprinkler was not in operation. The measurement days were selected, with or without the sprinkler system in operation, based on a set of pre-defined criteria such as rainfall events and length of drought periods, among other criteria. Measurements were taken over a 3-year span between April and October. Over this period, measurement data obtained on 10 days out of 243 days on which the sprinkler system was used were considered to be acceptable to conduct the comparative analysis.

Bonaficio (2009) reported that the water sprinkling system dust control efficiency ranged between 32% and 80% with a mean of 53%. However, it is uncertain if the data provide a true representation of the effectiveness of the water sprinkling system on dust emissions since the efficiencies were determined as a function of dust concentration measurements only and not the normalized emission rates. In other words, the calculations did not factor in the effects of dispersion on the measured concentrations considering that atmospheric conditions may have differed significantly on days when the sprinkler system was in operation relative to days when it was not.

5.3 Residual Effects of Dust Palliatives

Apart from the potential reduction of dust emissions from unpaved roads and feedlot pens there are other secondary benefits that may be derived from dust palliatives. In contrast, there are also certain limitations or even prohibitions that exist.

5.3.1 Secondary benefits

Along with reducing nuisance and health-related concerns to neighbouring residents caused by dust emitted directly or indirectly from CFOs, dust suppressants can provide additional benefits. These include, reducing the maintenance costs of unpaved roads, reducing unpaved road upgrade costs and ultimately, minimizing vehicle repair costs. They can also help ensure compliance with regulations on emissions (Bolander and Yamada 1999). Some dust suppressants are by-products of industrial processes that would otherwise have been disposed of as waste products, e.g. lignin sulphonate or $MgCl_2$ brine. Use of such products as dust suppressants can reduce the need for their disposal (USEPA 2002). In open cattle feedlots, Bonaficio (2009) reported that water application has been shown to reduce heat stress in cattle.

5.3.2 Limitations of dust palliatives

Negative risks associated with dust suppressants have not been well studied. Some of these products can contaminate surface or ground water bodies. Some can adhere to air-borne dust particles enabling their dispersion in the atmosphere. Adherence to the body surfaces of vehicles can also occur and may be a source of annoyance to other road users (USEPA 2002; Bolander and Yamada 1999). The negative risks posed by dust suppressants to the environment are a function of site characteristics, the amount and type of suppressant used, and climatic conditions.

5.3.2.1 Surface and ground water contamination

Salts and brines are typically water-soluble. Therefore, the potential exists for runoff or infiltration to carry these compounds into surface and ground water bodies (USEPA 2002). Lignin sulphonate, a natural polymer, is toxic to fish at high levels and can cause discoloration in water bodies.

5.3.2.2 Ecological effects

Most locations where dust suppressants are applied are devoid of vegetation so the effect on plant growth or development in those areas is minor. In situations where suppressants migrate off site, toxic effects could occur to vegetation, soil, and aquatic ecosystems. For example, organic petroleum-based products are reported to cause significant detrimental ecological effects (USEPA 2002). Thus, the ecological effects of dust palliatives depend on the type of product, method of application, proximity of the water source, and ecosystem sensitivity.

5.3.2.3 Water application on open feedlot surfaces

There are a few concerns with the use of water as a measure for reducing dust emissions from open cattle feedlot surfaces. A significant concern is the cost of installation and operation of water sprinkling systems (Bonifacio 2009). Bretz et al. (2007, 2008) reported total costs ranging between \$1.36 hd^{-1} capacity and \$3.77 hd^{-1} capacity depending on the type of water application system utilized and size of the feedlot.

Another concern is the potential effect water can have on other types of emissions such as odour and ammonia, although opinions differ about this effect. Harner et al. (2008) noted that there is limited information on the effects of water application on various emissions from feedlots. Conceptually, Lorimor (2005) showed that at a moisture content above 10%, the potential for odour emissions from an open feedlot surface increased with a corresponding decrease in the potential for dust emissions. At a moisture content of about 30%, the effect of the increased moisture content on the reduction in dust emissions outweighed the increase in odour emissions. As the moisture content increased further, dust emissions decreased exponentially while odour emissions increased exponentially. Conversely, Harner et al. (2008) reported that the operation of a water sprinkling system and changes in manure moisture content did not seem to change odour emissions from a feedlot. It is possible that their results may have been influenced by the highly variable nature of odour concentration measurements as opposed to the effects of the manure moisture content.

5.3.2.4 Other considerations

Careless application of dust palliatives, including overapplication, can pose hazards to the applicant and adjacent receptors. Proper application is therefore important to reduce risk to the operation as well as to ensure maximum reduction in dust emissions (USEPA 2002). Some products such as hygroscopic salts are corrosive to metals (USEPA 2002). Furthermore, since dust suppression operates on the principle of changing the characteristics of the soil surface, an increase in concentration of certain compounds following their repeated application over a long period of time may change physical and chemical properties of the soil (USEPA 2002).

5.4 Conclusions

Dust suppression is a widely used technique for reducing dust emissions from unpaved roads both in Alberta and other jurisdictions. Although data on the dust reduction efficiencies of various suppressants appear to be lacking, information pertaining to the various techniques suggests that, technically speaking, water may be an effective option for short-term dust control for unpaved roads. If medium-term (up to 8 months) dust control is desired then commercially available suppressants such as $CaCl_2$ or lignin sulphonate may be used. Furthermore, if longer-term (up to 3 years) dust control periods are required then bitumen or paving may be an option to consider.

Suppressants for reducing dust emissions from open beef cattle feedlots, on the other hand, are limited either to the application of water to the feedlot surface to help control the moisture content of the surface or to the application of mulch to inhibit the trajectory of fine particles into the air.

5.5 Knowledge Gaps and Recommendations

There are a number of knowledge gaps pertaining to the control of dust emissions from unpaved roads around CFOs and open beef cattle feedlots that need to be addressed. Generally speaking, the need to quantify the performance of dust suppressants still exists. In order to effectively achieve this goal, appropriate experiments backed by sound scientific and statistical principles must be designed and the resources to conduct the associated studies made available. In support of this recommendation, USNRC (2002a, b) stated that although the equipment and methodologies exist to measure and determine PM emission factors, there is a lack of qualitative, comprehensive, sound, science-based emission data. Schmidt et al. (2008) reported that the lack of standard quantification and reporting methodologies for air emissions has hindered progress in identifying and implementing viable mitigation technologies.

5.5.1 Unpaved roads

Personnel responsible for dust control programs at the municipal level in Alberta have indicated that there is a general lack of reliable performance and cost-benefit data to base their dust control decisions upon. Consequently, in most jurisdictions in Alberta, decisions related to dust control are often based on trial and error and anecdotal knowledge.

Dust suppression has also been a major focus in many of the southern and western arid areas of the U.S. where much land development is taking place. Jones and Emery (2003) provided some insight into a “fit-to-purpose” certification process being developed in South Africa to assist in choosing dust palliatives based on appropriate usage. Thus, in order to address some of the knowledge gaps, it may be beneficial to conduct an in-depth review and research the mitigation mechanisms used by other jurisdictions around the world.

Fortunately, most of the materials used to suppress dust emissions are reported to have low toxicity. With dust control coming into greater use in highly populated and perhaps environmentally sensitive areas, further knowledge is required to determine potential impacts on soil, water, plants, animals, ecosystems and people, especially in the event of improper application or accidental release.

As the need for increased dust control grows, new products or variants of old ones are emerging. No regulatory requirements exist at the present time for full disclosure of the contents of dust suppressants. Some types of suppressants are by-products of other industrial processes, e.g. lignin sulphonate or petroleum by-products. Therefore, the potential exists for undeclared impurities to be found in such products (USEPA 2002).

5.5.2 Open beef cattle feedlots

Although the number of dust suppressants for reducing PM emissions from open beef cattle feedlots appears to be limited to water and surface amendments, knowledge pertaining to the effectiveness of these suppressants is lacking. In cases where studies have been conducted, the results do not seem to provide a clear sense of the ability or inability of the suppressants to significantly reduce emissions. It would seem that the complex nature of these studies, i.e. considering the uniqueness of feedlots as non-point sources of emissions, weather-related effects, resource requirements and cost, among others, has provided significant challenges to the scientific community. However, these challenges will need to be overcome in order to provide decision makers with information that is both reliable and useful. Of course the residual negative effects associated with the application of various suppressants also need to be quantified.

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Chapter 6.0

Social Considerations of Select Beneficial Management Practices

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Contents

6.1 Introduction

Air quality is a growing concern for regulators of Alberta's livestock industry, agricultural producers, and the public alike. In particular, close attention is being paid to confined feeding operations[3] (CFOs). According to CASA[4] (2008):

> "Most public environmental concerns in Alberta related to CFO air quality have focused on beef feedlots and [swine] barns. These concerns have received much attention in recent years from policy makers, the media, environmental groups, local residents, and agricultural producers … Stakeholders identified a wide range of concerns for the [CASA CFO project] team to consider … [including] possible health impacts on residents, employees, and livestock from CFO emissions, as well as potential impacts on environmental sustainability. Quality of life for those living near CFOs was also noted as a concern. Generally, it was felt there was a need to consider stakeholder relationships and public perception of the industry."

Hence, a major challenge for Alberta's CFO industry and regulators is how best to address public concerns over air quality. One option is through the use of appropriate technologies to reduce or mitigate odour and other air emissions from CFOs. The CASA (2008) report outlined eight livestock "management mechanisms" as having the most promise to accomplish this. At the same time, important knowledge gaps remain on whether such management mechanisms will in fact improve air quality, alleviate concerns such as declining quality of life, and/or reduce complaints. This chapter reviews these and other social implications of the air emission management mechanisms for CFOs.

6.1.1 Social implications of livestock emissions

Declining air quality due to livestock operations is a growing issue among rural dwellers as farm family populations decline but the country population increases (Flora et al. 2002). Agricultural-residential conflicts seem to be increasing as residential development expands further out into rural areas while market conditions push farmers to intensify their production (ARD 2004a; Key et al. 2008). In Alberta, complaints are not commonly associated with non-farming rural residents such as acreage owners; instead, they more often involve farmers complaining about other farmers (J. McKinley, Senior Inspector and Project Manager, Natural Resources Conservation Board, Red Deer, AB, pers. comm.). The dramatic increase since the 1980s in the concentration of land and livestock ownership also means that fewer rural residents have a large financial interest in livestock, and are perhaps less tolerant of odour issues than before. Although it is unrealistic to expect CFOs to be "emissions-free", odour concerns and

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[3] In Alberta new provincial regulations and standards were released in 2002, changing the terminology from intensive livestock operations (ILOs) to confined feeding operations (CFOs).

[4] CASA, or the Clean Air Strategic Alliance, is a multi-stakeholder partnership, composed of representatives selected by industry, government, and non-government organizations, which recommends strategies to assess and improve air quality in Alberta.

complaints are frequent (CASA 2008), especially for rural residents living or working near CFOs.

Most complaints seem to relate to the type or size of livestock facility or the proximity of the complainant to the facility. In Illinois, for example, large swine operations, total confinement facilities, and those with no open feedlots have led to greater air emission violations and complaints than smaller or more open counterparts (Huang and Miller 2006). In Alberta, the so-called "feedlot alley" in the area between Calgary and Lethbridge has one of the largest concentrations of CFOs in Canada. Feedlot alley was home to 520,000 cattle and 180,000 swine in the early 2000s (Laurent 2002), with a little over 50% of the cattle in the province "finished" on about 30 feedlots (Price 2003). Although air quality studies pertaining to feedlot alley were not found for this review, local residents have long complained of water and air quality concerns related to the concentration of manure: "A few have moved away, while others flee during the summer simply because they can't stomach the pervasive stink of manure" (Gregorash 1998).

The following excerpted comments from the Alberta Natural Resources Conservation Board (NRCB) odour complaints database, for the period between 2002 and 2006, illustrate some of the negative effects on quality of life associated with odours and other emissions near specific CFOs:

- "No place to go - can't go out and can't stay in. I'm a real advocate of 'right to farm' but this is horrible".[5]

- "The odour is terrible. How long do we have to put up with it? How can we promote our farm for tours, etc. when the odour is so bad? ARD is telling us to promote our farms by diversifying and charging admission. How can we do this when it smells so bad?"

- "Farmer's market yesterday was very painful. The baseball game was affected. The smell follows you inside – you can't get away. ... I don't even know where it's coming from".

- "It's more than a bad smell. Makes my throat scratchy and sore. It must be unhealthy".

While a livestock operator's rights and obligations concerning air quality are generally well regulated and protected, the rights of neighbours residing in close proximity may be less salient (Dines et al. 2004). The situation can be even more challenging for those living much further away, because of the difficulty in pinpointing the source of emission. One of the issues faced by regulators and the public, i.e. other than identifying solutions for controlling odours and other livestock emissions, is the ability, or lack thereof, to assign responsibility to an emitter. The crux

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[5] Right to farm legislation in the U.S. context, for example, protects swine operations from nuisance suits on the basis that they were established before nearby non-agricultural activities, are consistent with good agricultural practices, and abide by the law (Chapin et al. 1998).

of the matter is that responsibility for the problem must first be assigned prior to taking any mitigative steps and this is not always a straightforward process.

In late October of 2008, strong winds blew “a powerful stink” over much of Edmonton, Alberta, prompting a rash of calls to the city’s Citizen Action Centre and provincial agencies (e.g. Alberta Environment), but nobody claimed responsibility (EJ 2008). To alleviate concerns, a government spokesperson assured the public that while unpleasant, the stench posed no public health threat. Investigators were unable to pinpoint the source, but suspected either the University of Alberta experimental farm or private farms located south of Edmonton, many of which spread manure in the fall: “It is unlikely such a powerful odour could be produced by farms further away,” said one government spokesperson (EJ 2008). Furthermore, wind patterns over the given period helped obscure responsibility, speaking to the diffusive qualities of odour and air emissions.

Against these concerns, what *social* considerations are relevant to the adoption of air quality management mechanisms by CFO operators? This can be partly illustrated through two possible approaches from different stakeholder groups, including farmers, neighbours, and regulators, with the expectation of alleviating concerns and providing social and environmental benefits. On one hand, neighbours may complain to regulatory agencies and others over perceived or actual threats to their health, quality of life, and environmental quality. These agencies include local authorities (e.g. municipal by-law officers, police, fire or health units), regional government agencies (e.g. NRCB, Alberta Environment), and/or the personnel associated with an odour-emitting operation (Nicell 2009). Complainants hope to compel livestock operators to modify their production practices and adopt measures to reduce nuisance emissions and odours. Conversely, farmers may protect themselves from conflict over deteriorating environmental and social conditions caused by odours and other air emissions by taking a proactive stance; in other words, adopting “acceptable” or “qualifying” management practices (Centner 2002). Both approaches and some of their ramifications are discussed in this study.

6.1.2 Study purpose and focus

In July 2008, Golder Associates Ltd. (Calgary) was commissioned by Alberta Agriculture and Rural Development (ARD) to conduct a social review relevant to air quality and CFOs in Alberta. The purpose of the review was to identify and analyze, to the extent possible, relevant social implications of those management mechanisms meant to mitigate emissions of six priority substances: ammonia (NH_3), hydrogen sulphide (H_2S), odour, particulate matter (PM), pathogens/bioaerosols, and volatile organic compounds (VOCs). The eight management mechanisms recommended in the 2008 CASA report for consideration by stakeholders in Alberta, which provide the basis for this study, include: a) frequent manure removal from animal housing facilities; b) manure application (specifically band spreading with immediate incorporation and/or manure injection); c) moisture management; d) biocovers; e) bottom loading; f) shelterbelts; g) composting (manure and dead animal); and h) dust palliatives for roadways or feedlots.

6.2 Scope of the Review

The questions listed below guided the social review of matters that pertain to CFOs and their influence on air quality. Particular emphasis was placed on the emission of the six priority substances and the potential control of these emissions by the eight management mechanisms of interest to the study.

1. What are the social challenges and benefits for communities and the livestock industry in Alberta?

2. Can certain management mechanisms reduce or minimize any negative social impacts and/or provide societal benefits?

3. What recommendations can be made on the social relevance of these management mechanisms?

Consequently, in order to address the three questions posed above, four main tasks were identified:

1. Gather, review, and summarize relevant published material (mainly within the last 10 years) on select management mechanisms related to air emissions from livestock facilities.

   Over 150 peer-reviewed research articles and grey literature (government documents, non-governmental organization reports, media reports, etc.) were examined for relevant findings. Due to the limited availability of relevant studies with a social dimension from Alberta, literature from other jurisdictions was also examined, in particular, jurisdictions within the United States. Some literature from Europe and Australia was also reviewed and certain relevant findings were presented.

2. Conduct field interviews for the purpose of validating, complementing, or refuting findings from the literature review, and to gather any additional insights for this study.

   A total of 15 potential interviewees familiar with CFOs and odour or other air quality issues were contacted: five were leading agricultural social scientists, four were regulators, four worked with the not-for-profit sector, and two represented the agricultural industry. Over half of the potential interviewees declined to be interviewed citing different reasons, for example, insufficient time to prepare, lack of knowledge/experience relative to the thematic material, or perceived bias of the review in favour of industry.[6] In total, six agricultural

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[6] An additional three individuals who had been recommended did not respond to repeated requests for an interview.

experts from Alberta consented to be interviewed: five from government agencies and one from the not-for-profit sector.[7]

3. Analyze NRCB odour complaints received from 2002 to 2006.

   The purpose was to relate some of the management mechanisms to social concerns and to highlight which ones were most prevalent in the context of CFO air emissions.

4. Report and summarize the results from the literature review, interviews, and analysis of the NRCB odour complaints database in the context of the management mechanisms and priority substances.

   Key findings and appropriate recommendations were also presented.

6.2.1 Limitations

Three caveats require mentioning due to their important implications for this and future research. First, it was hoped that analytical information on social linkages and impacts would be found on all six priority substances and eight management mechanisms. Instead, the vast majority of the social literature around CFO air quality related primarily to nuisance odours and manure management. Likewise, few studies provided analytical findings on social impacts of specific management mechanisms. Particulate matter (dust) and ammonia were occasionally mentioned or studied themes, as well as shelterbelts to reduce odours, albeit to a much lesser degree. Few analytical studies were found that discussed the social aspects of the select management mechanisms to the same degree as other air quality technologies, nor the social aspects of all the priority substances. This is not so surprising given that most of these priority substances tend to be mixed in with odours; for example, about 160 kinds of VOCs are emitted from liquid swine manure (Thu 2003). Moreover, “many gases are also odourless and tasteless, making them seem benign since they are difficult to detect with the human nose” (Chapin et al. 1998). The lack of analytical research on social factors made it difficult or impossible to apply and assess these for each mechanism.

Second, this study discusses air quality and management mechanism issues related to swine CFOs to a far greater extent than cattle feedlots or poultry operations. There was not an explicit intent to do this, but the socially relevant literature around air quality themes associated with CFOs and management mechanisms is frequently skewed toward swine. The fact is that most complaints and social conflicts tend to be related to swine odours, likely due to the greater intensity of smell. In one Oklahoma-based study, for example, swine odour was claimed to have “four times the intensity” of cattle feedlot odour (NCRCRD 1999). This presumably has led to a greater focus by authors and regulators on swine CFOs concerning social issues around air quality and appropriate technologies. This is not to say that social issues and management

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[7] While this mix might suggest that industry and academic views were not incorporated into the study, deliberate attempts to achieve a balanced approach were taken through the types of questions asked of all interviewees and of the literature reviewed.

mechanisms regarding air emissions from cattle or poultry CFOs are any less important. Wherever possible, findings related to these operations are also discussed in this review.

Third, while some health impacts relating to dust and other substances in the air are discussed in this review, the emphasis has been placed on social factors such as quality of life and conflicts. CASA (2008) reported difficulty in associating CFO emissions with human health impacts. Although several studies have examined health impacts of odours and other air emissions associated with the livestock industry (Cole et al. 2000; Donham et al. 2007; Thu 2003; Merchant et al. 2002; Nimmermark 2004; Loglisci 2008; Pip 2000; Schiffman et al. 1995; Schiffman 1998; Wing and Wolf 2000), research has yet to confirm consistent causal associations between CFO odour or other air emissions and clearly defined medical syndromes, illnesses, or psychological responses (ARD 2002). Furthermore, another factor taken into consideration was the broad nature of the topic on health matters and the limited amount of resources available to render a comprehensive treatment of the subject. As a result, health impacts associated with livestock emissions were considered to be beyond the scope of this study.

6.3 Literature Review Synopsis

In this section, a brief synopsis is provided of an extensive literature review in order to draw out some key social themes. A common theme is that odours and particulate matter are socially "visible" (whether by smell or sight) compared to the rather "non-visible" emissions such as NH_3, H_2S, pathogens/bioaerosols, and VOCs (Carolan 2008; Lorimer et al. 1994). While these other substances are likely present in the odorous and particulate mix produced in CFO operations, especially during manure storage and handling, most individuals are likely unaware of the specific chemical composition of odours associated with CFOs. Even dust particles suspended in the atmosphere may not be visible unless associated with smoke, fume, mist, or bright sunlight (Donham et al. 2007). In contrast, odour is readily noted by most humans, albeit to various degrees or levels of discomfort (Schiffman et al. 1995). Ultimately, odour perception is a thoroughly social process: "[O]dour is a complex, multifaceted phenomenon. Odour is something we 'do', and that 'doing' is situated within a particular historical and cultural milieu. … [Moreover,] odour is negotiated 'on the ground' by *individuals*" (Carolan 2008). This suggests that odour management and policy ought to be adapted and customized to a variety of circumstances.

Farm-based odours are a complex topic. Perception is everything as farm (and other) odours may be noxious to some but pleasing to others (Carolan 2008), and tolerance levels for odours vary from person to person (ARD 2008). Determining the offensiveness of an odour is a highly subjective process and relates closely to an odour's "hedonic tone" - the degree to which an odour is perceived as pleasant or unpleasant (UKEA 2002; Nicell 2009). In Manitoba, the smell of manure storage facilities has been described "as the 'rank, nose-prickling ammonia aroma of [swine] manure', considered by many as the most objectionable issue related to the [swine] industry" (Vandean 2003). A major concern among neighbours "is that feedlot production will disrupt their quality of life and affect their health, mainly due to nuisance odour and dust. ...

While manure odour and dust may not be an issue to those living or working on the feedlot, others may find it offensive" (ARD 2002).

As a result, controlling the intensity and geographic scope of odours presents serious challenges, as confirmed by much of the literature reviewed and interview results from this study. Questions also arise about whether odour concerns can be best resolved through technology or policy. Some researchers feel that odour cannot be objectively measured nor has it been adequately considered as a threat to the environment or public health (Novek 2003a). Yet contrary to the view that it is "immeasurable and therefore beyond the scope of policy" (NCRCRD 1999), odour lends itself to be as measurable as any other sensory mechanism. That said, sophisticated instrumentation and sampling protocols are required to accurately determine the main source(s) of nuisance in any given odour, and it is technically extremely difficult to identify whether an odour limit has been achieved or exceeded (Nicell 2009). Furthermore, odour is also treated as a "psychological" phenomenon sometimes. Schiffman et al. (1995) found that odours may be an important contributing factor in the development of psychological problems such as depression, anger, and tension among neighbours living in the vicinity of swine production facilities.

On the other hand, some feel that those living in rural areas must be prepared to accept manure smells and other odours: "If you live next door to one of these [CFOs], it's not going to smell like roses. Sorry. That's life" (Brawner 2007). In one U.S.-based study on the issue of acceptance of odours emanating from neighbouring farms, it was found that those lacking strong ties to a rural area were more likely to harshly judge their immediate environment, including how they perceived air pollution (Carolan 2008). These "place-based commitments" also appear to be a function of local, informal social networks that contribute to improved understanding. Some interviewees in this review made note of such ties:

- "If there's a good relationship [among neighbours], most people will tolerate that [the smell from manure application] is there for a week, and then it's done for another year" (B. West, Engineer, Westpeake Consulting Ltd., Sylvan Lake, AB, pers. comm.).

- "I think understanding the complaints that people have will improve adoption [of management mechanisms] – walk in the other person's shoes, go downwind, and see what their complaints are. It works both ways. Earlier we talked about the complainants learning and understanding what the industry is doing [with respect to minimizing odour]" (E. Ewaschuk, Executive Director, Land Stewardship Centre of Canada, Edmonton, AB, pers. comm.).

- "If an operator lives in an area where they've lived for a long time, when they're part of the community, people are more accustomed to the fact that they're going to spread manure every fall so it's not something as surprising as [it might be] to someone who's just moved out and doesn't know that's going to happen. Sometimes we have to make the neighbour aware of what's going to happen" (B. Hazelton, Inspector, Natural Resources Conservation Board, Red Deer, AB, pers. comm.).

- "If you know someone and you like them, you're less likely to complain about them - as long as they understand your discomfort and they're trying to do something about it" (J. McKinley, Senior Inspector and Project Manager, Natural Resources Conservation Board, Red Deer, AB, pers. comm.).

In any case, odour management would seem to benefit from public involvement due to the air quality concerns of neighbours of CFOs and consumers: "[O]dour problems and odour mitigation is not just a simple physical issue; rather odour mitigation is a function of complex physical and social system interaction. At the very least, it is a socio-technological issue which recognizes the importance of public input in the recommendation, use, and acceptance of agricultural technologies" (Tyndall 2006). In some contexts such as Australia, farm regulators and extension agencies are working with local citizenry on management mechanisms to resolve issues such as odour and dust control. Some authors feel that a grassroots approach would allow for local involvement in the development of policy that will ultimately affect people's own communities, and encourage ownership of the technologies by the producers who will be using them (Black 2000). Still, grassroots approaches on air emission issues may not work for everyone. Other research on this theme argues that while public involvement initiatives for siting intensive swine facilities "can reduce unnecessary community conflict, foster informed choices and make the process more effective for all interested parties", the public may prefer to debate more technical issues such as manure management in more formalized venues such as an appeal process (Mackenzie and Krogman 2001).

Education and practical learning are mentioned as factors that may encourage adoption of technologies, including the eight selected for this review. In an Australian study, Abadi Ghadim and Pannell (1999) emphasized the role of "hands on" learning and the impact of learning in adoption decisions. In a Quebec study, the social acceptability of two manure spreading techniques was measured, with and without information sessions describing various aspects of swine production and its impact on society (Veillette et al. 2008). The authors concluded that a thorough educational and information strategy, combined with the implementation of more effective manure application techniques such as liquid manure injection, should further enhance positive community relationships. Finally, in a U.S.-based study, consumers from Iowa, Kansas, Vermont, Oregon, and North Carolina were asked to place a value on benefits from reduced odour and runoff or manure spills; participants included pork producers, their neighbours, rural community residents, and urban residents living in locations ranging from those with extensive swine livestock operations to those living long distances from pork production facilities (Kliebenstein and Hurley 1999). The authors found that about 25% of the participants were neutral about manure storage and incorporation methods used by the producer, and an additional 10% to 20% had no opinion. It was concluded that education may be needed on the advantages of manure management.

Another common theme in the literature is the regulatory and legal aspects of air emissions and odours associated with CFOs. Jurisdictions differ on whether odour should even be considered as a possible or actual nuisance or threat to the social good and individual well-being. The province of Manitoba serves as an interesting example of the complexities involved in defining and legislating odours, and whether odour issues around CFOs can be resolved at local or provincial levels (Common-Singh et al. 2000; Flaten et al. 2007; Moyer et al. 2007; Novek 2003a, 2003b; Vandean 2003; Zhang et al. 2002). The Manitoba Clean Environment Commission defines odour as a nuisance and recommends that odour control be achieved through local land use planning to maintain minimum setback distances (Novek 2003a). When rural Manitoban municipalities were delegated the responsibility to make decisions based on local preferences and conditions, however, this led to local conflicts and political controversy, forcing the provincial government to consider more active regulation and province-wide standards (Novek 2003a, 2003b).

In Alberta, the *Agricultural Operation Practices Act* (AOPA) is in place to ensure that the province's livestock industry can grow to meet the opportunities presented by local and world markets in an environmentally sustainable manner (CASA 2008). Nonetheless, current environmental and agricultural regulations in Alberta or elsewhere do not measure the severity of or harm created by particular odours associated with the CFO industry. Regulations tend to vary from jurisdiction to jurisdiction. In Texas, for example, regulations concerning odours and other issues associated with large-scale poultry operations are considered as "subjective" and must take into account different stakeholders, balancing "the legitimate and competing interests" of groups such as private property owners and private citizens (Constance 2002), with odour measurement a continual challenge for regulators. Although provincial standards exist in Alberta for responding to odour complaints and for siting CFOs (e.g. see Mackenzie and Krogman 2001), standards for odour measurements are currently lacking. This could be partly due to the ambiguity and complexity in determining whether an odour is a "natural" phenomenon or a symptom of inappropriate management or pollution (Constance and Bonanno 1999). J. McKinley (Senior Inspector and Project Manager, Natural Resources Conservation Board, Red Deer, AB, pers. comm.) stated that "If [the operator] meets all of those [the regulations, then the operator] doesn't have to go any further. But if the neighbours are really concerned, [then the NRCB] encourages them [the operator] to alleviate the problem. Each situation is different and some things are just off the wall – some people want no odour at all. It's the magnitude we're trying to control; we have to convince people that there will [inevitably] be odour".

Numerous references to the regulatory aspects of odour control, and the CFO industry more generally, are found in the U.S. context (Abdalla et al. 2002; Centner 2002; Chapin et al. 1998; Horne 2000; Huang and Miller 2006; Lowe 1992; Ringquist et al. 1995; Starmer and Wise 2007; Whitehouse 2003). Horne (2000) argued that while existing U.S. regulations may have some effect on odour and air issues, water pollution issues are prioritized. According to B. West (Engineer, Westpeake Consulting Ltd., Sylvan Lake, AB, pers. comm.), several U.S. states have established odour abatements, setbacks, or emission standards for CFOs, including Iowa

(*Agriculture Odour Management Act*), Oklahoma (Odour Abatement Plan requirements under the *Oklahoma Concentrated Animal Feeding Operations Act*), and Texas (air quality authorization under the *Texas Clean Air Act*). Other jurisdictions are deficient in odour laws. For example, Mexico's environmental laws do not include agricultural wastes or odours from agricultural sources (Cloutier et al. 2003).

Substantial research suggests that living near a CFO can negatively impact several social and health factors, such as: quality of life (Thu 1995; Wing and Wolf 2000); property values (Abeles-Allison and Connor 1990; Gurian-Sherman 2008; Milla et al. 2005; Palmquist et al. 1997); physical health (Pip 2000); and psychological health (Schiffman et al. 1995; Schiffman 1998). These impacts are most often attributed to odours and other air emissions from swine facilities or land-applied manure (Mikesell et al. 2004). Above all, the literature suggests that quality of life is especially important for those living next to CFOs. For example, with reference to several of the priority substances for this review:

> "The quality of life of the folks living in close proximity to these large [swine] facilities is changed dramatically because of the odour. The odour and gases from these sites, which include hydrogen sulphide, ammonia, methane gases, and dust particles is atrocious. Folks cannot plan family reunions in their farm yards for fear the wind will be blowing in their direction. One lady stated she cannot hang clothes out to dry any more" (Thu 1995).

Other literature examined for this study included relevant articles and reports from Europe and Australia. European countries have stringent regulations and techniques for dealing with livestock manure emissions and odours. Individual countries as well as the European Union (EU) as a whole have enacted measures to move toward a common standardized procedure for measuring odour (RWDI 2005). Currently, the EU and the U.S. are the primary jurisdictions for the development of internationally recognized "olfactometry" standards.[8] Olfactometry is the science of odour measurement, which recognizes "that odours must first be measured objectively and reproducibly" prior to being effectively subjected to quantitative regulation and assessment of the effectiveness of odour control technologies (Nicell 2009).

While their research is somewhat outdated, Chapin et al. (1998) suggested that Europe has been more active than the United States in addressing air quality and odour problems from large-scale swine facilities. Chapin et al. (1998) indicated the Netherlands has an extensive program - from strict regulation/enforcement to market mechanisms - to address issues of gaseous emissions and odour from large swine facilities. In Denmark, early odour laws (dating back to the 1950s) required ventilation chimneys and setback distances from houses, and later regulations controlled the times manure may be applied to crops, depending on the type of manure (liquid or solid) and the type of crop. Denmark now has quantitative emission criteria

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[8] The olfactometry standard, "Air Quality – Determination of Odour Concentration by Dynamic Olfactometry" (EN 13725), was finalized in 2003, which follows International Organization for Standardization (ISO) protocols and has been adopted by EU member countries. Australia and New Zealand have developed their own standard modelled on the EN 13725 standard (RWDI 2005).

for either odour or for specific chemicals (RWDI 2005). Germany has many regulations governing odour in particular, and thresholds based on the use of olfactometers have withstood legal challenges. While Germany has taken a systematic approach using four of the FIDOL factors (frequency, intensity, duration, and location)[9] to measure odours, measurement typically requires six months and is labour-intensive, and consequently expensive (RWDI 2005). In Greece, due to its important tourism industry, livestock farms can legally operate only when odours and pollution are kept to a minimum. Legal action can be brought against even a well-run farm in European countries such as the United Kingdom, Denmark, and the Netherlands if it poses a significant odour problem for its neighbours.

A more current French study on the perception of the environmental impacts of current and alternative modes of swine production also revealed some relevant findings in terms of how different groups view issues differently concerning odours and management mechanisms (Petit et al. 2003). In Bretagne, a region of intensive swine production, a survey of seven stakeholder groups concerned with swine production was conducted. Most swine producers (93%) and their suppliers (100%) considered swine operations as an asset for the region, whereas a majority of scientists (58%), activists (78%), and consumers (54%) felt swine production to be a handicap. More pointedly, differences among stakeholder groups were minor with respect to the perceived importance of environmental and social issues. Stakeholders agreed on the relative level of responsibility of swine operations with respect to specific problems. For all groups, unpleasant odours and water quality came first with respect to responsibility. Perhaps the most relevant finding is the difference in preferences for the way swine manure was handled. To improve the swine production methods, most swine producers and their suppliers preferred a slurry-based housing system, which they felt to be technically superior, whereas all other groups preferred a more environmentally friendly and less odour-producing straw-based system.

Finally, it is worth noting that several studies have been carried out in the Netherlands and in Germany that demonstrate a strong correlation between calculated exposure to odours and surveyed percentages of odour-annoyed individuals in a population (UKEA 2002). In these surveys, the tipping point is generally correlated to when 10% of the population are “seriously annoyed” by odour exposure at a calculated exposure. This relatively high annoyance potential is associated with a clearly measurable behavioural effect as a result of odour exposure, and could help set limit values for managing exposure to environmental odours (UKEA 2002).

6.3.1 Summary of social factors

Primary social concerns associated with livestock emissions are summarized below, in order to apply these factors to the selected management mechanisms in the following section. Several commonalities and ambiguities from the preceding section are summarized from the literature

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[9] FIDOL consists of frequency (F), intensity (I), duration (D), offensiveness (O), and location (L). These factors influence the extent to which odours adversely affect individuals and can be used as a basis for odour investigations and impact assessments (Nicell 2009).

review and complemented by key interview findings. The following five social factors are the most relevant for this study:

1. Air emissions present serious social, political, and legal challenges. Social conflicts for those living near livestock operations, especially swine facilities, have resulted in complaints to regulatory agencies, and in some cases litigious actions have resulted as citizens assert their civic rights to clean air. Nuisance laws, “right to farm” legislation, and livestock emission standards have been developed, but such laws and standards vary greatly by jurisdiction. The feasibility of developing legislated requirements for each of the priority substances is becoming paramount, and Europe appears to be more advanced in this respect compared to North America. Success in reducing social conflict will largely depend on the effectiveness of odour and air emission legislation, policy, control, and management, which may require being adapted and customized to a variety of circumstances.

2. Odours are the main priority substance from two perspectives: they are the most discussed in the social science literature, and provide the focus of most complaints by neighbours of CFOs. Livestock operation odours are also directly responsible for declining quality of life factors among those living closest to CFOs.

3. Setting limits for odours is both problematic and promising. Although the science of odour measurement continues to be developed, it is used, in its current state, to judge the effectiveness of management mechanisms aimed at reducing odorous emissions from livestock operations. While odours are perceived differently and not always negatively so, research in Europe and elsewhere has indicated that thresholds do exist and these thresholds are typically associated with a definitive, permissible percentage of annoyance complaints by the general public.

4. Specific management mechanisms addressing livestock emissions are rarely singled out in the social literature.[10] That said, manure management techniques such as liquid injection are the primary mechanism discussed and perhaps, in the absence of cost-related and other information, the easiest for many producers to adopt with relatively quick and favourable results. Furthermore, some stakeholders may prefer systems that produce fewer odours to address air quality concerns, but give little or no consideration to other producer-related concerns such as cost, practicality, etc.

5. Management mechanisms to control and reduce air emissions offer potential social benefits. Positive social aspects of the management mechanisms rest in the fact that they can serve to address complaints and enhance positive community relationships, depending on how effective they are and how timely they are adopted. Some research has shown that

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[10] It was noted that, in contrast, many economic and technical studies discuss the advantages and disadvantages of each of the management mechanisms.

education combined with the implementation of more effective manure application techniques may offer the best results.

6.4 Social Considerations of Select Management Mechanisms

In this section, the social findings outlined in the previous sections are given due consideration, where applicable, in the examination of the eight management mechanisms. If the prior analysis appears to have concentrated on the negative aspects of social factors related to livestock emissions, this section will focus mainly on the positive implications. Anecdotal evidence supports the notion that management mechanisms can have a positive social effect, i.e. a societal benefit such as improved quality of life for rural residents. For example, in one Alberta case, odour complaints associated with a CFO were observed to cease within two years after the bottom loading technique was retrofitted into its manure handling system, windbreak fences were erected on the upwind side of an earthen manure storage (EMS) facility, an aerator was installed in the EMS, and liquid manure was injected into the soil (I. Edeogu, Engineer, Alberta Agriculture and Rural Development, Edmonton, AB, pers. comm.).

6.4.1 Frequent manure removal

Frequent manure removal activities from a livestock facility include scraping, flushing, or some other practice, and may be applied to indoor (barn) and outdoor animal housing facilities (feedlot pens). It is a recommended practice for cattle feedlots considering the fact that a properly maintained manure pile would likely develop a protective crust and subsequently reduce odour emissions (J. McKinley, Senior Inspector and Project Manager, Natural Resources Conservation Board, Red Deer, AB, pers. comm.). Compared to other animal housing management mechanisms, frequent manure removal is considered to be relatively cheap and specifically targets manure, the primary source of emissions (CASA 2008).

Still, frequent manure removal only addresses the removal of manure from the facility, but not how the manure is handled afterward. A couple of interviewees pointed out that frequent manure removal included the emptying of manure storage facilities, resulting in frequent transportation and application of manure, all potential sources of odour and other emissions. According to CARC (2003), ammonia emissions occur from the moment manure leaves the animal up to and including the moment it is applied in the field.

Few scientific studies have been done on the social benefits of frequent manure removal relative to odour or other air emission concerns. This deficiency includes literature from the U.S. and Canada, as well as other jurisdictions such as Europe and Australia. Much of the technical literature supports frequent manure removal from livestock facilities. This includes steps to prevent anaerobic degradation of the manure within the barn or pen, or to reduce the surface area of the exposed manure and place it in covered storage outside the barn or pen; in the process, this can reduce methane emissions and odour (Lemay 1999; Webb et al. 2005). Research has shown that the method and frequency of manure removal are critical in preventing the release of odours (Chapin et al. 1998), which presumably would reduce complaints, especially if these odours can be measured and monitored.

Furthermore, a policy that requires livestock producers to implement a frequent manure removal strategy might be difficult to enforce especially if it is at a significant cost to the livestock producer. For instance, if there is a requirement for livestock producers to remove manure more frequently, it might result in the need for additional manure storage capacity. One interviewee pointed out that such a policy would be difficult to enforce, particularly if the operator is not in direct contravention of any legislation or conditions of his or her permit to operate (B. Hazelton, Inspector, Natural Resources Conservation Board, Red Deer, AB, pers. comm.).

6.4.2 Manure application

Rapid incorporation of manure into the soil has been shown to reduce the potential for complaints where odours may be problematic (Weida 2000; Zhang et al. 2002). In contrast to manure injection, it has been suggested that band spreading is a cheaper practice that can be used to mitigate the release and transportation of emissions from manure applied on land. It is also presumed to be a technique to which CFO operators can easily adapt their practices (CASA 2008).

Changes in manure application methods in Alberta between 1995, 2000, and 2005, are illustrated in Table 6.1. Prior to 2002, surface spreading of liquid manure was more common than injection on all farms in Alberta. Since then, the number of farms and the land base associated with the manure injection practice have increased fivefold. The number of farms and area of land on which liquid manure was surface-applied decreased by 77% and 66%, respectively. While this may have been due in part to AOPA requirements, farmers may also have seen this as a way to protect themselves from conflict over environmental quality (Key et al. 2008), or perhaps were increasingly aware of manure’s soil quality benefits. Increased use of liquid manure injection likely also stems from a desire to keep fertilizer costs down (ARD 2004b). Another interesting trend is that although the number of farms injecting liquid manure increased by almost 500% (from 1995 to 2005), this represents only 703 additional hectares, likely due to the high cost of liquid manure injection.

ARD (2004b) conducted a research project on manure management related issues, including the assessment of social issues faced by the Alberta livestock industry. The report identified a gap in the lack of guidelines for addressing social issues, and recommended more social research be carried out related to manure management. The ARD study concurred with the contention by Flora et al. (2002) that conflict was expected to rise with an expanding rural non-farm population. It was concluded that if livestock operators did not address the social environment, that is, rural residents and their community infrastructure, they could expect objections to new or expanding projects as well as their manure management activities (ARD 2004a).

Table 6.1 Manure application practices in Alberta, 1995, 2000 and 2005

Manure application technique	1995 Farms reporting	2000 Farms reporting	2005 Farms reporting	Practice change from 1995 to 2005 (%)
Solid manure application*	17,091	14,988	10,571	-38
Irrigation system	95	49	26	-73
Liquid manure application: surface	1,704	1,345	385	-77
Liquid manure application: injection	141	230	844	499

Source: Statistics Canada 1996, 2001, and 2006, cited in CASA (2008).

* Note: Solid manure application includes surface application with incorporation and surface application without incorporation methods for 2005. Solid manure application techniques were not separated out in the 2000 and 1995 data.

As discussed in the previous section, liquid manure injection seems to offer significant potential for reducing complaints, especially when combined with educational and information strategies. In 2008, Red Deer County began a project to identify the number of dairy producers who injected liquid manure and to define any barriers to the adoption of liquid manure injection (K. Lewis, Conservation Coordinator, County of Red Deer, Red Deer, AB, pers. comm.). Preliminary findings suggested that producers who injected manure felt it made good business sense for their operation. Others believed the cost of adopting the injection technology was too high or found hiring contract manure applicators inconvenient; e.g. manure applicators with the injection technology were not available when needed. Dairy producers who injected manure also noted environmental reasons and social pressures as influential factors in their decision-making process (K. Lewis, Conservation Coordinator, County of Red Deer, Red Deer, AB, pers. comm.). According to Key et al. (2008) and Centner (2002), livestock operators can protect themselves from social and even legal conflicts through the adoption of liquid manure injection and other emission-reducing manure application techniques, e.g. incorporation of solid manure into the soil immediately after application. Still, economic factors remain a primary motivation or barrier to widespread adoption of this practice (K. Lewis, Conservation Coordinator, County of Red Deer, Red Deer, AB, pers. comm.), and possibly, only large livestock operations are able to inject liquid manure due to the high cost of application (Key et al. 2008).

Most odour complaints seem to be associated with land application of manure, as supported by the results of the odour complaint analysis (see below) and conclusions drawn by various studies (Huang and Miller 2006; Jacobson et al. 1998; Mikesell et al. 2004; Zhang et al. 2002). In Iowa, while a shift to manure injection decreased the number of complaints associated with manure application, it also resulted in an increase in the number of complaints attributed to the animal production and manure storage facilities (Flaten et al. 2007). In another Iowa study involving 329 participants in 1997 and 1998, surveys and experimental auctions were used to gauge the participants' willingness to pay for pork products produced under management mechanisms systems, including manure injection techniques. When asked about odour control, some participants indicated that they were concerned about manure injection methods (Kliebenstein and Hurley 1999). Although the study failed to elaborate on the nature of these concerns or indicate what percentage favoured manure injection for odour control, many (36%) were neutral or had no opinion on manure injection methods.[11]

6.4.3 Moisture management

Most of the social literature examined for this research did not consider moisture management. Moisture management aims to control the moisture content of manure in feedlot pens or manure litter (CASA 2008). It can reduce the formation of odorous gases and particulate matter, such as has been found in chicken houses (McGahan et al. 2002). According to the literature, excessive moisture increases odour emissions while too little moisture increases dust emissions and possibly airborne pathogen transportation. Studies on odour emissions from poultry facilities have indicated that a key element in keeping odour at a low level is to keep litter as dry as possible (Constance and Tuinstra 2005). Odour can be further minimized by a combination of good practice, facility design and management as well as adequately managing litter, providing optimum ventilation, and controlling temperature (McGahan et al. 2002). In short, moisture management may be best adopted as part of a larger barn management plan, rather than a single solution.

While the social literature lacked information on this management mechanism, interviewees gave some perspectives on potential social implications of moisture management, including the feasibility of developing a legislated requirement. In addition to reducing odour from feedlot pens and manure litter, moisture management may also be beneficial for animal welfare, which has its own social implications (J. McKinley, Senior Inspector and Project Manager, Natural Resources Conservation Board, Red Deer, AB, pers. comm.). Another consideration is that, as with frequent manure removal, the use of moisture management greatly depends on site-specific factors such as barn design, operation size, and type of feed; and the complexity of these factors could make a "blanket requirement" very difficult (B. Hazelton, Inspector, Natural Resources Conservation Board, Red Deer, AB, pers. comm.). The latter speaks to the notion that the successful implementation of management mechanisms and establishment of associated regulations need to take into account the specific circumstances to which they are intended to apply.

6.4.4 Biocovers

The use of biocovers to mitigate emissions from manure storage facilities (MSFs) involves the application of biodegradable organic matter on the surface of such facilities. Organic matter includes material such as wheat, barley, and oat straw. Since these materials are often readily available to CFO producers, this management mechanism is relatively low cost compared to other mechanisms used to mitigate emissions from MSFs (CASA 2008). Biocovers may also be

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[11] Several attempts were made to contact Dr. Kliebenstein to clarify some results, but no response was obtained.

recommended as a publicly acceptable mechanism for mitigating emissions from MSFs (partly due to their biodegradable nature) in more populated areas or where a history of conflict exists between livestock operators and their neighbouring residents. They have some challenges, however. According to B. Hazelton (Inspector, Natural Resources Conservation Board, Red Deer, AB, pers. comm.), biocovers can be difficult to maintain since some of the floating cover material such as straw can sink, possibly clogging the mechanical pumps used to pump out manure from the storage facility prior to application on land or may simply drift to one side of the manure storage facility rendering the cover ineffective. Furthermore, the fact that some lagoons are too large to accommodate current biocover application practices suggests that some facilities would need to be rebuilt to accommodate this practice. Therefore, in her opinion, a customized approach is necessary. NRCB inspectors have to weigh the options and look at each individual site to see what will work for the operator in question.

While many studies asserted that biocovers are an effective means of odour emission reduction in swine production (Flaten et al. 2007; Lemay 1999; Pip 2000), poultry production (Ullman et al. 2004), and livestock facilities generally (Webb et al. 2005; Zhang et al. 2002), few discussed the social benefits of using a biocover. Still, one study suggested that an adequate odour control strategy includes the application of barley straw on EMS facilities, which is a key component to establishing and maintaining good relationships (Lemay 1999).

Interviewees were asked whether biocovers can play a role in establishing or maintaining good community relationships and whether the usefulness of biocovers is easily observed by neighbours. E. Ewaschuk (Executive Director, Land Stewardship Centre of Canada, Edmonton, AB, pers. comm.) supposed that operators who made the effort to use a biocover (or any odour mitigating practice) might be viewed in a better light, not based on the perceived effectiveness of the cover, but rather on the appreciation that the operator made an effort to reduce the impact of odour for the neighbours' sake. He further emphasized that the usefulness of a biocover may be better observed by neighbours if the operator informs neighbours about installing the biocover and why, especially if the neighbours were new or maybe unaware of the potential benefits of having a cover on an EMS facility. J. McKinley (Senior Inspector and Project Manager, Natural Resources Conservation Board, Red Deer, AB, pers. comm.) agreed that letting neighbours or the community know there is a biocover in place would improve its perceived usefulness.

Furthermore, E. Ewaschuk (Executive Director, Land Stewardship Centre of Canada, Edmonton, AB, pers. comm.) was of the opinion that livestock operators might prefer biocovers over synthetic covers due to their relatively lower cost (i.e. biomaterial is potentially available on the farm) and environmentally friendly benefits, regardless of their relative effectiveness in reducing odours. B. Hazelton (Inspector, Natural Resources Conservation Board, Red Deer, AB, pers. comm.) pointed out that synthetic covers have the disadvantage of being very expensive and do not last as long as anticipated. On the other hand, while some neighbours to CFOs might prefer synthetic covers, such covers might constitute impermeable barriers above the surface of the manure, thereby creating anaerobic conditions that would make the liquid manure smell much more intense prior to and during land application (J. McKinley, Senior Inspector and Project Manager, Natural Resources Conservation Board, Red Deer, AB, pers. comm.).

Also worth noting is that data obtained from the NRCB indicate that some people are aware of the usefulness of applying biocovers to EMS facilities. Between 2002 and 2006, 33 complainants specifically mentioned the use of a cover or biocover on EMS facilities to reduce odour. Compliance with proper biocover use and maintenance is difficult to achieve, since the NRCB has insufficient resources to respond to each complaint with a site visit. Moreover, operators may be requested to install a biocover because of their proximity of neighbours, but the NRCB has to ensure that the conditions are reasonable and operators agree to them, since operators do not have to go beyond the requirements in the AOPA legislation (J. McKinley, Senior Inspector and Project Manager, Natural Resources Conservation Board, Red Deer, AB, pers. comm.).

6.4.5 Bottom loading

Technical information about bottom loading liquid manure was mainly lacking. According to CASA (2008), this management mechanism refers to filling manure storage facilities below the manure surface; in this way, "splashing or agitation of manure is avoided and the release of highly concentrated emissions into the air is minimized".

Of the eight management mechanisms, bottom loading is one of the least examined in the social literature, and likely even the technical literature. Still, one study has found that a substantial reduction of ammonia emissions is possible with bottom loading (Wieske 2005). Furthermore, AOPA now requires new or expanding CFOs to install bottom-loaded manure storage facilities as a means to reduce odours: "Nobody really thinks about it – it does reduce odours and we [the NRCB] recommend it, but it's never on the front page" (J. McKinley, Senior Inspector and Project Manager, Natural Resources Conservation Board, Red Deer, AB, pers. comm.).

6.4.6 Shelterbelts

Windbreaks such as shelterbelts appear to be used by many livestock producers. In 2002, Statistics Canada conducted a Farm Environment Management Survey (ARD 2004c). A total of 22,167 farms in Canada were selected for the survey, including 4,518 farms in Alberta. At the time, two-thirds (67%) of Alberta livestock producers took no measures to control manure odours. Of those that implemented some form of odour control, wind barriers were the most common with 11% of the livestock farms planting shelterbelts.

Unlike the other seven management mechanisms, while shelterbelts do not directly deal with the source of the emissions, they have a number of potential benefits. For example, as noted in the CASA (2008) report, as emissions leave the animal housing facility, shelterbelt trees direct the air into the upper atmosphere where additional mixing and dilution are presumed to occur. CASA (2008) further suggested that on low wind speed days, CFO emissions may be trapped in the foliage of the trees, therefore preventing further dispersion downwind.

Shelterbelts, similar to natural areas and forests, can have a positive impact on the physical and mental health of individuals (Kulshreshtha and Kort 2005). Shelterbelts may also have a psychological benefit that results in fewer complaints (CASA 2008). For example, a shelterbelt may improve the aesthetics of a CFO farm site by placing livestock housing and other facilities out of sight. According to Stolte (2005), an Ontario swine producer built a barn with an indoor manure storage facility approximately 1 km from a public road. The producer planted a shelterbelt of maple trees and high-bush cranberry shrubs to further hide the barn from view, declaring: "What's the science behind that? There isn't any. It's entirely social" (Stolte 2005).

The above example demonstrates a high appreciation for the "visual" response to odour issues. It has been suggested that windbreaks may alleviate odour complaints since human perception of nuisance odours can be influenced by visual images (Ullman et al. 2004). For example, shelterbelts have been found to positively influence the aesthetics of the plains (or prairie) landscape (Cook and Cable 1995). Some evidence also suggests that visual barriers can alleviate perceived odours or generate more positive opinions of odours associated with livestock production (Flaten et al. 2007; Tyndall and Colletti 2007; Ullman et al. 2004). There may also be a preference for the "natural look and feel" of shelterbelts relative to other bio-chemical-mechanical odour control technologies (Tyndall and Colletti 2006). Interestingly, Tyndall and Colletti (2006) also found that consumers in Iowa, North Carolina, and Washington were willing to pay more for pork products that originated from farms with shelterbelts for odour mitigation. This suggests that the incurred costs of abating odour may be shared by consumers.

In contrast, the absence of a visual barrier such as a shelterbelt may provoke odour complaints. The mere sight of the swine facility and its associated activities can evoke negative perceptions of its smell (Carolan 2008). Simply seeing a farmer apply a substance in the field can evoke a sense of "olfactory unease" among certain people (Carolan 2008).

Aside from the "out-of-sight, out-of-mind" argument, shelterbelts are reported to be effective in mitigating odour if designed properly (Flaten et al. 2007; Tyndall and Colletti 2007; Zhang et al. 2002). The literature also reports the effectiveness of shelterbelts on reductions in ammonia, particulate matter, and hydrogen sulphide (Tyndall and Colletti 2007). Shelterbelts may also reduce social conflict, assuming that the conflict is directly attributed to odour nuisances and not to other factors such as a negative relationship between the operator and complainant due to any number of reasons. With reference to the NRCB odour complaints analysis at the end of this section, it is worth noting that very few complainants made note of the use of shelterbelts to mitigate odour.

6.4.7 Composting

Composting is an aerobic process that facilitates rapid microbial decomposition of organic matter such as manure into a stable end product. It has generated attention due to pollution and odour concerns, along with the search for environmentally sound methods for treating livestock waste (Imbeah 1998). The key to the success of this management mechanism is to ensure that the conditions required for the aerobic decomposition to occur are adequately met (CASA 2008).

Composting may also be used as a means of mortality disposal. Livestock manure, wastewater, sludge from manure storage facilities, and mortalities contain useful nutrients which can be reapplied to soil for growing crops. Such "recycling" of nutrients must be done in an environmentally sound, economically feasible, and socially acceptable manner (Imbeah 1998).

As noted earlier, the social acceptability of odour and methods of odour control is dependant on several factors. In one study, when participants were asked about the best odour control mechanisms for swine production, the highest level of acceptance (43%) favoured composting with bedding material (Kliebenstein and Hurley 1999). Still, the process of composting itself may generate strong odours that could result in complaints (Zhang et al. 2002).

Composting manure and mortalities may be on the rise due to higher fuel costs for the transportation of manure and new costs for rendering livestock mortalities following the bovine spongiform encephalopathy (BSE) crisis, or mad cow disease (B. Hazelton, Inspector, Natural Resources Conservation Board, Red Deer, AB, pers. comm.). Composting may also be viewed as an environmentally sound practice for the management of manure and mortalities and, if done properly, can effectively reduce odours (B. West, Engineer, Westpeake Consulting Ltd., Sylvan Lake, AB, pers. comm.). Done improperly, composting could have the opposite effect and result in increased odour emissions and potential health risks (B. West, Engineer, Westpeake Consulting Ltd., Sylvan Lake, AB, pers. comm.).

As the popularity of composting increases, training and certification of CFO operators in composting techniques may become necessary. Large-scale livestock operators may be at an advantage as they may have more resources to invest in composting (J. McKinley, Senior Inspector and Project Manager, Natural Resources Conservation Board, Red Deer, AB, pers. comm.). Conversely, smaller operators face significant obstacles, including social pressure from other farmers and disagreements about the adequacy of their methods (Grey 2000), and the financial and human resources required to invest in composting technology.

6.4.8 Dust palliatives

Dust palliatives are management mechanisms that focus "on mitigating the emission of particulate matter from road surfaces as a result of truck traffic to and from CFOs" (CASA 2008) or that are aimed at reducing dust from feedlots. A number of dust palliatives are used to reduce dust levels, including water (CASA 2008).

Dust from manure in feedlot pens (floor or animal body surfaces) has the potential to affect human health: "[m]anure, when dry, can release irritating dust and mould spores into the air that are an irritant to airways, exacerbating bronchitis and asthma" (BCPHO 2006). Furthermore, according to Zhang et al. (2002) many of the respirable dust particles are odorous because of their fecal origin. Dust may also act as an important odour carrier in that odour compounds attached to small dust particles remain in the air longer or are transported over longer distances, thus having a greater downwind impact (Zhang et al. 2002; AAFC 1998). As such, removing dust can reduce odour intensity by 40% to 70% (Powers 1999).

Outside of the health-related literature and some brief references to manure dust, no key findings were found in the literature on the social implications of dust palliatives for feedlot or roadway management. Interviewees generally agreed that there would likely be a positive response from neighbours affected by dust if operators took responsibility for mitigating dust created by the transportation of animals and manure. Many property owners will cost-share dust control on roads near their homes with their municipality (B. Hazelton, Inspector, Natural Resources Conservation Board, Red Deer, AB, pers. comm.). Although the province could not enforce the use of dust palliatives by one industry without enforcing it for all other road users, any mitigation for dust on roadways is currently voluntary (B. Hazelton, Inspector, Natural Resources Conservation Board, Red Deer, AB, pers. comm.). It was also pointed out that liability issues exist between operators and municipalities for responsibility over roadway dust (B. Hazelton, Inspector, Natural Resources Conservation Board, Red Deer, AB, pers. comm.). Issues of liability and regulations again link to the social factor listed in the previous section, confirming that air emissions present serious social, political, and legal challenges.

Many operators are paid by the weight of their livestock, so they may suffer financial losses if longer transport times for bringing livestock to slaughter result in sweating off excess pounds (J. McKinley, Senior Inspector and Project Manager, Natural Resources Conservation Board, Red Deer, AB, pers. comm.). Therefore, the prospects of losing financial benefits may cause livestock transport drivers to travel quickly down unpaved country roads resulting in an increase in dust emissions (J. McKinley, Senior Inspector and Project Manager, Natural Resources Conservation Board, Red Deer, AB, pers. comm.) and an associated increased risk of accidents. Controlling speed may also be a factor in reducing the nuisance effects of dust (J. McKinley, Senior Inspector and Project Manager, Natural Resources Conservation Board, Red Deer, AB, pers. comm.). Moreover, B. Hazelton (Inspector, Natural Resources Conservation Board, Red Deer, AB, pers. comm.) suggested that, like livestock or manure odour, dust may be viewed as part of the agricultural or rural landscape and something that residents should be willing to accept if they live near a gravel road.

6.5 Management Mechanisms and Odour Complaints

A brief analysis of air quality (odour) complaints concerning specific farm operations in Alberta is provided below for two purposes. First, examining these complaints will help determine if there is any link on the social side to the preceding management mechanisms for this study. For example, complainants may have noted if a particular mechanism was lacking or misused. Do any mechanisms described above have a more salient effect on certain social factors? Second, this brief analysis also highlights from a public or neighbour perspective which specific social aspects might be relevant to air quality concerns around CFOs.

Prior to this analysis, it is worth briefly re-examining some of the key issues around livestock air emission complaints, which link to the summary of social concerns presented in the previous section. While some of the complaints have been against beef feedlots and meat packing plants, including some in Alberta (Broadway 2001), large-scale swine operations have borne the brunt of much of the public ire (Edwards and Ladd 2000; Ladd and Edwards 2002; Wing et al. 2000). In the U.S. where CFOs are predominant in Midwest States such as North Carolina, Oklahoma, and Iowa, "public opposition to corporate swine production is most often driven by the noxious character of its airborne odours" (Edwards and Ladd 2000). According to Smith (1998), swine odour is "the most divisive issue ever in agriculture, damaging the fabric of rural society and disenfranchising [swine] producers from their communities".

In a Pennsylvania study on conflicts over CFOs, an individual's or group's perception of a CFO's ability to control a situation was found to be the most important predictor of conflict behaviour; moreover, perceptions of unfairness, uncertainty, risk, threat, or mistrust could decrease perceptions of control (Abdalla et al. 2002). Almost 15% of complainants who noted a problem due to odour from a CFO expressed feelings of lack of control, experiences of conflict, and stress. Economic benefits, or lack thereof, may also affect odour tolerance. For example, "[t]o have an income from an operation which generates malodours, would most likely reduce annoyance and perceived risk, compared to living in malodour without benefit and without control" (Nimmermark 2004).

Complaints and conflicts around air emissions, specifically odours, are also increasingly common in the Canadian context. For instance, in 2000, the County of Forty Mile in southern Alberta was the site of an application by the Taiwan Sugar Corporation to establish an 80,000 swine operation but local resistance from farmers and activists stymied the company's efforts. Other Canadian provinces that have had conflicts over large-scale swine operations include Saskatchewan, Manitoba, and Ontario (Dines et al. 2004; Thu 2003; Novek 2003a, 2003b; Price 2003).

These issues are often handled by regulatory bodies that act as the go-between for operators and citizens. In Alberta, livestock production in the province is regulated through the NRCB,[12] which ensures that livestock production is conducted in compliance with AOPA. In addition to its other mandates, the board operates an information hotline through which members of the public may lodge complaints regarding odours from livestock farms or related sources, as well as any other environmental concerns associated with livestock farms or livestock-related businesses (I. Edeogu, Engineer, Alberta Agriculture and Rural Development, Edmonton, AB, pers. comm.). The NRCB received 3,719 odour complaints from January 2002 until September 2008, or an average of 531 complaints annually. Of the total number of complaints, three quarters (76%) were for swine operations alone. Therefore, due to the large proportion of complaints associated with swine CFOs, the rest of this analysis concentrates on swine-related complaints only.

Complaints for swine operations that identified an odour source, an odour effect, or both were selected for further analysis (see Table 6.2). Where an odour source was identified, 992 or 88% of

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[12] Established in 1991 as an independent, quasi-judicial board that reports to the Minister of Sustainable Resource Development. See the NRCB website at http://www.nrcb.gov.ab.ca/home/default.aspx for more information.

the 1,132 total complaints related to swine operations. Odour sources included the barn, manure storage facility, manure application, or the swine operation overall. Just over half of the complaints (59%) did not identify a specific source of the odour, almost one-third (29%) identified the manure application practice, 7% identified the manure storage facility, and 5% complained about the barn. In total, about 88% (873 out of 992) of the odour complaints for swine operations were most commonly associated either with the overall facility or the practice of manure application.

Table 6.2 Social factors and odour sources from swine operations, as identified by complainants

Social factor	**Odour sources**					
	Barn	**Manure storage**	**Manure application**	**Facility (general)**	**Total**	
					Count	**%**
Avoidance	12	7	15	166	200	20.2
Conflict, lack of control, and/or stress	11	6	18	108	143	14.4
Disruption of activities	2	5	15	77	99	10.0
Economic	1	2	5	21	29	2.9
Environmental	1	2	26	30	59	5.9
General (e.g. quality of life)	2	0	2	39	43	4.3
Health	7	5	20	103	135	13.6
Insufficient management, enforcement, and/or monitoring	11	45	191	37	284	28.6
Total complaints	**47**	**72**	**292**	**581**	**992**	**992**
% of total complaints	**4.7**	**7.3**	**29.4**	**58.6**	**100.0**	**100.0**

In addition to the above, Table 6.2 also summarizes the social factors as noted by complainants. Almost a third of complainants (29%) reported what they perceived to be either insufficient management on the part of the swine operator, or insufficient enforcement or monitoring by the regulator. Odour avoidance by, for example, closing doors and windows, staying inside, or leaving the area represented 20% of the complaints. Another 14% of complainants noted feelings of stress, a sense of powerlessness to change the situation, frustration, or a conflict either with the operator or the regulator. Similarly, 14% of complaints expressed concerns about health effects (e.g. headaches, breathing problems) caused by the odour or emissions from the swine operation. Ten percent of complainants noted the disruption of individual, family or community activities including sleep, mealtimes, vacations, BBQs, or other planned events. Six percent noted concerns about the effect of the facility on the environment, including air and water quality. Another 4% of complainants reported that the odours were specifically affecting their quality of life or had other general concerns, and only 3% noted negative economic impacts such as declining property values, businesses, and tourism.

Most relevant to this study, specific management mechanisms were noted by complainants as a means for odour mitigation or compliance with agreements or regulations. A breakdown of the number of complaints that included a remark about one or more of the eight management mechanisms is presented in Table 6.3. Only 170 of the 1132 complaints selected (or 15%) noted one or more of the eight management mechanisms reviewed in this study. Complainants reported that the mechanism was either absent, not properly monitored, and/or inadequately practiced. Manure incorporation and/or injection was mentioned by the greatest number of complainants (73%), followed by biocovers or other covers for manure (19%).

Table 6.3 Management mechanisms noted by complainants for swine operations

Management mechanism	Noted by complainants	
	Count	%
Manure removal	2	1.2
Manure incorporation and/or injection	124	72.9
Moisture management	2	1.2
Biocovers/covers	33	19.4
Bottom loading	2	1.2
Shelterbelts/windbreaks	2	1.2
Composting	3	1.8
Dust palliatives for roadway management	2	1.2
Total management mechanisms	**170**	**100.0**

6.6 Key Findings

The preceding analysis of odour complaints and the management mechanism overview point to some key connections between CFO practices and social concerns over air emissions. Three key findings on the social ramifications of odour and air emissions associated with CFOs and the selected management mechanisms are discussed in this section.

6.6.1 Primary social issues over odour and other air emissions associated with CFOs

At least three social factors can be outlined. First, among the substances and emissions of interest to this study, odour is *the* issue in the social literature. With the possible exception of particulate matter from roadways and dust from feedlot pens, which seem to be more prevalent in southern Alberta due to dry climatic conditions and a high concentration of feedlots, the other substances are not readily “seen”. Yet all may be present in air emissions from CFOs. Apart from odour, particulate matter seems to be the greatest nuisance, but dust palliatives remain untested from a social perspective. Unknown health risks associated with roadway dust also require further study.

Second, as mentioned in the beginning of this review, the social literature tends to focus on the social impacts of CFOs rather than specific management mechanisms. As several authors and interviewees alike indicated, non-farming rural neighbours may not understand the tradeoffs associated with different practices used to mitigate odour and other air emissions.

A third important theme is social conflict between host communities and neighbours and livestock operators. This is perhaps more so in the U.S., but increasingly the case in several Canadian provinces. Social concerns are often expressed by nuisance or odour complaints, and in some cases, through political and legal venues. Social conflict over air emissions is also associated in some cases with the siting or expansion of CFOs, with arguments that include decreasing quality of life and declining property values. Since an important predictor of conflict behaviour is the perception of one's ability to control a given situation (such as rights to voice concerns that are acted upon over CFO siting), this has ramifications for regulators and extension workers striving to alleviate social conflicts concerning poor or declining air quality. Individual or community perceptions of fairness and control seem to be key factors relating to the acceptance of standards for CFOs (ARD 2004a).

6.6.2 Socially acceptable management mechanisms

This study has shown that most of the eight management mechanisms appear to provide some social benefits to improving air quality around CFOs. The predominant management mechanism discussed in the literature is manure application, including solid manure spreading, irrigation systems, and liquid manure spreading (surface and injected), with liquid manure injection offering some of the greatest potential for addressing odour complaints. These techniques are readily observable, even to non-farm experts, with potentially immediate benefits to develop a more positive relationship among operators and neighbours. Other management mechanisms that also show promise from a social perspective include biocovers and shelterbelts. Not only are they relatively low cost for CFO operators, they may also be more pleasing from a visual or "natural" perspective. Still, questions about the specific effectiveness, measurability, and acceptability of various management mechanisms remain unanswered. More analytical research is needed on the social impacts described in this study to adequately assess each mechanism.

6.6.3 Social challenges for communities and the livestock industry

Introducing new management mechanisms or changing existing standards and regulations to ensure their implementation presents significant social challenges for rural communities and the livestock industry. Interviewees for this research all commented on the social and other challenges of the adoption of the eight management mechanisms designed to address air quality concerns. The unique design, history, and location of CFOs could limit the adoption of one or more of the management mechanisms. Dialogue and informed opinion were felt to be an important means to avoid conflict and reduce complaints. Some research reviewed for this study indicated that neighbours should be made aware of the options at the disposal of producers, and their associated social, economic, and environmental tradeoffs, either in communication with government, the producers themselves, or both. The challenge remains as to how this can be most effectively and fairly done.

6.7 Research Recommendations

This review has shown that several knowledge gaps remain concerning the social ramifications of air quality issues around CFO operations. At the root of conflicts about odour or CFOs in general are hard decisions about which lands should be used and for what purposes. Rural conflicts are likely to continue as farms become larger and intensify production. As CFO operators and other farmers in Alberta's rural landscapes find themselves closer and closer to urban centres, the boundaries between rural and urban are increasingly becoming blurred. In the process, the smells and other air emissions of livestock facilities and manure are increasingly coming into contact with non-farming neighbours and new or growing communities. The following recommendations are made based on this review.

1. It is recommended that additional research be carried out on social considerations regarding the potential of management mechanisms to ameliorate air emission concerns. Pertinent information on social factors concerning specific management mechanisms to reduce air emissions is still lacking. For example, little is known about how different stakeholders are affected by the wide range of management mechanisms available for mitigating air emissions such as odour. More information is needed on what works best under which circumstances, especially if certain management mechanisms will be provided with greater attention and support. Further consultation and analysis should be conducted on the livestock industry's perspective with regard to the management mechanisms. Acceptable emission standards and measurement techniques need to be defined and refined as new information becomes available, and communicated well to communities. It is also unknown if social capital or community perceptions of fairness would impact the introduction of specific management mechanisms and standards for CFOs.

2. More and improved education and dialogue are recommended among all stakeholders. One difficulty is that many of the management mechanisms identified for this review do not seem to be recognized as effective measures for mitigating emissions from CFOs. For example, regarding shelterbelts, it is not likely that observable features of the landscape such as natural windbreaks would be equated directly with reducing odours. Rather, the recognition of shelterbelts and anticipated effectiveness as an emissions mitigation strategy appears to rest primarily on their ability to visually screen CFO production activities from the public eye, ultimately resulting in a psychological as opposed to a physiological impact. More research is needed on the question of whether shelterbelts on land where CFOs are located can actually reduce complaints. Other examples include mechanisms where little is known about their social value. Bottom loading procedures, for instance, could be communicated to neighbours to involve them in evaluating the technique's usefulness, thus

potentially reducing odour complaints. Livestock operators could notify neighbours when they retrofit their manure storage facility with a bottom loading manure handling system and request feedback on any impacts, positive or negative. The development of educational, marketing, and monitoring programs could improve understanding and encourage long-term positive relationships with neighbours. It would also provide an opportunity for the industry and regulators to build and maintain a social license to operate.

3. Another recommendation is that further analysis of the NRCB's odour complaint database and interviews with NRCB inspectors, CFO operators, and neighbours of CFOs could reveal why and where complaints arise, who is making them, and what social or health issues are involved. The literature review showed that greater insight into nuisance substances and their potential social and health impacts is needed. This work could also suggest potential solutions that could be implemented at provincial and local levels of government. Some questions that could help guide this analysis include which management mechanisms for CFOs are best at reducing odour complaints, whether odour complaints increased or decreased over time by type or area of operation, and if those areas with the most complaints ("hotspots") are associated with size or siting (i.e. distance from residents). A more in-depth analysis could also help determine if complainants have a good grasp of the negative aspects (or risks) associated with each management mechanism.

4. Lastly, analytical and timely information on the potential social benefits and costs of these mechanisms would inevitably assist livestock business operators to make more informed decisions about mitigation technologies best suited for their individual situation. The information gathered should also provide government and research agencies with a better understanding of where potential knowledge gaps exist, and help facilitate the development of research plans or standards and policies to address these gaps, where applicable.

In closing, this review has provided some social perspectives on how producers adopt manure practices to potentially reduce air emissions, how these practices might be accepted by neighbours, and how they can be encouraged and monitored. Responsible mitigation of odour and other air emissions from livestock facilities is important for managing, and where necessary improving, a sustainable CFO industry. To achieve this aim, the social acceptability of practices aimed to reduce air emissions should be considered along with regulatory, technical, economic and environmental acceptability. The CFO industry and its regulators must also emphasize essential social benefits and costs for the mitigation of odour and other air emissions.

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Chapter 7.0

A Review of Potential Costs and Benefits of Select Beneficial Management Practices

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Contents

7.1 Introduction

Air emissions, including odour from livestock facilities, are an environmental concern for the livestock industry. In 2005 the Clean Air Strategic Alliance (CASA) established a multi-institutional and inter-disciplinary Confined Feeding Operations (CFO) project team to develop a strategy for improving the management of air emissions from existing and future CFOs in Alberta and to improve relationships amongst stakeholders (CASA 2008). As part of its strategic plan, the CFO project team developed a shortlist of potential management mechanisms (MMs) for reducing air emissions from CFOs in Alberta that were of interest for further evaluation. These included: (1) frequent manure removal; (2) manure application; (3) moisture management; (4) permeable covers; (5) bottom loading of manure storage facilities; (6) shelterbelts; (7) solid manure and dead animal composting; and (8) dust reduction for roads and feedlots.

The objective of this study is to evaluate the potential economic costs and benefits of the eight MMs for reducing six key emissions: (1) odour; (2) ammonia (NH_3); (3) hydrogen sulphide (H_2S); (4) particulate matter (PM); (5) pathogens and bioaerosols; and (6) volatile organic compounds (VOCs). The MMs may also provide other co-benefits such as improved aesthetics and/or carbon sequestration by changing management practices. These co-benefits were not evaluated in this study.

The evaluation is based on a review of the existing literature. The transfer of values from the literature, however, is not without challenges. In order to validate the results, interviews were conducted with key industry and academic experts for each of the MMs. The interviews were used to identify potential information gaps and uncertainties, and highlight additional considerations associated with applying these MMs in the Alberta context. In order to provide context for the results, we outline a typical or reference target area to which the literature review will be applied.

Typical CFO

Tables 7.1 and 7.2 below show baseline information for different types of livestock CFOs in Lethbridge County, selected as our 'representative' target area where CFO MMs would be applied, and for the province, respectively. The number of animals (livestock capacity) and number of CFOs presented in both tables are based on census data, which reflect the characteristics of the various CFOs on the day the questions were answered. Since costs and benefits of MMs are calculated on an annual basis per animal, it is necessary to multiply the livestock capacity by annual rates of turnover for livestock in order to determine the total number of animals affected by the MM per annum. Turnover rates for CFOs in Alberta were taken from: D. Bodnar (Supervisor of Agriculture and Municipal Services, County of Lethbridge, Picture Butte, AB, pers. comm.) for feeder cattle; CPC (2005) for swine; BCMA (1998) for poultry; and ARC (2007) for dairy. The results were divided by the total numbers of CFOs (broken down by type) for Lethbridge and Alberta, which were obtained from B. Hazelton (Inspector, Natural Resources Conservation Board, Red Deer, AB, pers. comm.). The total number of animals per annum by CFO type is provided in Tables 7.1 and 7.2 for Lethbridge and Alberta, respectively.

Table 7.1 Baseline CFO information for Lethbridge

Livestock type	Feeder cattle[a]	Dairy cattle	Swine	Broiler	Layer	Turkey
Number of animals (on census day)	383,063	8,495	120,020	1,007,257	86,052	N/A[b]
Annual rate of turnover	2.5	1[c]	2.26	10	1	4
Number of animals per year	957,658	8,496	271,245	10,072,570	86,052	N/A
Number of CFOs	145	75	74	43	97	8
Animals per operation/year	6,604	113	3,665	234,245	887	N/A

a. Feeder cattle represent the sum of beef cattle heifers for slaughter or feeding and steers aged 1 year and over presumed to be grown or finished on feedlots prior to slaughter for human consumption.

b. Statistics Canada does not provide data when there are too few operations (8 in this case) to represent the type of livestock.

c. A dairy cow can be placed in a dairy barn for approximately three years, but since we limit our scope of analysis to one full year we use a turnover rate of one instead of one-third.

Sources: SC (2006a); D. Bodnar (Supervisor of Agriculture and Municipal Services, County of Lethbridge, Picture Butte, AB, pers. comm.); CPC (2005); BCMA (1998); ARC (2007); B. Hazelton (Inspector, Natural Resources Conservation Board, Red Deer, AB, pers. comm.)

Table 7.2 Baseline CFO information for Alberta

Livestock type	Feeder cattle	Dairy cattle	Swine	Broiler	Layer	Turkey
Number of animals (on census day)	1,780,388	78,875	2,052,067	8,546,758	2,227,454	703,462
Annual rate of turnover	2.5	1	2.26	10	1	4
Number of animals per year	4,450,970	78,875	4,637,671	85,467,580	2,619,046	2,812,848
Number of CFOs	458	800	1,200	1,615	3,154	652
Animals per operation/year	9,718	99	3,865	52,921	830	4,316

Sources: SC (2006a); D. Bodnar (Supervisor of Agriculture and Municipal Services, County of Lethbridge, Picture Butte, AB, pers. comm.); CPC (2005); BCMA (1998); ARC (2007); B. Hazelton (Inspector, Natural Resources Conservation Board, Red Deer, AB, pers. comm.)

According to GOA (2005), a CFO is defined as, '…fenced or enclosed land or buildings for the purpose of growing, sustaining, finishing or breeding by means other than grazing…'.

However, the ‘number of animals per CFO per year’ derived for each livestock type, as presented in Tables 7.1 and 7.2, is based on the assumption that the ‘number of animals’ reported in the 2006 census of agriculture for Alberta was from farms also listed in the Natural Resources Conservation Board (NRCB) database of CFOs. Note that not all CFOs in Alberta are listed in the NRCB database of CFOs on which Tables 7.1 and 7.2 were based. Furthermore, the NRCB database, unlike the census data, typically reflects the licensed animal capacity of the CFOs listed in the database but not the number of animals at a given point in time.

Typical community

Most CFOs are and will continue to be based in rural Alberta communities which will be the primary beneficiaries of MMs. The relevance of the benefits estimates provided in Section 7.4 depends on the similarities between the studies reviewed and the rural Alberta context. As of 2006 there were 45,195 farm families and 71,660 farm operators working on 49,431 farms listed in the province (SC 2006a). Although CFO operations are located throughout the province, some types of CFOs concentrate in certain geographical areas because of access to meat processing plants and natural resources, such as water and fertile soil for growing crops for animal feed (CASA 2008). The feedlot industry is concentrated south of Calgary while the swine industry is concentrated in the Edmonton-Calgary corridor (CASA 2008). The combined population within regions south of Calgary, particularly within the Chinook and Palliser health regions, was 253,385 with a median age of 37, slightly above Alberta's median age of 36 (SC 2006b). Median family income in all census families was $59,863 and $66,861 for the Chinook and Palliser health regions, respectively, low in comparison to $73,823 for the province (SC 2006b).

The population along the Calgary-Edmonton corridor, which is assumed to encompass the David Thompson Health Region, was 298,766, half of Alberta’s total rural population of 590,499. The median age in the David Thompson Health Region was also 37, above that of Alberta (SC 2006b). The median family income in the David Thompson Health Region was $68,335, low in comparison to the province (SC 2006b).

Scope of report

This report proceeds as follows:

In Section 7.2, we identify the key cost drivers associated with implementing MMs, and summarize factors that should be considered when evaluating the relevance of related studies to the Alberta context. The section concludes with a set of criteria for evaluating the relevance of selected studies.

In Section 7.3, potential costs are developed for each MM based on reviewed literature. Interviewee comments provide additional information for evaluating the relevance of the studies to Alberta and are used to identify a single cost estimate from the range of costs provided by the literature. Unintended consequences of the MMs, such as increased nitrogen leachate into groundwater, are not considered.

In Section 7.4, we review the potential health impacts of each of the air emissions. The economic benefit of reducing emissions is based on the value of a statistical life (VSL) approach, using VSL estimates from the literature. The VSL approach attempts to measure the value of an individual's change in well being based on his/her willingness to pay to reduce or avoid health risks. There are a number of potential co-benefits from emissions reductions that were not considered including improved farmstead aesthetics (Malone et al. 2008), increased crop production, and reduced property damage from corrosion (Chestnut et al. 1999). Where there are co-benefits they will improve the net benefits associated with the practice.

In Section 7.5 we bring the costs and benefits of each MM together and provide a ranking of the net benefit associated with each MM. The benefits of emissions reductions are usually measured in terms of individuals or households, while the costs of the MMs are expressed in terms of the number of livestock. To make the costs and benefits commensurable, the benefit values are converted to the common denominator $ *per head of livestock*. These conversions were based on a number of simplifying assumptions about the number of individuals affected by air emissions from CFOs, as well as the baseline level of emissions in the community. These assumptions are discussed further in Section 7.5. All cost and benefit values are reported relative to the value of the Canadian dollar in 2008 (2008 CDN$). Section 7.5 concludes with a ranking of MMs and a discussion of key uncertainties in the results and areas for further analysis.

7.2 Cost Drivers and Potential Costs per Head by MM in Alberta

The cost of implementing an MM includes direct costs, costs for compliance with environmental regulations and zoning restrictions, opportunity costs, and costs associated with other unintended consequences. Each of these cost components is outlined below. The study focuses primarily on on-farm cost drivers. However, information on the other three cost categories was included where possible.

Even though MM costs are presented against operation size, we emphasize that other variables likely influence cost values too. For example, the cost of shelterbelts for swine barns is affected by the size as well as shape and structure of the barn (J. Tyndall, Social Scientist, Iowa State University, Ames, IA, pers. comm.). Similarly, manure application is influenced by the capacity or depth of manure storage structures. However, the studies we used for the cost assessment of this MM (Foster 1994) did not discuss this aspect.

Direct on-farm costs

Direct costs include variable costs associated with transportation, labour, materials, and energy, as well as capital costs which include depreciation and amortization costs. Several studies showed a relationship between operation size (e.g. number of animals, quantity of manure produced) and costs associated with MMs. In some cases, variable costs associated with the MM dominate the fixed costs, increasing as the head of livestock increase due to diseconomies of scale associated with transportation costs and increased hauling distances for manure, for example. In other cases the fixed costs are a greater factor in the cost of the MM, due for instance to costs associated with planting shelterbelts or the application of dust palliatives on unpaved roads. In the latter case, the costs decrease with increasing head of livestock.

Environmental compliance costs

Compliance costs refer to costs for complying with environmental regulations and land use planning and zoning restrictions. Many environmental compliance costs are fixed costs and therefore costs per head for this component tend to decline with the size of the livestock operation (Metcalfe 2001; Kaplan et al. 2004; Fleming et al. 1998; Roka and Hoag 1996). One example of how compliance cost affects on-farm costs in Alberta is the regulated minimum size of a manure storage facility that may be required to have the capacity to store 9 months worth of accumulated manure (GOA 2005).

Opportunity costs

The opportunity cost associated with the adoption of an MM is the income lost by virtue of the change in management practice (Henderson 2008).

Costs of unintended consequences

Unintended consequences may influence either the private or social costs of an MM. In terms of social costs, certain mechanisms to reduce NH_3 emissions may result in increased water quality problems due to increased nitrogen runoff (Ribaudo et al. 2006). From a private cost perspective manure injection or incorporation may also have a negative impact on other farm outputs. For example, deep injection of manure on grasslands has not been well accepted because of root damage and occasional yield reductions (Meisinger and Jokela 2000).

7.2.1 Selection of relevant cost studies

Studies evaluating the costs of each MM were identified by searching well-known databases[13]. For each of the MMs, we selected two to three studies based on a number of criteria viewed to be applicable to the Alberta context. In the end, this resulted in a total of 11 studies that were used to assess the on-farm costs of implementing the MMs. A number of factors affected the applicability of the select studies to Alberta. These are discussed further below:

Environmental stringency of the study site vs. policy site

Costs of MMs may differ between jurisdictions because of differences in the stringency of environmental and land use restrictions. In Alberta, CFOs that commenced operations prior to 2002 fell under municipal jurisdiction and were regulated according to municipal bylaws and land use plans. In 2002 the regulation of CFOs was transferred from the municipalities to the Province under the *Agricultural Operation Practices Act* and *Regulations* (AOPA). When studies from outside the province were considered, key interviewees were asked what impact they thought the regulatory differences would have on costs if the MMs were applied in Alberta. For

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[13] Environmental Valuation Reference Inventory database (EC 2006), EconLit, AgriCola, Web of Science, JStor and Google. The search was conducted by cross referencing keywords related to the MMs and emissions. Additional studies were located by browsing bibliographies.

example, net costs associated with using permeable covers in Denmark (Jacobsen 2006) may be lower than in Canada due to regulations related to conserving manure-based nitrogen in Denmark which could result in higher co-benefits from nutrient offsets (J. Feddes, Professor Emeritus, University of Alberta, Edmonton, AB, pers. comm.). Similarly differences in regulations related to setbacks between fields and water bodies affect costs of manure application. Overall, however, interviewees did not regard differences in regulations as a significant issue in cost transfer.

Agro-geoclimatic conditions

Ideally, the agro-geoclimatic conditions of the study site should correspond to conditions at sites in Alberta. For example, Montana, North Dakota and Iowa have cold winters, strong winds, and summer drought, all of which may influence the uptake and costs of an MM. As another example, the frequency of replacing straw covers used to reduce emissions from manure storage facilities is influenced by rainfall (CPC 2005; Jacobsen 2006). Interviewees were asked to comment on the influence of climate on the potential adaptability of the results from other jurisdictions to Alberta.

Agglomeration economies

Study locations should be comparable to Alberta in terms of costs and availability of inputs, particularly land, machinery, and labour. For example, manure application costs are influenced by the lack of available land for spreading manure (Ribaudo et al. 2003, 2006). The northern U.S. Plains have less suitable cropland for applying manure due to the higher agglomeration of CFOs compared to other regions in the U.S., such as the Mid-West (Kaplan et al. 2004). Since manure has to be transported to further destinations it results in increased transportation costs (Kaplan et al. 2004). Therefore, when evaluating potential costs for Alberta we put more weight on studies from jurisdictions that were similar to Alberta in terms of density of CFOs where agglomeration economies were important cost drivers.

Government programs

In some jurisdictions, governments have shared the initial costs associated with MMs. For example, shelterbelts have been subsidized in both the U.S. and Canada. In Canada, the Agroforestry Development Centre (Agriculture and Agri-Food Canada - AAFC) provides trees at no cost (AAFC 2008), whereas in the U.S., the government shares 50% of the cost of initially establishing the shelterbelt under the Environmental Quality Incentives Program - EQIP (Tyndall and Grala 2008). The difference in government subsidy was used to adjust for costs for planting shelterbelts.

7.2.2 Criteria for selecting applicable cost studies

Based on the transferability factors described above, several criteria were selected to determine the applicability of the studies reviewed to the Alberta context. These included: size of operation; geographic location and relevant climate factors (study sites in the Plains and Western North America were preferred); operational practices and technologies implemented; number of cost factors included in the study; and whether or not the study was peer reviewed.

If a study met only one criterion, it was ranked as 'low'; if it met two, it was ranked as 'medium'; and if it met three or more, it was ranked as 'high'. Table 7.3 outlines the evaluation criteria used to select relevant studies.

Table 7.3 Criteria for selecting relevant cost studies

Criteria	Indicators
Validity/reliable	• Study was peer reviewed • Study considered the relationship between compliance cost and size of operation (manure application, compost, frequent manure removal, shelterbelt) • Study considered the relationship between the type of manure (liquid versus solid) and the MM (manure application) • Study considered the relationship between the MM and manure nutrient content (manure application)
Relevant to policy site	• Comparable stringency of environmental regulations between the study site and policy site, if applicable to MMs (mortality composting and manure application) • Similarity of agro-geoclimatic conditions and size of operation • Comparable practice and technology • Comparable climate (permeable covers) • Consideration of government cost share (e.g. shelterbelt)

Relative to the outlined criteria, the average cost per head of livestock per MM was derived based on the outcome of 11 select studies. These values as well as key characteristics and assumptions of each study are summarized in Table A1 in Appendix A.

7.3 Potential Costs of Each MM

In this section we evaluate the potential costs associated with each MM. We describe the MM, identify the key cost drivers, and provide a summary of the cost studies that were deemed relevant for Alberta based on the evaluation criteria provided in Section 7.2. Interviewee comments were summarized and used to develop a single value for the cost per head per MM.

7.3.1 Frequent manure removal

Frequent manure removal refers to either the daily removal of manure from livestock buildings housing dairy cattle, swine (solid manure) or chickens (layers), or the removal of manure from feedlots more frequently than once or twice per year (I. Edeogu, Engineer, Alberta Agriculture and Rural Development, Edmonton, AB, pers. comm.). As a management mechanism for emissions it is mainly applied in beef cattle feedlots and the dairy industry. This MM is thought to be particularly beneficial because manure is the main source of CFO emissions and manure removal helps reduce odour and PM, e.g. dust (CASA 2008).[14] However, if the manure is not stored in an enclosed facility or incorporated immediately into the soil following its removal

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[14] Other sources of emissions in the facility may include the animals themselves as well as walls or structures.

from a livestock building or feedlot pen, then emissions are not likely to be reduced but are instead "transferred" from the original location to a secondary location (I. Edeogu, Engineer, Alberta Agriculture and Rural Development, Edmonton, AB, pers. comm.). Co-benefits of the MM include improved livestock health and improvement of manure's nutrient content, which increases its value when applied to fields (QG 2006).

7.3.1.1 Frequent manure removal cost drivers

The following cost drivers associated with frequent manure removal were identified in the literature:

- Reduced storage costs: Removing and applying manure more frequently would reduce the cost of having it stored, reducing manure storage costs when this MM is adopted (Vogt and Kastens 2005).

- Reduced peak labour demand: Frequent manure removal spreads the demand for labour evenly throughout the year (compared with removing manure once or twice per year), leading to an overall reduction in labour costs (Ashraf and Christensen 1974; Vogt and Kastens 2005*)*.

- Reduced dust levels: Manure not removed from pens for over a year tends to dry out and create dust, which enters respiratory tracts of beef cattle causing illness. Frequent manure removal reduces dust within feedlot pens leading to improved livestock health (QG 2006).

- Enhanced nutrient offset benefits: If manure is not removed from pens for over a year, for example, it tends to lose its nutritive value. Removing and applying manure more frequently will provide crops with a higher level of nutritive content, improving their yield (QG 2006).[15]

Based on the evaluation criteria, the study by Vogt and Kastens (2005) was selected to provide benchmark cost estimates. Highlights from the study are summarized in Table 7.4. Vogt and Kastens (2005) compared the costs of installing and implementing a daily manure removal and application system with a less frequent hauling system for dairy cattle manure. They did not specify whether the manure was liquid or solid. The daily hauling system reduced transportation costs relative to less frequent hauling because of the reduced need for investment

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[15] The nutrient offset benefit is only applicable during the growing season, because legislation does not allow manure to be applied in winter without special approval, and manure removed will be stockpiled and applied in spring either just before or just after crops emerge, provided the emerged crops are small (B. Hazelton, Inspector, Natural Resources Conservation Board, Red Deer, AB, pers. comm.). Legislation requires that the applied manure be incorporated within 48 hours, unless it is applied to forage or direct seeded lands, in which case it does not need to be incorporated (B. Hazelton, Inspector, Natural Resources Conservation Board, Red Deer, AB, pers. comm.). When manure is applied to forage or direct seeded lands, legislation requires that the setback distance be increased (B. Hazelton, Inspector, Natural Resources Conservation Board, Red Deer, AB, pers. comm.).

in manure storage[16]. Vogt and Kastens did not specify what proportion of the cost savings associated with the MM was related to the reduced storage requirement. A manure storage system was estimated to cost approximately $25 per animal per year (USDA 2003). Table 7.4 shows cost savings both with and without savings from manure storage.

Table 7.4 Features of frequent manure removal cost studies

Study	Cost drivers included	Location of study	Type of livestock	Number of dairy cattle	Cost 2008CDN$/ head/year	Reason study was selected
Vogt and Kastens. 2005. A study of the financial impact of dairy manure storage systems in Northeast Kansas. *Review of Agricultural Economics* 27(3): 336-49.	Compares costs of a daily haul system with a less frequent hauling system. Savings in storage and manure spreading (labour and fixed costs).	U.S. Mid-West	Dairy	Storage cost is included as a cost driver		The most recent literature available on daily manure removal
				60	-$82.00	
				250	-$46.00	
				Storage cost is excluded as a cost driver		
				60	-$57.00	
				250	-$20.00	

7.3.1.2 Interviewee comments on frequent manure removal costs

Interviewees provided the following additional comments on the study (T. Wallace, Nutrient Management Specialist, Alberta Agriculture and Rural Development, Leduc, AB; G. Montgomery, Environmental Economic Specialist, Alberta Agriculture and Rural Development, Vegreville, AB; B. Auvermann, Professor, Texas A&M University, Amarillo, TX; S. Amosson, Professor and Extension Economist, Texas A&M University, College Station, TX):

- While frequent manure removal reduces costs for dairy operations, it increases costs for feedlots because of differences in technology. For dairy, the MM reduces both peak labour demand and capital investment costs because automated equipment like scrapers are relatively inexpensive. For feedlots, on the other hand, this MM increases both labour and capital costs because the typical technology is based on tractors and front-end loaders, which are both expensive and labour intensive to operate.

- Frequent use of tractors in feedlots could stress animals, although this effect might diminish over time as animals adapt. This would be less of an issue for dairy cows, which have adapted to frequent interaction with farmers.

- Even if this MM were adopted in an Alberta dairy, we would see lower cost savings than those reported by American studies (Vogt and Kastens 2005) because Alberta winters are longer and therefore manure storage facilities are necessary since in most cases it is not feasible to apply manure year round.

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[16] The main characteristics of this study are summarized in Table A1 in Appendix A.

7.3.1.3 Final cost assumptions for frequent manure removal

The cost savings estimated by Vogt and Kastens (2005), assuming continued need for storage, are $57 per cow for a small dairy barn with 60 animals, and $46 per cow per year for a larger dairy barn of 250 animals. Costs are expected to be higher than these estimates for feedlots since dairy and feedlot operations use different equipment to adopt this MM. According to the interviewees, while dairies use manure removal technologies such as automated scrapers, feedlots use tractors, a more labour intensive technology that could even result in net costs and not savings following the implementation of this MM. Unfortunately, specific cost estimates for feedlots were not available.

7.3.2 Manure application

There are two prominent methods of applying manure, namely manure injection and surface application with immediate manure incorporation, that have the potential to reduce NH_3 and odour emissions in relation to manure application via broadcasting without incorporation or with the delayed incorporation of manure (Meisinger and Jokela 2000). While manure injection is mainly used in the dairy and the swine industries, manure incorporation is used in all CFO industries (feedlot, swine, poultry and dairy). Manure injection involves injecting liquid manure 7.6 cm to 10.1 cm below the surface of the soil using a knife or chisel cultivation system. As mentioned above, legislation requires that surface-applied manure be incorporated within 48 hours, unless it is applied to forage or direct seeded lands (B. Hazelton, Inspector, Natural Resources Conservation Board, Red Deer, AB, pers. comm.). While Alberta Agriculture and Rural Development (ARD) uses this legislative requirement to regulate manure incorporation, Meisinger and Jokela (2000) suggested that if incorporated within 24 hours, manure would still lose 10% to 50% of its NH_3 compared to what it would lose were it not incorporated at all. Manure injection reduces odour and NH_3 emissions by as much as 90% compared to surface spreading because manure exposure to air is minimized (Muhlbauer et al. 2008).

In terms of on-farm costs, manure injection is more capital intensive and results in greater wear and tear on machinery compared to surface spreading (Muhlbauer et al. 2008). Similarly, immediately incorporating manure requires higher machinery costs since the producer has to pull a cultivator or disk with a tractor in order to bury the manure below the surface (J. McKinley, Senior Inspector & Project Manager, Natural Resources Conservation Board, Red Deer, AB, pers. comm.). Immediately incorporating manure is not considered extra work if the producer is a conventional till farmer who buries the manure simultaneously with stubble as part of the conventional agronomic practice (J. McKinley, Senior Inspector & Project Manager, Natural Resources Conservation Board, Red Deer, AB, pers. comm.). A co-benefit of incorporating manure immediately after application is that it improves nitrogen availability to crops (Hanna et al. 2008).

7.3.2.1 Manure application cost drivers

The following cost drivers associated with methods of manure application were identified in the literature:

- Manure transportation costs: These include costs of moving manure from within feedlot pens or stockpiles located immediately outside the barns onto manure spreading devices such as trucks and manure irrigation/injecting devices as well as the costs of hauling the manure to the field for application (Fleming et al. 1998; Smith et al. 2006).

- Nutrient testing costs: These refer to costs associated with testing soil nutrient levels in order to comply with regulation (Fleming et al. 1998; Smith et al. 2006).

- Cost of land: This refers to the cost of additional land needed to spread manure so that limits on regulated application rates are not exceeded (Fleming et al. 1998; Smith et al. 2006).

- Nutrient offset benefits: This refers to cost savings from substituting manure for inorganic fertilizer (Fleming et al. 1998; Smith et al. 2006).

Based on the evaluation criteria, three studies were selected to provide benchmark cost estimates for manure application methods in Alberta. Highlights of these studies are summarized in Table 7.5. Muhlbauer et al. (2008) calculated the cost of injecting swine slurry manure in terms of the cost per litre of swine slurry manure. As we would like to derive the annual cost of injecting manure per pig, we multiply Muhlbauer et al.'s results by the quantity of manure that a pig produces per year, which is approximately 2,760 litres according to B. Hazelton (Inspector, Natural Resources Conservation Board, Red Deer, AB, pers. comm.). We arrive at a cost estimate of between $10.71 per pig and $13.77 per pig. Costs were found to increase with decreasing rates of manure application because in order to achieve low rates of application, farm machinery has to be driven at greater speed which increases wear and tear and therefore increases maintenance and replacement costs.

Fleming et al. (1998) estimated the net cost of immediately incorporating swine manure after application in Iowa where their estimates ranged from -$1.72 per head per year to $7.23 per head per year. Costs increased with the number of animals because of increased transportation costs. Note that on the lower end of the cost range the benefits associated with nutrient offsets actually outweighed the other cost drivers.

Smith et al. (2006) assessed the costs of solid and liquid manure application for swine, beef cattle, dairy cattle, and broilers in Alberta. They included costs of manure hauling and application as well as nutrient offset benefits. Nutrient offset benefits were reported as weight (kg) of nitrogen and phosphorus nutrients conserved in manure. The economic value of the nutrient offset benefit was calculated by multiplying the weight of nutrients by $1 per kg of nitrogen and $0.90 per kg of phosphorus, based on ARD 2006 and 2008 fertilizer prices and fertilizer application recommendations (ARD 2008). Based on these assumptions, we determined the net costs of manure application for swine, beef cattle, dairy cattle, and broilers to be $3.67 per animal per year, $3.30 per animal per year and -$0.61 per animal per year, respectively. Application of broiler manure resulted in a net benefit because of its greater nutrient offset benefit attributable to the higher concentration of nutrients.

Table 7.5 Features of manure application cost studies

Study	Cost drivers included	Location of study	Type of livestock	Sub type of MM	Animals marketed per year	Cost 2008CDN$/ head/year	Reason study was selected
Smith et al. 2006. Effects of market and regulatory changes on livestock manure management in southern Alberta. *Can. J. Agric. Econ.* 54: 199-213.	Costs of loading, hauling, application and nutrient offset benefits for several types of livestock, for solid and slurry manure	Lethbridge, Alberta	Beef - solid manure			$3.30	Study is from Lethbridge; it considered differences in cost for two levels of solid content (solid and slurry) which affect the level of air emissions
			Swine farrow to finish - slurry manure			$3.67	
			Broiler - solid manure			$-0.61	
			Layer - solid manure			$0.03	
			Turkey - solid manure			$0.16	
Muhlbauer et al. 2008. In *Mitigating Air Emissions from Animal Feeding Operations Conference Proceedings.* Des Moines, Iowa. May 19-21.	Equipment wear and tear and maintenance costs for injection (i.e. loading, hauling and application)	Iowa	Swine	Manure injection		$10.71 to $13.77	A recent study from Iowa which has similar agro-geoclimatic conditions to Alberta
Fleming et al. 1998. Resource or waste? The economics of swine manure storage and management. *Review of Agricultural Economics* 20(1): 96-113.	Application, transport, hauling costs and nutrient offset benefit for swine manure incorporation	Iowa	Swine	Manure incorporation	3,300	-$1.72 to $5.53	Study considered cost of manure incorporation after application and estimated costs under different numbers of pigs marketed per year
					9,900	$0.08 to $6.53	
					16,800	$1.31 to $7.23	

7.3.2.2 Interviewee comments on manure application costs

Interviewees (B. Hazelton, Inspector, Natural Resources Conservation Board, Red Deer, AB; J. McKinley, Senior Inspector & Project Manager, Natural Resources Conservation Board, Red Deer, AB; K. Seward, Inspector, Natural Resources Conservation Board, Lethbridge, AB; V. Nelson, Project Engineer, Alberta Agriculture and Rural Development, Lethbridge, AB) provided the following additional comments on manure application costs:

- Manure injection may turn out to be cheaper than incorporation over a 10-year period if the soil is moist enough and without too much clay to allow convenient use of the injection equipment.

- Both manure injection and manure incorporation immediately after surface application (within 24 hours) can achieve the same level of effectiveness in reducing emissions.

- Manure incorporation immediately after surface application is easier to adopt because farmers can use existing unmodified equipment (disk, plough) to incorporate the manure into the soil.

- While manure injection and surface application without incorporation are practices compatible with direct seeding, manure incorporation immediately after surface application is compatible with conventional tillage practices.

- Fuel and labour costs involved in hauling and applying manure are the main cost drivers for both manure injection and manure incorporation immediately after surface application.

- The costs of manure incorporation reported by Fleming et al. (1998) may be too high because fertilizer prices have increased significantly since 1998, which will increase nutrient offset benefits.

7.3.2.3 Final cost assumptions for manure application

Since our interviewees agreed with the range of cost estimates for *manure injection* reported by Muhlbauer et al. (2008), we settled with the central value of $12.24 per pig per year reported in the study. The interviewees disagreed with the range of cost estimates for *manure incorporation* soon after application reported in Fleming et al. (1998) due to higher fertilizer prices. Unfortunately Fleming et al. (1998) did not show the contribution of nutrient offset benefits to total manure incorporation costs. Instead ARD 2006 and 2008 fertilizer prices and fertilizer application recommendations (ARD 2008) are used to determine that nutrient offset benefits reduce manure injection costs by approximately 20%. The costs reported by Fleming et al. (1998) were reduced by 20% resulting in a value of $1.86 per pig per year for manure incorporation. Manure injection has been discussed in relation to swine manure because it is in a liquid state that could be conveniently injected below the surface of land, but injection would not be convenient to use with more solid types of manure. For this reason, dairy manure could be injected where dairy cattle manure is handled as a liquid (Vogt and Kastens 2005). Although, literature on manure incorporation after application has been discussed in relation to swine manure, manure incorporation is also a standard practice utilized by the beef cattle, dairy cattle, and poultry industries in Alberta.

7.3.3 Permeable covers

Permeable covers (also referred to as biocovers) are placed over manure storage structures to help filter manure emissions such as odour. They are primarily applied in the swine industry. Permeable covers are typically constructed of straw, geotextile (a type of fabric), or lightweight expanded clay aggregate (ISU 1998). They reduce odour, NH_3 and H_2S both by providing a physical barrier against emissions, and by oxidizing and making odorous compounds less offensive when they pass through the cover (Burns and Moody 2008). A co-benefit of permeable covers is that they help improve the nutrient content of slurry manure (Jacobsen 2006).

7.3.3.1 Permeable cover cost drivers

The following cost drivers associated with the three types of permeable covers were identified in the literature:

- Operating costs: Operating costs include the labour required to set up the cover, fuel and energy required to power the equipment to chop straw, and repair and maintenance of the cover when wind and rain damage it (Burns and Moody 2008; CPC 2005).

- Type of cover: According to CPC (2005), the type of cover used will have an impact on several costs including the investment or fixed cost, labour and maintenance. For example, while a straw cover is a relatively cheap investment cost, it needs to be replaced every two to six months. Expanded clay on the other hand, is a relatively expensive investment, with a lifespan of 4 years to 10 years. In contrast, the performance of geotextiles significantly decreases by the second year.

- Fixed costs: Fixed costs are associated with initial investment in the cover, and include depreciation and interest costs (Zhang and Small 2008; CPC 2005).

- Nutrient offset benefits: This refers to the benefits of nitrogen conserved in the manure as a direct consequence of the permeable cover which can be used to improve crop yields and reduce fertilizer use (Jacobsen 2006).

Based on the evaluation criteria, two studies were selected to provide benchmark cost estimates for installing permeable covers in Alberta. These studies are summarized in Table 7.6. The CPC (2005) study was selected because the climatic conditions and type of covers assessed are representative of the Alberta context. Jacobsen (2006) was selected because it was the only study to provide a value for the on-farm benefits derived from the conservation of nitrogen. CPC (2005) included operational and fixed costs of installing several permeable covers on manure storage facilities belonging to a 10,000-head swine operation in Saskatchewan. It used a rate of 8% interest on fixed costs before reporting a total cost of \$0.26 per head per year associated with straw covers, $1.21 per head per year associated with geotextile covers, and $2.77 per head per year associated with expanded clay covers.

Jacobsen (2006) included fixed and operating costs, and on-farm nutrient conservation benefits relative to swine operations in Denmark. Because Jacobsen (2006) provided costs per square metre of a cover, we assumed that a square metre of a permeable cover would be sufficient for 17 marketed pigs per year to 23 marketed pigs per year (ISU 1998). We multiplied the range of costs per square metre provided by Jacobsen (2006) by our number of pigs marketed per year per square metre of permeable cover, to obtain a cost estimate ranging between -$0.03 per pig per year and $0.04 per pig per year. The negative value reflects a net benefit when the value of the nitrogen conserved outweighs the cost of applying the permeable cover.

7.3.3.2 Interviewee comments on permeable cover costs

One interviewee (J. Feddes, Professor Emeritus, University of Alberta, Edmonton, AB) provided the following additional comments on the costs of permeable covers:

- The interviewee felt that straw would be most effective in reducing emissions, most convenient to adopt by CFOs in Alberta, and the cheapest over a period of 10 years, even if it had to be replaced every year.

- Expanded clay covers have only been used in research field trials.

- The effectiveness and durability of straw covers would increase if this MM were combined with shelterbelts or bottom loading. The former could be used to reduce wind speed and consequently limit the movement and distribution of the cover due to wind, while the latter would reduce agitation at the manure surface minimizing premature sinking and non-uniform distribution of the straw cover.

- The cost of covers estimated by CPC (2005) could be considered to be representative of costs applicable in Alberta.

- The nutrient offset benefit in the Danish study (Jacobsen 2006) is likely higher than what might be experienced in Alberta.

7.3.3.3 Final cost assumptions for permeable covers

Because the interviewee expressed greater confidence in the estimates of the CPC study, we base our cost estimate on that study and assume costs of $0.26 per head per year for straw covers, $1.21 per head per year for geotextile covers, and $2.77 per head per year for expanded clay covers. Permeable covers have been discussed in relation to swine manure because the permeable cover has to float on a liquid or slurry surface, which would preclude its use where manure is handled as a solid as with the beef cattle and poultry industries in Alberta.

Table 7.6 Features of permeable cover cost studies

Study	Cost drivers included	Location of study	Type of livestock	Type of cover	Cost 2008CDN$/ head/year	Reason study was selected
CPC. 2005. Practices and technologies aimed at reducing environmental impacts from swine production: scientific and economic evaluation.	Operational costs included labour; fixed costs included depreciation, amortization of the cost of the cover and machinery	Saskatchewan	Swine	Straw	$0.26	Study was comprehensive in variables; type of cover, climate and geography are representative of Alberta
				Geotextile	$1.21	
				Expanded clay	$2.77	
Jacobsen. 2006. Reduce the nitrogen loss and maintain the income – the economics of manure handling. *Paper prepared for presentation at the 13th International Farm Management Congress*. Wageningen, Netherlands.	Fixed and operating costs, on-farm nutrient conservation benefits and benefits of reduced manure hauling costs due to keeping precipitation out of manure	Denmark		Straw	-$0.03 to 0.04	This is the only study found to include on-farm benefits of conserving manure-based nitrogen

7.3.4 Shelterbelts

Shelterbelts are rows of trees and shrubs planted around CFOs to meet a variety of objectives specific to each side of the farm (Tyndall 2008) and to reduce emissions moving downwind of the farm by diluting, filtering, and absorbing emissions onto the leaves of plants, as well as reducing wind speeds (Kulshreshtha and Knopf 2003). These emissions addressed by shelterbelts include PM, odour, and NH_3 (Kulshreshtha and Knopf 2003). We assumed that shelterbelts could be used in all types of CFO operations considered in this report (feedlots, dairy, swine and poultry). Co-benefits of planting shelterbelts include improving neighbour perceptions by enhancing site aesthetics, providing recreational areas, reducing energy losses from livestock buildings, and storing carbon (Malone et al. 2008; Tyndall and Grala 2008; Kulshreshtha and Knopf 2003).

7.3.4.1 Shelterbelt cost drivers

The following cost drivers associated with shelterbelts established around CFO farmsteads were identified in the literature:

- <u>Site preparation costs</u>: Cost of site preparation such as tilling, disking, and spraying (Tyndall and Grala 2008; J. Kort, Shelterbelt Biologist/Agroforester, Agriculture and Agri-Food Canada, Indian Head, SK, pers. comm.).

- <u>Establishment costs</u>: These costs include purchasing trees and shrubs, spraying herbicides, and watering the trees (Tyndall and Grala 2008).

- <u>Maintenance costs</u>: Costs of maintenance include the cost of the herbicides, as well as costs for tractor use and labour incurred to apply herbicides, and also the cost of watering the established trees (Tyndall and Grala 2008; J. Kort, Shelterbelt Biologist/Agroforester, Agriculture and Agri-Food Canada, Indian Head, SK, pers. comm.).

- <u>Government subsidies</u>: Trees for establishing shelterbelts are provided at no cost in Canada (J. Kort, Shelterbelt Biologist/Agroforester, Agriculture and Agri-Food Canada, Indian Head, SK, pers. comm.)

Based on the evaluation criteria, the study by Tyndall and Grala (2008) was selected to provide benchmark cost estimates for installing shelterbelts in Alberta. The study is summarized in Table 7.7. The study was selected because it was peer reviewed, included a comprehensive set of cost drivers, and compared costs for different operation sizes. Tyndall and Grala (2008) assumed a time horizon of 20 years for the shelterbelt and a rate of return of 7% to find a cost per animal. We adjusted costs reported by Tyndall and Grala (2008) for differences in government subsidies between Iowa and Alberta. In particular, we subtracted the cost of trees because trees are provided free of charge (AAFC 2008) in Canada. The adjusted costs ranged between $0.03 per pig and $0.11 per pig, decreasing with increasing number of animals.

7.3.4.2 Interviewee comments on shelterbelt costs

Interviewees (J. Tyndall, Social Scientist, Iowa State University, Ames, IA; G. Malone, Extension

Table 7.7 Features of shelterbelt cost studies

Study	Cost drivers included	Location of study	Type of livestock	Number of animals	Cost 2008CDN$/ head/year	Reason study was selected
Tyndall and Grala. 2008. Financial feasibility of using shelterbelts for swine odor mitigation. **Agroforestry Systems.** Published online May 2008.	Cost of site preparation, establishment, and maintenance of shelterbelts around swine operations	Iowa	Swine	1,500	$0.08	Study included a comprehensive suite of cost drivers; similarity of context; compared costs against operation size; and was peer reviewed
				2,000	$0.11[a]	
				2,500	$0.05	
				10,500	$0.03	

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a. In our interview with Tyndall, he confirmed that we do not always see costs declining with operation size because costs are also influenced by other variables like shape and structure of swine barns that are not strictly controlled for in each study.

Poultry Specialist (rtd.), University of Delaware, Princess Anne, MD) provided the following additional comments on shelterbelt costs:

- Establishment, i.e. purchasing trees and shrubs, planting and spraying them to control weeds, represents approximately 95% of all costs.

- On-farm benefits include savings in feed and energy costs from protection of animals and buildings from cold winds.

- Costs in Iowa were anticipated to be similar to those in Alberta due to similarities in regulatory stringency, agglomeration of CFOs, and climate.

- Since Tyndall and Grala (2008) assumed that CFOs had sufficient idle land available to cultivate trees, they excluded land rental costs. However, when a CFO does not have sufficient land to cultivate trees, the cost of renting land would increase the estimates reported by Tyndall and Grala (2008).

- Costs should also include water to maintain the shelterbelt, especially in the semi-arid areas of Alberta.

7.3.4.3 Final cost assumptions for shelterbelts

Because our interviewees expressed confidence in applying the Tyndall and Grala (2008) estimates to Alberta, we adjusted their values with respect to the value of the tree subsidy in Canada and assumed a cost of $0.07 per pig per year. While the discussion on shelterbelts was in relation to swine, shelterbelts can be deployed to serve the same purpose around other types of CFOs like feedlots, poultry and dairy operations.

7.3.5 Composting

Composting may be defined as the rapid decomposition of organic matter (manure or animal carcasses) into a stable end-product via aerobic microbial activity (CASA 2008). Manure composting is mainly used by the feedlot and poultry industries (van Kooten et al. 1998; V. Nelson, Project Engineer, Alberta Agriculture and Rural Development, Lethbridge, AB, pers. comm.). It reduces NH_3 emissions from poultry operations by 25% to 35% compared to manure stored in a deep pit manure storage system, i.e. a system where manure is stored beneath the floor where livestock are housed in a livestock building (V. Nelson, Project Engineer, Alberta Agriculture and Rural Development, Lethbridge, AB, pers. comm.). Windrow composting is one of several manure composting methods; it involves placing manure in rows without an enclosed structure. Manure can also be composted in an enclosed structure (V. Nelson, Project Engineer, Alberta Agriculture and Rural Development, Lethbridge, AB, pers. comm.). Both methods are applicable in Alberta.

Mortality composting (composting of animal carcasses) is utilized by all CFO industries (beef cattle, dairy cattle, swine, and poultry) in Alberta. Cattle carcasses are composted on an outdoor concrete floor to prevent leaching of nitrogen and phosphorus but without an enclosure (V.

Nelson, Project Engineer, Alberta Agriculture and Rural Development, Lethbridge, AB, pers. comm.). Swine carcasses are composted in an open, but confined structure comprising of a concrete floor, a fence to keep away pets and wildlife, a tarp to prevent runoff in heavy rainfall areas and a carcass grinder driven by a hydraulic cylinder (Foster 1994). Poultry carcasses may either be composted in the open in windrows or, like swine, in an apparatus comprising of a concrete floor covered with a timber structure that includes certain components of machinery and a supply of water (USDA 2003). The costs of composting involve labour and capital investment in the composting structure (Smith et al. 2006; Foster 1994; USDA 2003). A co-benefit of composting on a concrete floor is that the concrete surface protects the quality of groundwater resources by retaining nutrients like phosphorus in the compost instead of allowing them to leach into the water table (Osei et al. 2000). Compost is also a marketable by-product that may be considered to be more acceptable for application on land than manure by non-livestock crop producers (van Kooten et al. 1998; Smith et al. 2006).

7.3.5.1 Composting cost drivers

The following cost drivers associated with livestock manure and mortality composting were identified in the literature:

Manure composting

- Operating costs: Operating costs include: the cleaning of pens; piling compost mixtures of manure and straw, or other carbon amendments, to form windrows; turning composting piles frequently; and wetting the composting piles to provide sufficient moisture for the composting process (Smith et al. 2006).

- Fixed costs: These include costs of compost turning equipment and equipment maintenance (Smith et al. 2006).

- Nutrient offset benefits: These benefits are valued by the market price of compost (Smith et al. 2006).

Livestock mortality composting

- Operating costs: These are primarily associated with the labour required to operate, load carcasses into the composting unit or unload the finished product from the composting unit (Foster 1994; USDA 2003).

- Fixed costs: Fixed costs are associated with setting up composting piles, particularly for poultry or swine, e.g. cost of constructing a concrete pad and possibly an enclosure (Foster 1994; USDA 2003). The USDA study also included the cost of water services and equipment to load mortalities, turn material and offload the compost from the structure as fixed costs (USDA 2003).

- Nutrient offset benefits: Nutrient benefits are valued by the market price of compost (Foster 1994).

Based on the review criteria, three studies were selected to represent composting costs for Alberta. The studies are summarized in Table 7.8. The Smith et al. (2006) study was selected because it is a peer reviewed Alberta study on composting beef cattle manure using the windrow technique. Smith et al. reported costs of $27 per head per year for beef cattle in Lethbridge. The size of operation was not specified.

Foster (1994) and USDA (2003) examined swine and poultry mortality composting, respectively, utilizing technology comparable to technology utilized in Alberta (open, confined structure). Both studies included a comprehensive suite of cost and benefit drivers. Foster (1994) reported costs between $10 and $15 per sow per year for Missouri, but did not indicate the associated size of the operation, in terms of the number of pigs marketed per year. Foster indicated that their costs applied to an operation holding between 100 and 150 sows. In order to find an approximate number of animals produced a year, we multiply the number of sows by the number of weanlings (22) that a sow produces in a year (see Broadway and Fadellin 2006) to obtain an indication of the approximate size of the operation in this study, i.e. between 2,200 and 3,300 animals. Foster estimated these costs for a sow operation without explicitly stating if it also included the feeder pigs in the same operation. Thus, it is uncertain what the corresponding size of sow operation might have been in Alberta. Consequently, for the purposes of our study, we assumed that the sow farrowing operation co-existed with the feeder (finishing) operation based on the CPC (2005) case study[17] that equally assumed the co-existence of the two types of swine operation as a single sow farrow-to-finish operation.

The USDA (2003) reported mortality composting costs of poultry to range between $0.05 and $0.17 per bird per year in North Carolina, where the lower cost was associated with smaller birds (broilers) and the higher cost was associated with larger birds (turkeys).

7.3.5.2 Interviewee comments on composting costs

One interviewee (V. Nelson, Project Engineer, Alberta Agriculture and Rural Development, Lethbridge, AB, pers. comm.) provided the following additional comments on composting costs:

- Costs of equipment and maintenance are the main cost drivers for manure composting, with the costs for turning and watering devices being the most significant.

- For mortality composting, operating costs such as labour are the main drivers when no structure is required (e.g. for composting beef or dairy cattle mortalities). Where a structure is required (e.g. for composting swine or poultry mortalities), the cost of the structure becomes more significant.

- Costs from the U.S. should be similar to costs in Alberta because the same processes are applied.

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[17] See CPC case study for manure storage cover costs.

Table 7.8 Features of composting cost studies

Study	Cost drivers included	Location of study	Type of livestock	Sub type of MM	Number of animals	Cost 2008CDN$/ head/year	Reason study was selected
Smith et al. 2006. Effects of market and regulatory changes on livestock manure management in southern Alberta. *Can. J. Agric. Econ.* 54: 199-213.	Operating and fixed costs and nutrient benefit of windrow composting (piling manure in long rows called windrows) for beef cattle manure	Lethbridge, Alberta	Beef or Dairy Cattle	Manure composting	Not provided	$27.74	Study is peer reviewed; local study site; comparable technology (piling manure in long rows)
Foster. 1994. Cost analysis of swine mortality composting	Operating and fixed costs and nutrient benefit of composting dead swine	Missouri	Swine	Dead animal composting	2,200 to 3,300	$10.00 to $15.00	Study uses a comparable technology; comprehensive in cost variables; and costs shown against operation size
USDA. 2003. Costs associated with development and implementation of nutrient management plans	Operating and fixed costs of composting dead poultry	North Carolina	Broiler	Dead animal composting	25,000	$0.05	Study uses a comparable technology and shows net cost against operation size
			Layer		50,000	$0.02	
			Turkey		5,000	$0.17	

7.3.5.3 Final cost assumptions for composting

The interviewee suggested that the cost of mortality composting in the U.S. is similar to that in Alberta. The interviewee also expressed confidence in the values from the Alberta study on manure composting. Therefore, we assumed costs reported by Foster (1994), USDA (2003) and Smith et al. (2006) with $12.50 per pig per year for composting swine mortalities (Foster 1994); $0.17 per bird per year for composting turkey mortalities (USDA 2003); and $0.05 per bird per year for composting broiler mortalities (USDA 2003). For composting beef cattle manure, we assumed $27.00 per head per year (Smith et al. 2006). Note that with regards to this study, costs were only provided with respect to composting swine and poultry mortalities and beef cattle manure.

7.3.6 Dust reduction for unpaved roads

Dust suppressants or palliatives may be applied to inhibit dust particles (PM) from rising into the air. Particles larger than 2.5 microns (µm) in aerodynamic diameter lodge in the upper respiratory tract and cause severe irritation, while smaller particles go deeper into the lungs and even pass into the blood stream (K. Chawla, Engineer - rtd., Alberta Agriculture and Rural Development, Edmonton, AB, pers. comm.; ASHRAE 2005). Dust reduction mechanisms work by adhering fine particles together. This reduces dust suspended in the air due to vehicle traffic (FCM 2005), for example. We distinguished between dust reduction on unpaved roads in general, unpaved roads around all types of CFOs (feedlots, dairy, swine and poultry), and dust reduction on feedlots, i.e. applied specifically by the feedlot industry. Alberta Transportation uses materials such as lignin sulphonate and bitumen-based compounds as dust suppressants for unpaved primary highways, whereas municipalities like Red Deer use calcium salts like calcium chlorides for unpaved roads around agricultural operations (T. Becker, Operations Manager, Alberta Transportation, Lethbridge, AB, pers. comm.; B. West, Engineer, Westpeake Consulting, Sylvan Lake, AB, pers. comm.). Co-benefits of dust palliatives include reduced road maintenance costs and improved crop yields due to the reduced presence of dust on leaves and the subsequent reduction in leaf temperature and water loss (FCM 2005; K. Chawla, Engineer - rtd., Alberta Agriculture and Rural Development, Edmonton, AB, pers. comm.).

7.3.6.1 Unpaved road dust reduction cost drivers

The following cost drivers associated with dust reduction mechanisms for roads were identified in the literature:

- Type of palliative: The cost of reducing dust on roads depends on the type of dust palliative used. For example, the cost of applying lignin sulphonate is higher than that of bitumen when compared over a long period of time, e.g. 6 years, because lignin sulphonate needs replacement approximately every 6 months while bitumen needs replacement every 2.5 years.

- Operating costs: Operating costs include labour associated with applying the dust palliatives and for repairing equipment, where required (AT 2008).

- Fixed costs: Fixed costs include graders and rollers, which are the types of equipment used to apply dust palliatives (AT 2008).

- Reduced road maintenance costs: Because the dust palliative protects the road surface from damage caused by the force of vehicle tires, the dust palliative also provides a co-benefit by reducing costs associated with road repair. The value of this co-benefit depends on traffic volume (FCM 2005).

Based on the review criteria, we selected two studies to provide benchmark cost estimates for dust palliatives for unpaved roads. The studies are summarized in Table 7.9. FCM (2005) provided a cost per kilometre of suppressant (calcium chloride), delivered to storage or point of use, equipment and labour costs for applying suppressant at the required frequency, and reduced road maintenance benefits in Missoula, Montana. As costs for this MM are typically stated in cost per kilometre of roadway, we converted the cost of the dust palliative into a cost per animal. The cost per kilometre of roadway per year was divided by 20,000 head of cattle based on information obtained from Westpeake Consulting (B. West, Engineer, Westpeake Consulting, Sylvan Lake, AB, pers. comm.).[18] Based on the assumption alluded to in the footnote, we arrived at a range of costs between -$0.78 and $0.28 per head per year. The net benefits at the lower end of the cost range are due to reduced road maintenance costs.

Secondly, AT (2008) published an activity costing report that showed what Alberta Transportation, District of Lethbridge spent annually on the application of bitumen compounds and lignin sulphonate on 150 km of unpaved roadways, enabling us to estimate the cost per kilometre of roadway. The report outlined costs for the dust suppressants, equipment and labour costs for applying the suppressants. To convert these costs to a cost per animal we divided the cost per kilometre of roadway by 20,000 animals. Once again, based on the assumption outlined in the footnote (6), the annual cost of applying the dust palliatives per head of beef cattle was calculated to range between $0.07 and $0.39 for the bitumen compounds and lignin sulphonate, respectively.

7.3.6.2 Interviewee comments on dust reduction costs for unpaved roads

One interviewee (B. West, Engineer, Westpeake Consulting, Sylvan Lake, AB) provided the following additional comments on dust palliative costs:

- Calcium chloride and lignin sulphonate are preferred over bitumen because of lower initial costs and application convenience. However bitumen is cheaper over 10 years because it requires less frequent application.

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[18] 20,000 animals were assumed based on information obtained from Brian West (Engineer, Westpeake Consulting, Sylvan Lake, AB, pers. comm.). Although the number differs from the 6,604 animals per feedlot assumption given in Table 1, this number was used because it was based on local information collected from individuals who actually apply this MM. A greater number of animals would reduce the cost per animal of applying this MM.

Table 7.9 Features of roadway dust palliative cost studies

Study	Cost drivers included	Location of study	Type of livestock	Number of animals	MM sub type	Cost 2008CDN$ /head/year	Reason study was selected
FCM. 2005. Dust control for unpaved roads. www.infraguide.com	Examines costs and benefits of calcium chloride per km of road. Costs include operating costs, fixed costs, frequency of application and reduced road maintenance costs of calcium chloride.	Missoula, Montana	Beef cattle	Not provided	Calcium chloride	-$0.78 to 0.28	Study site is similar in climate and geography to Alberta; study discusses the same technology
T. Becker, Operations Manager, Alberta Transportation, Lethbridge, AB, pers. comm.	Provides operating costs and fixed costs for application of lignin sulphonate and bitumen on primary highways of southern Alberta. Estimates are dependent on frequency of application.	Southern Alberta	Beef cattle		Lignin sulphonate	$0.39	Study site is Alberta
					Bitumen	$0.07	
B. West, Engineer, Westpeake Consulting, Sylvan Lake, AB, pers. comm.	Provides primary data on dust palliative costs for southern Alberta feedlots.	Southern Alberta	Beef cattle		Lignin sulphonate and calcium chloride	$0.45	Study site is Alberta and based on primary survey data
					Bitumen	$0.20	

- Costs for bitumen compounds fluctuate with the price of oil. The prices of calcium chloride and lignin sulphonate are more stable.

- Cost estimates from Missoula should be similar to those in southern Alberta due to similar population densities.

- Feedlot operators and the county share the costs for dust control on a fifty-fifty basis.

- Each of the dust palliatives helps reduce road maintenance costs by about $1,000 per kilometre per year.

7.3.6.3 Final cost assumptions for unpaved road dust reduction

The studies obtained from the literature review focused on municipal cost estimates which were derived from data obtained from Montana. Our interviewee provided us with primary data on the cost of dust palliatives for feedlots in southern Alberta (B. West, Engineer, Westpeake Consulting, Sylvan Lake, AB, pers. comm.). Currently dust palliatives are used primarily by beef cattle CFOs (B. West, Engineer, Westpeake Consulting, Sylvan Lake, AB, pers. comm.). Based on these data the annual cost of applying bitumen was derived by dividing the application cost of $15,000 per kilometre by the number of years bitumen can last before reapplication, i.e. 2.5 years on average. In addition we subtracted the savings for road maintenance over two years at a rate of $1,000 per km per year. The annual cost of applying lignin sulphonate and calcium chloride was derived by multiplying the application cost of $5,000 per kilometre by two (the number of times lignin sulphonate or calcium chloride must be applied each year). Again, we subtracted the savings for road maintenance at a rate of $1,000 per km per year. Next we divided the annual cost per kilometre by 20,000 head of beef cattle in order to arrive at $0.20 per head per kilometre per year for bitumen products; and $0.45 per head per kilometre per year for both calcium chloride and lignin sulphonate. Although the three dust suppressants have been used almost solely as dust reduction mechanisms for unpaved roads near beef cattle feedlots, these and other types of dust palliatives can be used for unpaved roads near any type of CFO.

7.3.7 Dust reduction for beef cattle feedlots

Similar to unpaved roads, dust reduction mechanisms for beef cattle feedlot pen and alley surfaces work by adhering fine particles together and reducing their ability to be suspended in air due to the action of cattle hooves or feed trucks on the surfaces (Amosson et al. 2006, 2008). Feedlot dust reduction mechanisms include water sprinklers and water trucks to sprinkle water on and around the facilities (Amosson et al. 2006, 2008; FCM 2005). It is assumed that other types of livestock housing do not generate as much dust as beef cattle feedlots, therefore this MM is targeted towards suppressing dust emissions from beef cattle CFOs in Alberta.

7.3.7.1 Beef cattle feedlot dust reduction cost drivers

The following cost drivers associated with dust reduction mechanisms for beef cattle feedlots were identified in the literature (Amosson et al. 2006, 2008):

- Capital costs: These costs include investment, interest and depreciation costs for water sprinklers and water trucks.

- Operating costs: Operating costs include maintenance, energy, insurance and labour costs for water sprinklers and water trucks and the cost of supplying water.

- Operation size: Cost per animal is expected to decline with operation size because fixed costs are greater than operating costs.

Based on the review criteria, two studies were selected to provide benchmark cost estimates for dust reduction in feedlots in Alberta. These studies are summarized in Table 7.10. Both studies by Amosson et al. (2006, 2008) were selected because of the comprehensiveness of cost drivers considered. Amosson et al. (2006) estimated operating and fixed costs associated with using sprinklers (i.e. water was pumped directly from a well, dugout or other water storage facility) to reduce feedlot dust in Texas. Operating costs included an annual energy cost to pump the water, and maintenance and repair of the sprinkler system. Amosson et al. (2006) assumed a useful life of 25 years for the sprinklers and an annual discount rate of 6% to obtain a range of costs between \$1.44 and \$2.73 per head per year for sprinkler-based water application systems. However, Amosson et al. (2006, 2008) underestimated costs since they did not consider the cost of supplying water to a sprinkler system, e.g. costs associated with the installation of a new groundwater source and pumping water from that source or from a new irrigation reservoir.

On the other hand, when the water tank and sprinklers were mounted on a truck the operating costs were a direct reflection of the number of hours the equipment was used, and included energy, labour, maintenance and repair costs for using trucks to apply water to the respective feedlot surfaces. Furthermore, operating costs were anticipated to decrease with increasing number of animals. For fixed costs, trucks were assumed to last 25 years, and water tanks were assumed to last 15 years. An annual discount rate of 6% was applied and used to derive costs that ranged between \$1.39 and \$2.32 per head for truck-based water application systems.

7.3.7.2 Interviewee comments on dust reduction costs for beef cattle feedlots

One interviewee (B. West, Engineer, Westpeake Consulting, Sylvan Lake, AB) provided the following additional comments on dust reduction costs:

- Water trucks are more economical for spraying water than irrigation equipment because the latter requires higher investment and setup costs.

- Since southern Alberta already has irrigation infrastructure in place, sprinklers may be more applicable in that region. However central and northern Alberta do not have such infrastructure in place; therefore water trucks may be more appropriate in these regions.

- Even though Amosson et al. (2008) showed costs decreasing with increasing operation size, our interviewee suggested that after a certain point costs remain constant.

Table 7.10 Features of beef cattle feedlot dust reduction cost studies

Study	Cost drivers included	Location of study	Type of livestock	MM sub type	Number of animals	Cost 2008CDN$/ head/year	Reason study was selected
Amosson et al. 2006. Economic analysis of solid-set sprinklers to control dust in feedlots. *Selected paper for presentation at the Southern Agricultural Economics Association Annual Meetings.* Orlando, Florida.	Estimate operational and fixed costs of using sprinklers. Operating costs include maintenance, energy, and repair. Fixed costs include investment, interest and depreciation.	Texas Panhandle	Beef cattle	Sprinkler	17,500	2.73	The technology was considered applicable to Alberta, the study is explicit on all cost drivers, the costs were valued against different operation sizes (and numbers of animals marketed per year)
					20,000	2.39	
					22,500	2.12	
					52,500	1.97	
					60,000	1.72	
					67,500	1.54	
					87,500	1.86	
					100,000	1.63	
					112,500	1.44	
Amosson et al. 2008. Economic analysis of a water truck for feedyard dust suppression. *Selected paper for presentation at the Southern Agricultural Economics Association Annual Meetings.* Dallas, Texas.	Estimate operational and fixed cost of using water trucks to reduce feedlot dust. Operating costs include maintenance, insurance, fuel and labour costs. Fixed costs include investment, interest and depreciation.	Texas Panhandle	Beef cattle	Water truck	17,500	2.32	The technology was considered applicable to Alberta, the study is explicit on all cost drivers, the costs were valued against different operation sizes (and numbers of animals marketed per year)
					20,000	2.03	
					22,500	1.81	
					52,500	1.87	
					60,000	1.64	
					67,500	1.46	
					87,500	1.78	
					100,000	1.56	
					112,500	1.39	

- Since central and northern Alberta have higher moisture levels relative to southern Alberta, and since moisture helps to reduce dust, feedlots in central and northern Alberta may find dust reduction cheaper than in southern Alberta.

- Dust reduction in Texas is probably more expensive than in Alberta due to lower moisture levels and a longer season for dust reduction.

7.3.7.3 Final cost assumptions for beef cattle feedlot dust reduction

Due to the interviewee's concerns about cost differences due to shorter seasons in Alberta compared to Texas when dust reduction would be required and the option for using irrigation systems in southern Alberta as opposed to water trucks, we used the lowest cost value from the Texas study by Amosson et al. (2006) resulting in a cost of $1.44 per head per year for sprinkler-based systems and $1.39 for water truck-based systems relative to a beef cattle feedlot size of 17,500 animals marketed per year. Given that the latter number of animals is higher than the 6,604 animals assumed in Table 7.1, we expect that these costs were underestimated.

7.3.8 Management mechanisms with limited information

7.3.8.1 Bottom loading

Some livestock facilities transfer manure from the animal building to an outdoor manure storage facility with a drain gutter or pipe. If the point of discharge is just above the surface of the manure storage facility, the manure transfer system is called top loading (B. West, Engineer, Westpeake Consulting, Sylvan Lake, AB, pers. comm.). With a top loading system, every time manure is transferred it disturbs the surface of the manure storage facility, agitating the manure and releasing odours and gases. In contrast, bottom loading discharges liquid manure below the surface of the manure storage facility and reduces disturbance of the manure surface and release of odour (CASA 2008; B. West, Engineer, Westpeake Consulting, Sylvan Lake, AB, pers. comm.). We did not find sufficient information on the cost of implementing this MM and it was not evaluated further.[19]

7.3.8.2 Moisture management

Controlling the level of moisture in indoor or outdoor livestock housing facilities reduces odour and dust, with excess moisture increasing odour emissions and too little moisture increasing dust emissions (Amosson et al. 2008). In indoor facilities such as barns, moisture is controlled by mixing manure with absorbent litter when manure is handled as a solid (CASA 2008). Other methods for controlling moisture include minimizing water spills, providing adequate drainage (slope), providing adequate ventilation to remove excess moisture from the air, and frequently removing manure or poultry litter (I. Edeogu, Engineer, Alberta Agriculture and Rural Development, Edmonton, AB, pers. comm.). We did not find information on the cost of implementing this MM and it was not evaluated further.

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[19] Note that one reviewer suggested comparing the cost of burying the inlet pipe to the lagoon at 3.1 m to 3.7 m compared to the existing depth of 1.2 m to 1.8 m (K. Seward, Inspector, Natural Resources Conservation Board, Lethbridge, AB, pers. comm.).

7.3.9 Summary of cost values

Table 7.11 summarizes the cost assumptions for each MM that was considered for the net benefit analysis in section 7.5.

7.4 Potential Benefits of Emission Reduction

Benefits associated with reduced emissions from CFOs include improved human health (reduced mortality and morbidity), improved farmstead aesthetics (Malone et al. 2008), increased agricultural crop production, reduced damage to property due to corrosion, and improved recreation opportunities (Chestnut et al. 1999). For example, composting ultimately reduces phosphorus loads and enhances water quality by providing the opportunity for livestock manure to be transported for use beyond the immediate vicinity of the source (Osei et al. 2000). Similarly, shelterbelts improve aesthetics, provide recreational areas, reduce energy losses from livestock buildings, reduce pesticide drift, flooding and erosion, and store carbon (Malone et al. 2008; Tyndall and Grala 2008; Kulshreshtha and Knopf 2003). To value all of the benefits associated with each MM is beyond the scope of this study. Instead we focus only on direct human health benefits from emissions reductions. Note however, that the co-benefits may be more important than health benefits for some MMs, and therefore, may require further investigation. The impacts of each emission on human health are discussed below.

Odour

Odour is associated with stress. People living near CFOs who experienced odour reported significantly more tension, more depression, more anger, less vigour, more fatigue, and more confusion than control subjects (Schiffman et al. 1995). Consumers in North Carolina, Iowa, and Washington State were willing to pay more ($0.35 per kg) to consume pork that was produced on CFOs that implemented odour reduction mechanisms (Tyndall and Colletti 2007).

Hydrogen sulphide

H_2S occurs naturally in the environment. In relation to CFOs, H_2S is produced by anaerobic digestion of manure. At high concentrations (over 250 ppm) H_2S is very toxic. Many studies have documented adverse effects of acute exposure to relatively high levels of H_2S including neurotoxicity of the central nervous system, pulmonary oedema, cardiovascular toxicity, and gastrointestinal disturbances (Legator et al. 2001). Although uncommon, a phenomenon known as "knockdown" has been reported among workers who experienced short-lived exposure to very high concentrations of H_2S (around 750 ppm to 1,000 ppm), with a brief loss of consciousness followed by immediate full recovery. Prolonged exposure to concentrations in excess of 250 ppm can lead to the development of pulmonary oedema. While potential impacts are severe, it is not clear that acute situations due to short intense releases would ever be a concern for CFOs. Eye irritation is the most commonly reported effect on workers exposed to levels of H_2S between 50 ppm and 100 ppm, and at concentrations of 0.25 ppm to 0.30 ppm, the odour of H_2S can create a nuisance among exposed communities (Milby and Baselt 1999). Impacts of acute exposure on livestock include pulmonary oedema, tuberculosis and

Table 7.11 On-farm costs and assumptions for MM implementation

MM	Sub category	Livestock	Cost $/head/year	Key assumptions	Comments
Daily manure removal		Dairy	-$20.00	250 dairy cows per year	The expected size of a dairy operation in Lethbridge and in Alberta is half that assumed in Vogt and Kastens (2005). Since the costs of this MM increases with size, this cost estimate is high.
Manure application	Incorporation	Swine	$1.86	3,300 to 19,800 pigs	The average size of swine operations in Lethbridge and in the province is similar to that assumed in Muhlbauer et al. (2008); therefore we expect costs are comparable.
	Injection	Swine	$12.24	Not provided	
Permeable covers	Straw	Swine	$0.26	10,000 pigs per year	The average size of a farm in Lethbridge and in the province is smaller (20%) than that assumed in the CPC (2005) study. Given economies of scale in the industry, we expect costs to be underestimated for Lethbridge and Alberta.
	Geotextile	Swine	$1.21		
	Expanded clay	Swine	$2.77		
Shelterbelts			$0.07	1,500 to 10,500 pigs per year	The expected size of a farm in Lethbridge and in Alberta is within the range assumed by Tyndall and Grala (2008); therefore we expect costs are comparable.
Composting	Manure	Beef or Dairy Cattle	$27.00	No cattle numbers provided	The study by Smith et al. (2006) was conducted in Lethbridge; therefore we assume the values are applicable to Lethbridge and Alberta.
	Mortality	Swine	$12.50	100 to 150 sows per year (2,200 to 3,300 pigs per year)	Average farm size for Lethbridge and Alberta is similar to farm size assumed in Foster (1994); therefore we expect costs are comparable.
		Turkey	$0.17	5,000 birds per year	Average farm size for Lethbridge and Alberta is similar to the farm size assumed in the USDA (2003) study; therefore we expect costs are comparable.
		Broiler	$0.05	250,000 birds per year	The size of a broiler farm in Lethbridge is similar to that used in the USDA (2003) study. However, the average size of a broiler farm in Alberta is much smaller (20%) than that assumed in the study; therefore we expect that costs for Alberta are underestimated.
Dust reduction for roadways	Bitumen	Beef cattle	$0.10	17,500 head per year	Average farm size for Lethbridge and Alberta is similar to farm size assumed in the studies by FCM (2005) and AT (2008); therefore we expect costs are comparable.
	Calcium chloride	Beef cattle	$0.1623		
Dust reduction for feedlots	Sprinkler	Beef cattle	$ 1.44	17,500 head per year	The expected size of a typical feedlot in Lethbridge and in Alberta is somewhat smaller than that assumed in Amosson et al. (2006). Since there are economies of scale, we expect costs to be underestimated for Lethbridge and Alberta.
	Water truck	Beef cattle	$ 1.39		

emphysema (Donham 2000). Studies of the impacts of chronic exposure to H_2S at low levels on livestock were not found.

Particulate matter

PM refers to solid or liquid particles of different size fractions. Two size fractions with potential health effects include $PM_{2.5}$ and PM_{10}. $PM_{2.5}$ refers to particles with an equivalent aerodynamic diameter of 2.5 microns (μm) or less while PM_{10} refers to dust particles with an equivalent aerodynamic diameter of 10 μm or less (USNRC 2002).

$PM_{2.5}$ can affect human and animal respiratory health (Muller and Mendelssohn 2007; Adamowicz et al. 2004). Human health effects associated with $PM_{2.5}$ include greater mortality risk, chronic bronchitis, increased asthma symptoms with a corresponding increase in restricted activity days, and increased acute respiratory symptoms resulting in emergency room visits, respiratory hospital admissions, and cardiac hospital admissions (Chestnut et al. 1999). Non-health impacts of $PM_{2.5}$ include reduced visibility caused by light scattering and absorption by particulates in this size range.

PM_{10} is the size fraction of airborne particulates that are small enough to be inhaled into the lungs. According to Chestnut et al. (1999), PM_{10} was the measure upon which most ambient air quality standards for PM were based in the U.S. and Canada. PM_{10} is associated with chronic bronchitis, and cardiac hospital admissions and mortality. Non-health environmental impacts of PM include damages from dirt, erosion, corrosion, blistering, and discoloration of paint on exposed surfaces, reduction of tensile strength of fabrics, and reduced visibility (Chestnut et al. 1999).

Ammonia

No information was found on the direct health effects of NH_3. Although NH_3 is a precursor to $PM_{2.5}$, PM in this size range is not entirely (100%) composed of particles formed via the reaction of NH_3 in the atmosphere but also includes particles formed by the reaction of other chemical compounds in the atmosphere and the physical breakdown of coarse solid particles into fine particles on the ground CASA (2003).

Volatile organic compounds

No information was found on the direct effects of VOCs on human health. VOCs interact with oxides of nitrogen (NOx) in the troposphere in the presence of heat and sunlight to form ozone (O_3), which causes damage to human health and the environment (Muller and Mendelssohn 2007; Adamowicz et al. 2004; CASA 2003). Although the proportion of O_3 in the atmosphere can provide an indication of the proportion of VOCs that was present in the atmosphere prior to the formation of O_3, it does not account for the percentage of VOCs in the atmosphere that has not reacted with NOx to form O_3.

7.4.1 Approach for assessing health benefits from emission reduction

Reduced air emissions lead to improvements in health status as measured by reduced mortality and morbidity. Two approaches can be used to value the economic impact of changes in health status. The cost of illness (CI) approach measures the value of goods and services for which payment was made for treatment and rehabilitation due to illness or injury (including hospital, drug, and physician costs) as well as lost productivity from mortality and short- and long-term morbidity. The CI approach is incomplete, however, in that it does not reflect the cost to individuals from being made worse off because they bear increased health risk. The value of a statistical life (VSL) approach measures the value of an individual's change in wellbeing based on the person's willingness to pay to reduce or avoid health risks. VSL can be based on willingness to pay to avoid health risk, and can be estimated by observing tradeoffs individuals make, for example between wages and occupational risk, or by directly eliciting an individual's willingness to pay to avoid risk through survey approaches. Collection of primary data for Alberta on the health benefits associated with employing MMs to reduce emissions was beyond the scope of this study. Instead we used CI and VSL values from the literature to assess potential benefits. Information on physical emission reduction relative to each MM was combined with the potential emission reduction value in order to derive total benefit values for each MM.

A review of candidate studies for evaluating health benefits of MMs was conducted by searching the environmental valuation reference inventory database (EC 2006) as well as several other databases of peer reviewed studies. Additional studies were located by browsing bibliographies. Over 90 studies were identified. The validity of transferring values from the literature depended on how well the original study was conducted and how well the study assumptions matched the context of Alberta. Nonetheless, even simple approaches were used to provide a rough estimate of potential environmental benefits. The criteria used to assign reliability measures to studies included: whether the studies were based on adequate data and correct empirical techniques; whether the emissions and changes in emissions valued by the study were similar to the expected changes using MMs in Alberta; and whether the study included socio-economic and demographic characteristics of respondents as explanatory variables. Studies that were peer reviewed were assumed to have high reliability. Similarly, indicators of the study relevance included: whether the study region had an agricultural setting similar to Alberta's (with preference for the Plains, the Mid-West, and the West); whether the socio-economic characteristics were similar; and whether the study evaluated comparable changes in emission levels. The criteria used to evaluate the benefit studies are outlined in Table 7.12.

After reviewing the 90 studies, we selected a final subset of five studies that were used to assess potential benefits from emissions reductions. In the following sections, we briefly describe the main characteristics of the studies and the monetary values that were used to calculate net benefits. Table 7.13 summarizes the range of potential benefit values per person (reported as either lower and upper bounds or averages across studies) for reducing emissions by one unit for each emission. The table also outlines the various assumptions associated with the primary study, as well as comments about our confidence in the benefit numbers. All values are reported equivalent to 2008 CDN$ per person per year.

Table 7.12 Criteria for evaluation of human health benefits studies

Criteria for evaluation	Indicators
Validity	• Study is peer reviewed • Study includes socio-economic and other demographic variables
Relevance	• Similar agricultural setting (preference for Plains, West or Mid-West) • Similar socio-economic and demographic characteristics • Comparable baseline level of emissions • Comparable changes in emission levels

7.4.1.1 Odour

The benefit of reducing livestock odour was found in the results of a survey on consumer willingness to pay (WTP) to consume pork produced on a livestock operation that utilized management mechanisms (e.g. shelterbelts) to minimize the downwind impact of odour (Tyndall 2006). Tyndall did not specify the percentage or proportion of odour reduction associated with the WTP. Because of this we assumed a flat benefit for all levels of odour reduction. According to Tyndall, consumers were willing to pay $0.35 per kg of pork. Multiplied by a mean annual per capita pork consumption in Canada of 25 kg (SC 2007), we estimated the benefit value of mitigating odour from a CFO at roughly $9.00 per person per year.

7.4.1.2 Hydrogen sulphide

Communities that are not located in the vicinity of CFOs may be exposed to relatively low 1-h average concentrations (0.001 ppm or less) of H_2S (AENV 2007).[20] Legator et al. (2001) is one of the few studies that evaluated the health effects associated with the release of H_2S from industrial sites in close proximity to two exposed populations (communities). Legator et al. reported that periodic H_2S hourly average concentrations ranging between 0.2 ppm and 0.5 ppm released from one of the industrial sites were reported in the years (unspecified) prior to their study. At the other industrial site, an air model estimated H_2S concentrations at a distance of 1.6 km from the site. Concentrations peaked between 0.3 ppm and 0.5 ppm over an 8-h period; peaked between 0.1 ppm and 0.2 ppm over a 24-h period; and averaged between 0.007 ppm and 0.027 ppm over a year.

The study by Legator et al. (2001) presented the benefits of reducing H_2S concentration by reporting the probability of reducing 12 human health symptoms. They compared the occurrence of these symptoms in rural communities in Texas and Hawaii and in reference communities with no known exposure to H_2S in those states. For the purposes of this study, we

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[20] Note the "knockdown" effects associated with high levels of H_2S emissions are omitted in this study because the effects are related to indoor air quality hazards which were not in the scope of this study.

Table 7.13 Per person benefits of emissions reductions

Author	Emission	Abatement level	Community exposure levels reported in study	Location	Community exposure levels for Alberta	Valuation method	Annual benefits per person[a] (2008 CDN$)	Confidence
Tyndall 2006	Odour	Not reported	Not reported	Iowa, Washington, N. Carolina	2-286 OU m^{-3}[b]	VSL	Avg $ 9.00	The study does not report community exposure levels, demographic, socio-economic data, or industry level features that might confound the community exposure levels. We attribute a low level of confidence to the study.
Chestnut et al. 1999	$PM_{2.5}$	1 μg m^{-3}	18-23 μg m^{-3}	U.S. and Canada	4-15 μg m^{-3}[c]	VSL	L $ 27.74[d] H $423.73[d]	The range of community exposure levels reported in the study is higher than the range of community exposure levels relative to Alberta. The study does not distinguish between rural/urban differences. We attribute a medium level of confidence to the study.
Chestnut et al. 1999	PM_{10}	1 μgm^{-3}	25-40 μg m^{-3}	U.S. and Canada	21-31 μg m^{-3}[c]	VSL	L $ 16.39[d] H $259.79[d]	The range of community exposure levels reported in the study is similar to the range of community exposure levels relative to Alberta. The study does not distinguish between rural/urban differences. We attribute a medium level of confidence to the study.

[a] Equivalent to WTP.

[b] Data obtained from measurements obtained at a distance of approximately 720 m from a swine CFO in central Alberta in 2003 (Feddes 2006).

[c] Averaged ambient air concentrations in major urban centres in Alberta between 2008 and 2010 obtained from CASA data warehouse (CASA 2011).

[d] Annual benefits per person per unit reduction in emissions.

considered only cardiovascular and respiratory disease symptoms among the 12 health symptoms. We multiplied the change in the probability of being admitted to hospital due to these symptoms by the average annual rate of such hospital admissions for the Chinook Health Region in Alberta, a region with several CFOs.[21] The willingness to pay to reduce hospital admissions related to cardiovascular and respiratory disease symptoms was obtained from Chestnut et al. (1999). However, we determined that the results of Legator et al. (2001) could not be applied to this study since the peak hourly ambient air concentrations of H_2S (0.5 ppm) reported by Legator et al. (2001) were an order of magnitude greater than peak hourly concentrations (0.003 ppm to 0.042 ppm) measured in urban centres in Alberta between 2000 and 2010 (CASA 2011). Consequently, no further analysis was undertaken on H_2S.

7.4.1.3 Particulate matter

Literature on the benefits of emission abatement for PM was compiled for the Canadian air quality valuation model - AQVM (Chestnut et al. 1999), and results from the AQVM analysis were used to value reductions in $PM_{2.5}$ and PM_{10}[22]. The AQVM was constructed using concentration-response functions and VSL values from studies across North America. The results published by Chestnut et al. (1999) ranked 'high' in terms of validity because studies included in the model were selected to minimize bias, reduce potential confounding effects, and be robust to alternative functional form. Values that could be converted to a common emissions metric (e.g. parts per billion) were selected. Conversely, the results ranked 'medium' in terms of relevance to Alberta since they were compiled from literature from across North America, rather than literature specific to rural Alberta.

Chestnut et al. (1999) provided values for 'low', 'medium' and 'high' dose-response scenarios, whereby each scenario represented a change in mortality and morbidity across a range of illness categories resulting from an increase in emission levels by one unit. Chestnut et al. also provided 'low', 'medium', and 'high' values for CI, i.e. to value changes in morbidity, and VSL, i.e. to value changes in mortality, for each disease. We used these numbers in order to generate 'low' and 'high' value scenarios associated with changes in emissions by virtue of applying MMs. In particular, we multiplied the low probability of the response with low value (CI and VSL) estimates, and aggregated across all outcomes and diseases in order to generate the 'low' value scenario per unit of emission reduction. We used a similar method to calculate a 'high'

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[21] The average annual rate of admissions for the Chinook Health Region was estimated assuming that the provincial hospital discharge rates reported by the PHAC's Chronic Disease Infobase (http://www.phac-aspc.gc.ca/cd-mc/facts_figures-faits_chiffres-eng.php) and assuming that they follow the same variation by health region as the mortality from these causes as reported by AHW (2007).

[22] The AQVM can be run to find the monetary value of health benefits of reducing air emissions within Canada or North America. The AQVM consists of two components. The first component uses concentration response functions to show the improvement in health outcomes (mortality and morbidity) when air emissions are reduced by a given level. The second component shows the monetary value individuals are willing to pay for improved health outcomes.

value scenario for each unit of emission reduction. The final low and high monetary values (per person per year) of reducing one unit (μg m^{-3}) of $PM_{2.5}$ and PM_{10} are provided in Table 7.13.

However, these values should be applied with caution. First, Chestnut et al. (1999) did not distinguish between rural and urban differences, which affected baseline air quality concentrations (and concentration responses) as well as income and other socio-economic characteristics that confounded the valuation results. As shown in Table 7.13, the range of community-level $PM_{2.5}$ concentrations (18 μg m^{-3} to 23 μg m^{-3}) cited by Chestnut et al. (1999) was approximately 2 to 3 times higher than the mean 1-h average concentration (8 μg m^{-3}) measured in urban centres across Alberta between 2008 and 2010 (CASA 2011). Conversely, in comparison to the range of community-level PM_{10} concentrations (25 μg m^{-3} to 40 μg m^{-3}) cited in the study by Chestnut et al. (1999), the mean hourly PM_{10} concentration in urban centres in Alberta between 2008 and 2010 was approximately 24 μg m^{-3} (CASA 2011).

7.5 Potential Net Benefits by Management Mechanism

In this section we use the information developed in Sections 7.3 and 7.4 to assess potential net benefits per unit of livestock for each of the MMs, and then to rank the MMs accordingly. For the purposes of this report the net benefit of a particular MM is defined as the difference between per unit costs and the value per unit of livestock for benefits derived by reducing emissions. Starting from presumed baseline concentrations in the community we adjusted for the abatement effectiveness of each MM and valued the reduction in emissions on the monetary value of health benefit per unit of abatement using both low and high values. This gave us a total benefit for each MM. The average benefit of each MM per unit of livestock was obtained from the sum of benefits over all emissions reductions associated with the MM divided by the number of livestock units for which the particular MM applies. Average costs per livestock unit for each MM were then subtracted to arrive at net benefits.

Equation 7.1 captures the main elements of these procedures:

$$\frac{NB_{MM}}{H_{MM}} = \frac{\sum_{i=1}^{k}\left(V_i ER_i POP_i\right)}{H_{MM}} - AC_{MM} \qquad (7.1)$$

where

$\frac{NB_{MM}}{H_{MM}}$ = total net benefits per head of livestock associated with applying the MM.

V_i = average value per person per unit of reduction in emission *i* (see Table 7.13 above)

POP_i = total population affected by reduction of emission *i* due to the application of the MM (see Tables 7.17 to 7.19 below)

ER_i = mean reduction in emission i following application of the MM (see Table 7.15 below)

H_{MM} = total number of livestock to which the MM applies (see Table 7.16 below)

AC_{MM} = average cost per head of livestock to which the MM applies (see Table 7.11 above)

k = total number of emissions of interest reduced by a given MM.

The first term in Eq. 7.1,

$$\frac{\sum_{i=1}^{k}\left(V_i ER_i POP_i\right)}{H_{MM}}$$

represents the sum of the average benefit associated with reductions in each emission of interest for a given MM per head of livestock.

The methods used to generate average costs by MM as well as the value per person per unit reduction in emissions (V_i) were developed in the previous Sections 7.3 and 7.4, respectively. In the remainder of this section, we present the assumptions and transformations required to identify the rest of the variables in Equation 7.1 in order to calculate net benefits for each MM per head of livestock.

7.5.1 Emission reduction by MM

Emission reduction is the difference between the level of emission from an emission source and the level of emission from that source after a specific MM has been implemented. The percentage emission reductions of various emissions of interest associated with permeable covers, manure composting, shelterbelts, and dust palliatives are presented in Table 7.14 below.

Table 7.14 shows the values we used for the upper and lower bounds of effectiveness (reported in percent) of MMs in terms of emissions reductions based on values from the literature. The percentage amounts are applied to background levels in order to come up with unit value changes in emissions for each MM. Some MMs, such as shelterbelts, reduce several emissions. To calculate total health benefits per person, we sum all emissions reductions relevant for the MM.

7.5.2 Number of livestock and persons affected

To convert the benefits per person as a result of reductions in emissions to total health benefits *per head of livestock* it was necessary to identify the livestock population (H_{MM}) in Alberta to which a specific MM could be applied, as well as the human population (POP_i) affected by the MM. To arrive at the total aggregated monetary benefits across the population in Alberta, we

Table 7.14 Potential emission reduction associated with various MMs

Management Mechanism	**Emission Reduction (%)**									
	Odour		**H_2S**		**NH_3**		**PM**		**VOCs**	
	Low	High	Low	High	Low	High	Low	High	Low	High
Permeable covers										
Straw	40[a]	90[a]	82[b]	98[b]	59[c]	100[c]	-	-	-	-
Geotextile	50[d]	80[d]	-	-	44[e]	86[f]	-	-	-	-
Expanded Clay	69[c]	89[c]	64[b]	84[b]	64[c]	95[g,h]	-	-	-	-
Manure composting										
Beef cattle	-	-	-	-	-	-	-	-	-	-
Poultry	-	-	-	-	25[i]	35[i]	-	-	-	-
Windbreaks										
Shelterbelts	26[j]	51[k]	66[l]	87[l]	15[k]	100[m,n]	22[k]	76[k]	-	-
Dust suppressants										
Unpaved roads	-	-	-	-	-	-	10[o]	92[p]	-	-
Feedlot pens and alleys	-	-	-	-	-	-	10[o]	88[p,q]	-	-

[a] Nicolai et al. (2005)
[b] Clanton et al. (1999)
[c] Guarino et al. (2006)
[d] Bicudo et al. (2004)
[e] Bicudo et al. (2002)
[f] Clanton et al. (2001)
[g] Sommer et al. (1993)
[h] Bundy et al. (1997)
[i] Keener et al. (2002)
[j] Malone et al. (2008)
[k] Malone et al. (2006)
[l] Nicolai et al. (2006)
[m] Patterson et al. (2008)
[n] Adrizal et al. (2008)
[o] WRAP (2006)
[p] Razote et al. (2005)
[q] Razote et al. (2006)

estimated the neighbourhood population that would actually be affected by reductions in emissions[23]. An analysis of populations affected by CFO emissions was beyond the scope of this study. Based on the *Agricultural Operations Practices Act and Regulation*, NRCB is required to notify each municipality of all CFO applications within its boundaries. NRCB is also required to notify all households within pre-determined distances of CFO applicants of such applications. The number of households notified about a given application is determined based on criteria outlined in the regulations (B. Hazelton, Inspector, Natural Resources Conservation Board, Red Deer, AB, pers. comm.).

Since the number of households that could potentially be impacted by a CFO would vary depending on the type and nature of the CFO, we analyzed the sensitivity of 10, 40 and 100 households being affected per CFO in order to estimate the net benefit per MM, on the assumption that an average of three people lived in a typical household in Alberta (SC 2006a). Thus, the net benefits were estimated relative to the sensitivities of 30, 120 and 300 people that would potentially be affected directly per CFO as shown in Table 7.15. Table 7.15 also shows how each MM applies to each livestock category, as well as the impacts of the MMs in terms of number of animals affected.

7.5.3 Calculating average benefits per head of livestock per MM [24]

Net benefits per livestock unit per type of emission for each of the MMs were derived by applying Eq. 7.1. The high and low net benefits with respect to various MMs and livestock categories are presented in Tables 7.16 to 7.18 and summarized in Table 7.19.

For odour, the term $V_{odour}ER_{odour}POP_{odour}$ in Eq. 7.1, i.e. the average benefit to the affected population, was obtained by multiplying the annual benefit per person (Table 7.13) by the emission reduction associated with the MM (Table 7.14) and the estimated population potentially affected by emissions from the respective CFOs (Table 7.15). In other words, the annual benefit per person was influenced by the odour emission reduction efficiency of the given MM with a maximum benefit derived when the reduction efficiency was 100%.

On the other hand, the average benefit to the affected population, $V_{PM_{2.5}}ER_{PM_{2.5}}POP_{PM_{2.5}}$ and $V_{PM_{10}}ER_{PM_{10}}POP_{PM_{10}}$ relative to reductions of $PM_{2.5}$ and PM_{10} emissions, respectively, were derived by multiplying the average benefit to the affected population by an additional parameter, the community exposure level for Alberta (Table 7.13). The difference between the latter calculation and the former (for odour) is because the annual benefits per person (V_i) for $PM_{2.5}$ and PM_{10} were derived by Chestnut et al. (1999) per unit reduction (1 $\mu g\ m^{-3}$) in emissions. Thus, the average benefits to the affected populations were derived based on the assumption

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[23] A decision was made to only assess the impacts to the public of the emission reductions, and not benefits to workers within the CFO. Note that individuals working on the farm are compensated for adverse health impacts already by the wages or wage premiums paid to work in the facility.

[24] In the following calculations we also assume that there is only one MM in effect at a time, and that the MM is adopted by all CFOs in the province to which it applies.

Table 7.15 Number of livestock and people affected by select MMs

MM	Feedlots		Dairy		Swine		Poultry		Total people[a]	Reference
	Animals	# CFOs	Animals	# CFOs	Animals	# CFOs	Animals	# CFOs		
Frequent manure removal	4,450,970	458	78,875	800					37,740 150,960 377,400	Dairy - (Vogt and Kastens 2005); Feedlots - (T. Wallace, pers. comm.; S. Amosson, pers. comm.)
Manure injection			78,875	800	4,637,671	1,200			60,000 240,000 600,000	Dairy - (B. Hazelton, pers. comm.; J. McKinley, pers. comm.); Swine - (Muhlbauer et al. 2008)
Manure incorporation	4,450,970	458	78,875	800	4,637,671	1,200	90,899,474	5,421	236,370 945,480 2,363,700	Swine - (Fleming et al. 1998); Beef or dairy cattle and poultry - (B. Hazelton, pers. comm.; J. McKinley, pers. comm.)
Permeable covers					4,637,671	1,200			36,000 144,000 360,000	Swine - (CPC 2005)
Shelterbelts					4,637,671	1,200			36,000 144,000 360,000	Swine - (Tyndall and Grala 2008)
Manure composting	4,450,970	458					90,899,474	5,421	176,370 705,480 1763,700	Feedlots - (Smith et al. 2006); Poultry - (van Kooten et al. 1998)
Mortality composting	4,450,970	458	78,875	800	4,637,671	1,200	90,899,474	5,421	236,370 945,480 2363,700	Beef or dairy cattle - (V. Nelson, pers. comm.); Poultry - (USDA 2003); Swine - (Foster 1994)
Dust reduction roads	4,450,970	458							13,740 54,960 137,400	Beef cattle - (B. West, pers. comm.);
Dust reduction feedlots	4,450,970	458							13,740 54,960 137,400	Beef cattle - (Amosson et al. (2006, 2008)

[a] We estimated total people affected under three sensitivities of 30, 120 and 300 people per CFO multiplied by the number of CFOs per livestock type.

Table 7.16 Annual net benefits (CDN$) per animal per MM when 30 people are potentially affected by emissions from a CFO

Management Mechanism	Livestock Type	Benefit ($/animal/year)								Average Cost per Unit of Livestock ($/animal/year)	Net Benefit	
		Odour		$PM_{2.5}$		PM_{10}		Sum				
		Low	High	Low	High	Low	High	Low	High		Low	High
Permeable Covers												
Straw	Swine	0.03	0.06					0.03	0.06	0.26	-0.23	-0.20
Geotextiles	Swine	0.03	0.06					0.03	0.06	1.21	-1.18	-1.15
Expanded clay	Swine	0.05	0.06					0.05	0.06	2.77	-2.72	-2.71
Windbreaks												
Shelterbelts	Swine	0.02	0.04	0.19	37.45	0.58	47.63	0.79	85.12	0.07	0.72	85.05
Composting												
Manure	Beef cattle									27.64		
Mortality	Swine									12.5		
	Turkeys									0.17		
	Broilers									0.05		
Dust Suppressants												
Unpaved roads-bitumen	Beef cattle			0.03	18.05	0.10	22.95	0.14	41.00	0.20	-0.06	40.80
Unpaved roads-calcium chloride	Beef cattle			0.03	18.05	0.10	22.95	0.14	41.00	0.45	-0.31	40.55
Feedlots-sprinklers	Beef cattle			0.03	17.27	0.10	21.95	0.14	39.21	1.44	-1.30	37.77
Feedlots-water trucks	Beef cattle			0.03	17.27	0.10	21.95	0.14	39.21	1.39	-1.25	37.82
Manure Removal												
Daily	Dairy									-20.00		
Manure Application												
Injection	Swine									12.24		
Immediate incorporation	Swine									1.86		

Table 7.17 Annual net benefits (CDN$) per animal per MM when 120 people are potentially affected by emissions from a CFO

Management Mechanism	Livestock Type	Benefit ($/animal/year)								Average Cost per Unit of Livestock ($/animal/year)	Net Benefit	
		Odour		$PM_{2.5}$		PM_{10}		Sum				
		Low	High	Low	High	Low	High	Low	High		Low	High
Permeable Covers												
Straw	Swine	0.11	0.25					0.11	0.25	0.26	-0.15	-0.01
Geotextiles	Swine	0.14	0.22					0.14	0.22	1.21	-1.07	-0.99
Expanded clay	Swine	0.19	0.25					0.19	0.25	2.77	-2.58	-2.52
Windbreaks												
Shelterbelts	Swine	0.07	0.14	0.76	149.79	2.32	190.54	3.15	340.47	0.07	3.08	340.40
Composting												
Manure	Beef cattle									27.64		
Mortality	Swine									12.5		
	Turkeys									0.17		
	Broilers									0.05		
Dust Suppressants												
Unpaved roads-bitumen	Beef cattle			0.14	72.20	0.42	91.78	0.56	163.99	0.20	0.36	163.79
Unpaved roads-calcium chloride	Beef cattle			0.14	72.20	0.42	91.78	0.56	163.99	0.45	0.11	163.54
Feedlots-sprinklers	Beef cattle			0.14	69.06	0.42	87.79	0.56	156.86	1.44	-0.88	155.42
Feedlots-water trucks	Beef cattle			0.14	69.06	0.42	87.79	0.56	156.86	1.39	-0.83	155.47
Manure Removal												
Daily	Dairy									-20.00		
Manure Application												
Injection	Swine									12.24		
Immediate incorporation	Swine									1.86		

Table 7.18 Annual net benefits (CDN$) per animal per MM when 300 people are potentially affected by emissions from a CFO

Management Mechanism	Livestock Type	Benefit ($/animal/year)								Average Cost per Unit of Livestock ($/animal/year)	Net Benefit	
		Odour		$PM_{2.5}$		PM_{10}		Sum				
		Low	High	Low	High	Low	High	Low	High		Low	High
Permeable Covers												
Straw	Swine	0.28	0.63					0.28	0.63	0.26	0.02	0.37
Geotextiles	Swine	0.35	0.56					0.35	0.56	1.21	-0.86	-0.65
Expanded clay	Swine	0.48	0.62					0.48	0.62	2.77	-2.29	-2.15
Windbreaks												
Shelterbelts	Swine	0.18	0.36	1.89	374.47	5.80	476.34	7.88	851.17	0.07	7.81	851.10
Composting												
Manure	Beef cattle									27.64		
Mortality	Swine									12.5		
	Turkeys									0.17		
	Broilers									0.05		
Dust Suppressants												
Unpaved roads-bitumen	Beef cattle			0.34	180.51	1.05	229.46	1.39	409.97	0.20	1.19	409.77
Unpaved roads-calcium chloride	Beef cattle			0.34	180.51	1.05	229.46	1.39	409.97	0.45	0.94	409.52
Feedlots-sprinklers	Beef cattle			0.34	172.66	1.05	219.48	1.39	392.14	1.44	-0.05	390.70
Feedlots-water trucks	Beef cattle			0.34	172.66	1.05	219.48	1.39	392.14	1.39	0.00	390.75
Manure Removal												
Daily	Dairy									-20.00		
Manure Application												
Injection	Swine									12.24		
Immediate incorporation	Swine									1.86		

that community exposure levels would decrease by percentages equivalent to the emission reduction efficiencies of the respective MMs.

Tables 7.16, 7.17 and 7.18 show the net benefits for various MMs that correspond to low emission reduction efficiencies, low annual benefits per person and low community exposure levels in Alberta compared to high emission reduction efficiencies, high annual benefits per person and high community exposure levels in Alberta. Values under the low scenario represent a more conservative estimate of net benefits while values under the high scenario represent the estimated upper bound on net benefits.

Combining the low and high effectiveness scenarios with the three scenarios for "number of people affected" yielded six different scenarios for net benefits. Note that although these scenarios were derived from coefficients taken from the literature, they were considered hypothetical for the context of Alberta, and valuable for the purposes of ranking and prioritizing MMs for further evaluation. In Table 7.19, the lower bound for net benefit values was calculated by combining the low effectiveness and minimum people scenarios while the upper bound was calculated by combining the high effectiveness and maximum people scenarios. Net benefits were multiplied by the number of livestock on CFOs in the province to which specific MMs could be applied in order to calculate the potential net benefit in Alberta.

Table 7.19 Ranking of management mechanisms by net benefit

Management mechanism	Livestock type	Potential net benefits CDN$2008 per head of livestock		Potential net benefit CDN$2008 for province	
		Minimum possible	Maximum possible	Minimum possible	Maximum possible
Shelterbelts	Swine	0.72	851.15	3,328,045	3,947,118,180
Dust reduction: Roadway (bitumen)	Beef cattle	-0.06	409.77	-271,574	1,823,862,251
Dust reduction: Roadway (calcium chloride)	Beef cattle	-0.31	409.52	-1,384,316	1,822,749,508
Dust reduction: Feedlots (water sprinkler)	Beef cattle	-1.30	390.70	-5,790,777	1,739,005,985
Dust reduction: Feedlots (water truck)	Beef cattle	-1.25	390.75	-5,568,228	1,739,228,534
Permeable covers (straw)	Swine	-0.23	0.37	-1,076,195	1,710,205
Permeable covers (geotextiles)	Swine	-1.18	-0.65	-5,449,582	-3,019,582
Permeable covers (expanded clay)	Swine	-2.72	-2.15	-12,622,790	-9,962,750

Based on available information as indicated in Tables 7.13, 7.14 and 7.15, shelterbelts yielded the highest net benefits for Alberta and the least cost of implementation. Net benefits ranged between $0.72 per pig per year and $851.15 per pig per year and aggregated over the entire swine industry in Alberta ranged from about $3.3 million per year to about $4 billion per year. In addition, shelterbelts also offer a wide range of other co-benefits that would improve the net benefits of this MM such as, providing a source of carbon offsets which could be leveraged to reduce adoption costs, help with erosion control, improve aesthetics of the rural community, provide habitats for wildlife, and facilitate flood control.

Dust reduction for roadways and feedlots, applicable to the beef cattle feedlot industry, showed the second and third highest net benefits, respectively. The highest net benefit associated with dust reduction from roads was slightly less than half of that associated with shelterbelts. Net benefits for roadway dust reduction ranged between -$0.06 and $409.77; net benefits for feedlot dust reduction ranged between -$1.25 and $390.75. Costs for reducing dust emissions ranged between $0.20 and $0.45 for roadways, and between $1.39 and $1.44 for feedlots, depending on the particulars of the applied mechanisms. Using suppressants to reduce dust emissions also has co-benefits such as decreasing road maintenance costs (Bolander and Yamada 1999) and reducing heat stress in the animals (Bonaficio 2009).

Straw permeable covers used to cover swine liquid manure in outdoor manure storage facilities showed the fourth highest net benefits. The cost of utilizing a straw cover was estimated at about $0.26 per pig per year while the net benefits ranged between -$0.23 and $0.37 per pig per year with the possibility of a net annual cost to the swine industry of about $1.1 million or a net annual benefit of $1.7 million. Utilizing geotextile or expanded clay permeable covers was estimated to result in net costs of up to $12.6 million to the swine industry annually.

7.5.4 Conclusions

Eight management mechanisms were evaluated in terms of the economic costs and benefits for air emission reductions. In the end we compared six selected MMs because we did not have sufficient information on two of them, namely bottom loading and moisture management.

We reviewed the potential range of on-farm or private costs of implementing alternative MMs and public health benefits that these MMs were estimated to provide in terms of reducing the related emissions. However, due to lack of information on emission reduction potential, we were not able to evaluate all the six remaining MMs. In the end we were only able to rank three MMs namely, shelterbelts, permeable covers and dust reduction from unpaved roads and beef cattle feedlots. While we found costs of implementing manure and mortality composting, manure application mechanisms and frequent manure removal, we did not have sufficient information to estimate the benefits of the latter three MMs.

Shelterbelts ranked highest in terms of net benefits primarily because of their impact on a suite of benefits and their application to the swine industry, which has a large number of animals. Shelterbelts may also be deployed around feedlots and other types of CFOs. It is important to note that the emission reduction efficiencies used to determine the net benefits associated with shelterbelts lacked confidence. Often the efficiencies reported were either derived from individual studies or studies that signified a strong need for further research. On the other hand, shelterbelts provide several co-benefits not valued in this report, including benefits from carbon sequestration which could be leveraged to reduce adoption costs for producers.

Dust reduction from unpaved roads ranked second highest with the value of the net benefits dependent on the type of dust suppressant used. This MM was found to be effective at a modest cost. Although we only evaluated this MM in terms of its applicability to feedlots, dust reduction for roadways could provide similar benefits around other types of CFOs. Dust reduction from beef cattle feedlots ranked third. Note that the emission reductions reported in the literature for unpaved road and beef cattle feedlot dust were with respect to PM_{10} emissions.

Straw-based permeable covers used to cover liquid manure surfaces ranked fourth highest in terms of net benefits. Of the three types of permeable covers considered, the estimated cost of utilizing straw covers was least and most likely adaptable to Alberta. Because permeable covers are typically used over liquid manure, this MM was assumed to be most suitable for the swine industry. The cost of permeable covers was reported to be lower when deployed in combination with shelterbelts or bottom loading structures that could help extend the durability of this type of cover.

The results of this review suggest that targeting MMs applicable to the swine industry will yield the highest overall net benefits. Interventions in the beef cattle industry will also yield positive net benefits for some MMs (e.g. dust reduction) when upper bound benefit values are assumed. It is important to note that our estimates did not factor in additional benefits (or co-benefits) to reductions in emissions. It is unlikely that the consideration of co-benefits will change the ranking of shelterbelts; rather, it will likely improve the benefit:cost ratio for more marginal MMs.

7.5.5 Recommendations

In terms of information gaps, the report identified several which can be prioritized. First, the lack of information on the impacts of MMs meant that the evaluation of some MMs was conducted with a low degree of confidence or could not be conducted at all. More information is required in order to evaluate bottom loading and moisture management mechanisms with respect to costs. Moisture management MMs could not be evaluated due to the lack of information on their effectiveness in reducing various emissions. In terms of health impacts, more information on the effects of chronic exposure to low levels of H_2S is required in order to understand the value of associated emission reductions. More information is also required on the value of health benefits from reducing bioaerosol emissions.

The studies that were used to evaluate potential costs and benefits contained several uncertainties. First, cost studies for frequent manure removal and dust palliatives were not available for livestock production practiced in the prairies. While the interviewees agreed frequent manure removal in a dairy CFO would offer savings, they suggested that such an MM would be too expensive for beef cattle feedlots to implement. However, neither the interviewees nor the literature offered any costs for frequent manure removal from beef cattle feedlots. Although the costs shown related to the size of CFO, several other variables influence costs. For example, the type of swine barns and their shape affect the costs of shelterbelts, and manure volume stored affects the cost of manure application. Some studies did not provide a complete picture of variables that influence costs making them less comparable with other MM costs. For example, while the literature on poultry composting included the cost of water supply, the literature on water sprinklers for dust reduction ignored the cost associated with water supply.

Values for health benefits were based on assumptions about the emission reduction potentials of the various MMs with more information available about some MMs than others. In addition, benefits derived from studies conducted under different circumstances and settings from Alberta such as community exposure levels, expected changes in emissions, other confounding sources of emissions, and differences in demographic and socio-economic variables, were used to calculate the net benefits assumed to apply to CFOs and the value placed on health in Alberta. One of the principal studies from which "annual benefits per person" was assumed, i.e. Chestnut et al. (1999), was selected due to its rigour. Furthermore, the benefits per person were reported per unit of emission reduction, thereby reducing the number of assumptions made in order to utilize values from the study. However, Chestnut et al. (1999) acknowledged the fact that the many assumptions upon which their study was based created uncertainty with their model, including the assumption that changes in emissions would have a linear impact on health. Finally the health impacts relative to reductions in emissions were implied (from regression values) and were not measured directly from medically reported casualties.

7.6 References

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Appendix A. Summary of Cost Studies

Table A1. Features of cost studies

Study	Cost drivers included	Location of study	Type of livestock	Sub type or control	Animals marketed per year	Cost 2008CDN$/ head/year	Reason study was selected
Frequent manure removal							
Vogt and Kastens. 2005. A study of the financial impact of dairy manure storage systems in Northeast Kansas. *Review of Agricultural Economics* 27(3): 336-49.	Compare costs of a daily haul system with a less frequent hauling system. Savings in storage and manure spreading are considered	U.S. Mid-West	Dairy	Storage cost is included as a cost driver	60	-$82	The most recent literature available on daily manure removal
					250	-$46	
				Storage cost is excluded as a cost driver	60	-$57	
					250	-$20	
Manure application							
Smith et al. 2006. Effects of market and regulatory changes on livestock manure management in southern Alberta. *Can. J. Agric. Econ.* 54: 199-213.	Costs of loading, hauling, application, and nutrient offset benefits for several types of livestock, for solid and slurry manure	Lethbridge, Alberta	Beef - solid manure		Not provided	$3.30	Study is from Lethbridge and considers the differences in cost for two levels of solid content (solid and slurry), which have an impact on the level of air emissions
			Swine farrow to finish - slurry manure			$3.67	
			Broiler - solid manure			-$0.61	
			Layer - solid			$0.03	
			Turkey - solid manure			$0.16	
Iowa State University. 2008. *Mitigating Air Emissions from Animal Feeding Operations Conference Proceedings*. Des Moines, Iowa. May 19-21.	Equipment wear and tear, loading, hauling, and application costs compared for injection versus broadcasting	Iowa	Swine	Manure injection	Not provided	3,000 gallons/ac $ 0.09	Considers manure injection
						5,500 gallons/ac $ 0.08	
						12,000 gallons/ac $0.07	
Fleming et al. 1998. Resource or waste? The economics of swine manure storage and management. *Review of Agricultural Economics*, 20(1): 96-113.	Application, transport, hauling costs and nutrient offset benefits for swine manure incorporation	Iowa	Swine	Manure incorporation	3,300	-$1.72 to 5.53	Focus on cost of manure incorporation; consideration of operation size
					9,900	$0.08 to 6.53	
					16,800	$1.31 to 7.23	

Study	Cost drivers included	Location of study	Type of livestock	Sub type or control	Animals marketed per year	Cost 2008CDN$/ head/year	Reason study was selected
Permeable covers							
CPC. 2005. Practices and technologies aimed at reducing environmental impacts from swine production: scientific and economic evaluation.	Operating costs including labour; fixed costs, amortized cost of the cover and machinery	Saskatchewan	Swine	Straw	10,000	$0.26	Climate and type of covers used are representative of Alberta
				Geotextile		$1.21	
				Expanded clay		$2.77	
Jacobsen. 2006. Reduce the nitrogen loss and maintain the income – the economics of manure handling. *Paper prepared for presentation at the 13th International Farm Management Congress*, Wageningen, Netherlands.	Fixed and operating costs, on-farm nutrient conservation benefits and benefits of reduced manure hauling costs due to dry manure	Denmark	Swine	Straw		-$0.03 to 0.04	This study included on-farm benefits as well as costs
Shelterbelts							
Tyndall and Grala. 2008. Financial feasibility of using shelterbelts for swine odor mitigation. **Agroforestry Systems.** Published online May 2008.	Cost of site preparation, establishment, and maintenance of shelterbelts around swine operations	Iowa	Swine		1,500	$0.08	Estimates cost per animal; compares costs against operation size; geographic agglomeration of CFOs similar to southern Alberta
					2,000	$0.11	
					2,500	$0.05	
					10,500	$0.03	
Composting							
Smith et al. 2006. Effects of market and regulatory changes on livestock manure management in southern Alberta. *Can. J. Agric. Econ.* 54: 199-213.	Provide operating and fixed costs and nutrient benefit of windrow composting	Lethbridge, Alberta	Beef or dairy cattle	Manure composting	Not provided	$27.74	Local study site; technology applicable in Alberta
Foster. 1994. Cost of swine mortality composting	Operating and fixed costs and nutrient benefit of composting dead swine	Missouri	Swine	Dead animal composting	100 to 150	$10 to $15	Use of enclosed composting technology; considers operation size

Study	Cost drivers included	Location of study	Type of livestock	Sub type or control	Animals marketed per year	Cost 2008CDN$/ head/year	Reason study was selected
USDA. 2003. Costs associated with development and implementation of nutrient management plans	Operating and fixed costs of composting dead poultry	North Carolina	Broiler	Dead animal composting	25,000	$0.05	Considers alternative technology (an enclosed method using a bin) and shows net cost against operation size; considers poultry
			Layer		50,000	$0.02	
			Turkey		5,000	$0.17	
Dust reduction for roadways							
Federation of Canadian Municipalities. 2005. Dust control for unpaved roads. www.infraguide.com	Includes operating costs, fixed costs, frequency of application and reduced road maintenance costs of calcium chloride.	Missoula, Montana	Beef cattle	Calcium chloride	Not provided	-$0.78 to 0.28	Calcium chloride is used around municipalities and feedlots in southern Alberta
T. Becker, Operations Manager, Alberta Transportation, Lethbridge, AB, pers. comm.	Provides operating costs and fixed costs for application of lignin sulphonate and bitumen on primary highways of southern Alberta. Estimates are dependent on frequency of application	Southern Alberta	Beef cattle	Lignin sulphonate		$0.39	Lignin sulphonate and bitumen are used around primary highways in Southern Alberta. These are actual application costs for southern Alberta
				Bitumen		$0.07	
Dust reduction for feedlots							
Amosson et al. 2006. Economic analysis of solid-set sprinklers to control dust in feedlots. *Selected paper for presentation at the Southern Agricultural Economics Association Annual Meetings.* Orlando, Florida.	Estimate operating and fixed costs of sprinklers. Operating costs include maintenance, energy, and repair; fixed costs include investment, interest and depreciation	Texas Panhandle	Beef cattle	Sprinkler	17,500	2.73	The technology was considered applicable to Alberta; the study was explicit on all cost drivers; the costs were valued against different operation sizes (and numbers of animals marketed
					20,000	2.39	
					22,500	2.12	
					52,500	1.97	
					60,000	1.72	
					67,500	1.54	
					87,500	1.86	
					100,000	1.63	

Study	Cost drivers included	Location of study	Type of livestock	Sub type or control	Animals marketed per year	Cost 2008CDN$/ head/year	Reason study was selected
					112,500	1.44	per year)
Amosson et al. 2008. Economic analysis of a water truck for feedyard dust suppression. *Selected paper for presentation at the Southern Agricultural Economics Association Annual Meetings*. Dallas, Texas.	Estimate operating and fixed cost of using water trucks to reduce feedlot dust. Operating costs include maintenance, insurance, fuel and labour costs. Fixed costs include investment, interest and depreciation.	Texas Panhandle	Beef cattle	Water truck	17,500	2.32	The technology was considered applicable to Alberta; the study was explicit on all cost drivers; the costs were valued against different operational sizes (and numbers of animals marketed per year)
					20,000	2.03	
					22,500	1.81	
					52,500	1.87	
					60,000	1.64	
					67,500	1.46	
					87,500	1.78	
					100,000	1.56	
					112,500	1.39	

Appendix B. Interview Questionnaires for Each MM

B.1 Frequent manure removal

Dear:

Thank you for agreeing to participate in the study!

This information sheet summarizes the main cost and benefit drivers for frequent manure removal that were found in the literature. The purpose of the interview is to identify whether the cost and benefit drivers we have identified are complete and to help us determine whether there are any additional considerations that are relevant for implementing frequent manure removal in Alberta.

Part I Identification of Cost Drivers

Frequent removal of manure from dairy barns and feedlots reduce emissions, odour and dust. This is particularly beneficial in reducing emissions from such facilities because manure is the main cause of emissions within them. This will improve livestock health. Frequent manure removal will also remove manure before it loses its nutrient content, which will improve its nutritive value when applied to fields. Based on the literature we summarise cost/benefit drivers involved with frequent manure removal.

Questions

1. **Table 1 broadly organises cost/benefit drivers we found to be common to frequent manure removal. Please rank the top three cost drivers? (1 being the most important cost driver)**

Table 1 Cost/benefit drivers

Cost/benefit drivers	Rank
Changes in investment, depreciation, amortization costs of manure scrapers	
Nutrient conservation benefits	
Reduction in crop returns due to adoption of forage systems	
Reduction in feed costs due to adoption of forage systems	
Reduction in peak labour demand costs	
Transportation costs	
Improved livestock health	
Other:…	
Other:…	

Part II Evaluation of Estimates of Costs from Literature Review

Based on a review of the literature and a suite of review criteria which included comprehensiveness of cost drivers and geographic location of the study we selected a few relevant studies for each mechanism which could be applied to provide benchmark cost estimates for the Alberta context. We selected one study for providing benchmark cost estimates for implementing dust reduction mechanisms for roads in Alberta. The main features are summarized in Table 2. We first considered that storage costs were a driver of costs/benefits. Second we decided to ignore or add back storage costs (at $37 per head) because CASA (2008) addresses removal of manure from the facility but not how it is handled after that.

Table 2. Features of study

Study	Cost drivers included	Location of study	Type of livestock	Number of dairy cattle	Cost 2008CDN$/head/year	Reason study was selected
Vogt et al. 2005. A study of the financial impact of dairy manure storage systems in Northeast Kansas. *Review of Agricultural Economics* 27(3): 336-49.	Compare costs of a daily haul system with a less frequent hauling system. Savings in storage and manure spreading (labour and fixed costs)	U.S. Mid-West	Dairy	Storage cost is included as a cost driver		The most recent literature available on daily manure removal
				60	$-82	
				250	$-46	
				Storage cost is excluded as a cost driver		
				60	$-57	
				250	$-20	

Questions

2. **Are there any additional factors which should be considered for transferring these cost estimates to Alberta or central and northern Alberta (due to differences in climate, agricultural practices, density of farms)?**
3. **Would the cost of frequent manure removal in Alberta (or central and northern Alberta) be much less, about the same, a lot more than indicated by the literature?**
4. **Are you aware of any relevant studies which would provide better benchmark cost estimates for Alberta?**
5. **Are you aware of any opportunities or barriers to adopting these practices in Alberta?**
6. **Do you have any other comments about frequent manure removal that are relevant to their application in Alberta?**

Thank you for your time!

B.2 Manure application

Dear:

Thank you for agreeing to participate in the study!

This information sheet summarizes the main cost and benefit drivers for manure application that were found in the literature. The purpose of the interview is to identify whether the cost and benefit drivers we have identified are complete and to help us determine whether there are any additional considerations that are relevant for implementing manure application in Alberta.

Part I Identification of Cost Drivers

Manure injection and manure incorporation soon after application are mechanisms that mitigate the release and transportation of emission from manure applied to land. The level of solid content in the applied manure also influences the level of emissions. The literature reviewed included cost and benefit drivers related to these two manure application methods as well as manure application under different levels of solid content.

Questions

1. **Based on your knowledge of manure application methods please rank (1 for best, 2 for worst) the application method based on cost, environmental performance, and convenience of use to or likelihood to be adopted by producers. Assume that the time frame for evaluating cost and performance is 10 years.**

Table 1 Ranking of manure application methods over cost, performance and ease of use

Manure application method	Cost (10 years)	Performance in emission abatement	Convenience/ adoptability
Injection			
Incorporation after broadcasting			

2. **Table 2 broadly organises cost/benefit drivers we found to be common to each of manure application method. For the application method which is most effective at reducing emissions are there any cost/benefit drivers that we are missing? Please rank the top three cost drivers for the most effective cover type (1 being the most important cost driver).**

Table 2 Cost/benefit drivers

Cost/benefit drivers	Rank
Manure loading	
Manure hauling	
Manure application	
Soil and manure testing	
Cost of extra land required to apply manure	
Nutrient offset benefits (substituting for inorganic fertiliser)	
Other:…	
Other:…	

Part II Evaluation of Estimates of Costs from Literature Review

Based on a review of the literature and a suite of review criteria which included comprehensiveness of cost drivers and geographic location of the study, we selected two or three relevant studies for each mechanism which could be applied to the Alberta context. Three studies were selected for providing benchmark cost estimates for implementing dust reduction mechanisms for roads in Alberta. The main features are summarized in Table 3. We estimated nutrient offset (benefit of substituting manure for inorganic fertiliser) by multiplying nutrient levels by $1/kg of nitrogen and $0.90/kg of phosphorus based on Alberta Agriculture 2006/2008 fertiliser prices and fertiliser application recommendations. We assumed a pig produces 16.8 L of manure per year to find manure injection cost per pig.

Questions

1. **Are there any additional factors which should be considered for transferring these cost estimates to Alberta or central and northern Alberta (due to differences in climate, agricultural practices, density of farms)?**
2. **Would the cost of injecting / incorporating manure in Alberta be much less, about the same, a lot more than indicated by the literature?**
3. **Are you aware of any relevant studies which would provide better benchmark cost estimates for Alberta?**
4. **Are there any extra comments about manure application reducing emissions you would add?**
5. **Are you aware of any opportunities or barriers to adopting these practices in Alberta?**
6. **Do you have any other comments about manure application that are relevant to their application in Alberta?**

Thank you for your time!

Table 3 Features of the study

Study	Cost drivers included	Location of study	Type of livestock	Sub type	Animals marketed per year	Cost 2008CDN$/head/ year	Reason study was selected
Smith, E., G. Card, and D. Young. 2006. "Effects of market and regulatory changes on livestock manure management in southern Alberta". *Can. J. of Agric. Econ.* 54: 199-213.	Costs of loading, hauling, application and nutrient offset benefits for several types of livestock, for solid and slurry manure	Lethbridge, Alberta	Beef - solid manure			$3.30	It is a study from Lethbridge and it reflects the differences in cost for two levels of solid content (solid and slurry) which have an impact on the level of air emissions
			Swine farrow to finish - slurry manure			$3.67	
			Broiler - solid manure			$-0.61	
			Layer - solid			$0.03	
			Turkey - solid manure			$0.16	
Iowa State University. 2008. *Mitigating Air Emissions from Animal Feeding Operations Conference Proceedings*. Des Moines, Iowa. May 19-21.	Equipment wear and tear and maintenance costs between injection with broadcasting (i.e. loading, hauling and application)	Iowa	Swine	Manure injection		3,000 gal/ac $ 0.09	It compared the cost of manure injection with broadcasting which have implications for manure emissions
						5,500 gal/ac $ 0.08	
						12,000 gal/ac $0.07	
Fleming, R.A., B.A. Babcock and E. Wang. 1998. Resource or waste? The economics of swine manure storage and management. *Review of Agricultural Economics*, 20(1): 96-113.	Application, transport, hauling costs and nutrient offset benefit for swine manure incorporation	Iowa	Swine	Manure incorporation	3,300	$-1.72 to 5.53	Because they value cost of manure incorporation and they estimated costs for different numbers of pigs marketed per year
					9,900	$0.08 to 6.53	
					16,800	$1.31 to 7.23	

B.3 Permeable covers

Dear:

Thank you for agreeing to participate in the study!

This information sheet summarizes the main cost and benefit drivers for permeable covers that were found in the literature. The purpose of the interview is to identify whether the cost and benefit drivers we have identified are complete and to help us determine whether there are any additional considerations that are relevant for implementing permeable covers in Alberta.

Part I Identification of Cost Drivers

Permeable covers provide effective odour and air emission control for manure storage structures. We consider three types of dust reduction mechanisms: straw, geotextiles (a type of fabric) and light weight expanded clay aggregates (a cover produced by heating clay in a kiln). The type of cover used will have an impact on several costs including the investment/fixed cost, labour and maintenance. For example, a straw cover has a low initial cost, but needs replacement every two to six months. Expanded clay has an initial high capital cost, but it has a lifespan of four to 10 years and requires less frequent maintenance. Geotextiles effectively lasts for one year because it's performance significantly decreases during the second year.

Questions

1. **Based on your knowledge of permeable covers please rank (1 for best, 3 for worst) the cover types based on cost, environmental performance, and convenience of use or likelihood to be adopted by producers. Assume that the time frame for evaluating cost and performance is 10 years.**

Table 1 Ranking of permeable covers by cost, performance, and convenience

Cover	Cost (10 years)	Performance in emission abatement	Convenience/ adoptability
Straw			
Geotextile			
Expanded clay			

2. **Table 2 broadly organises cost/benefit drivers we found to be common to each of the cover types. For the cover type which is most effective at reducing emissions, are there any cost/benefit drivers that we are missing? Please rank the top three cost drivers for the most effective cover type (1 being the most important cost driver)**

Table 2 Cost/benefit drivers

Cost/benefit drivers	Rank
Operating costs include labour, fuel and energy, and repair and maintenance	
Fixed costs include depreciation and interest of the type of cover	

Cost/benefit drivers	Rank
Nutrient conservation benefits include the value of nitrogen conserved in the manure as a result of being covered	
Reduced manure hauling costs due to keeping precipitation out of manure	
Other:…	
Other:…	

Part II Evaluation of Estimates of Costs from Literature Review

Based on a review of the literature and a suite of review criteria which included comprehensiveness of cost drivers and geographic location of the study we selected two or three relevant studies for each mechanism which could be applied to provide benchmark cost estimates for the Alberta context. Two studies were selected for providing benchmark cost estimates for installing permeable covers in Alberta. The main features are summarized in Table 3.

Questions

3. **Are there any additional factors which should be considered for transferring these cost estimates to Alberta or central and northern Alberta (due to differences in climate, agricultural practices?**
4. **Would the cost of adopting the types of covers in Alberta or central and northern Alberta be much less, about the same, a lot more than indicated by the literature?**
5. **Are you aware of any relevant studies which would provide better benchmark cost estimates for Alberta?**
6. **Are you aware of any opportunities or barriers to adopting these practices in Alberta?**
7. **Do you have any other comments about permeable covers that are relevant to their application in Alberta?**

Thank you for your time!

Table 3 Features of study

Study	Cost drivers included	Location of study	Type of Livestock	Type of Cover	Cost 2008CDN$/head/ year	Reason study was selected
Canadian Pork Council. 2005. Practices and technologies aimed at reducing environmental impacts from swine production: scientific and economic evaluation.	Operational costs included labour; fixed costs included depreciation, amortization of the cost of the cover and machinery	Saskatchewan	Swine	Straw	$0.26	Climate and type of covers used are representative of Alberta
				Geotextile	$1.21	
				Expanded clay	$2.77	
Jacobsen, B. 2006. Reduce the nitrogen loss and maintain the income – the economics of manure handling. *Paper prepared for presentation at the 13th international Farm Management Congress.* Wageningen, Netherlands	Fixed and operating costs, on-farm nutrient conservation benefits and benefits of reduced manure hauling costs due to keeping precipitation out of manure	Denmark		Straw	$-0.03 to 0.04	This study included on-farm benefits

B.4 Shelterbelts

Dear:

Thank you for agreeing to participate in the study!

This information sheet summarizes the main cost and benefit drivers for shelterbelts that were found in the literature. The purpose of the interview is to identify whether the cost and benefit drivers we have identified are complete and to help us determine whether there are any additional considerations that are relevant for implementing shelterbelts in Alberta.

Part I Identification of Cost Drivers

Shelterbelts reduce particulate movement, downward NH_3 concentration and downward odour concentration using the dilution and dispersion, filtration, fallout due to gravitational forces enhanced by reduced wind speeds, and adsorption and absorption onto the leaves of plants (Iowa State University 2008). Based on the literature we found several common cost/benefit drivers involved in installing shelterbelts around CFOs. They are discussed on Table 1.

Questions

1. Table 1 broadly organises cost/benefit drivers we found for installing shelterbelts. Are there any cost/benefit drivers relevant to shelterbelts that we are missing? Please rank the top three cost drivers (1 being the most important cost driver)

Table 1 Cost/benefit drivers

Cost/Benefit Driver	Rank
Cost of site preparation such as tilling, disking and spraying	
Cost of establishment, such as the cost of purchasing trees, shrubs and spraying	
Benefit of a government subsidy (trees provided at no cost in Canada)	
Other:…	
Other:…	

Part II Evaluation of Estimates of Costs from Literature Review

Based on a review of the literature and a suite of review criteria, which included comprehensiveness of cost drivers and geographic location of the study, we selected a few relevant studies for each mechanism which could be applied to the Alberta context. The following study was selected for providing benchmark cost estimates for installing shelterbelts in Alberta. The main features are summarized in Table 2. We adjusted the net cost from their study by adding back the cost of the trees in this study, because the Prairie Farm Rehabilitation Administration provides trees free of charge.

Table 2 Features of study

Study	Cost drivers included	Location of study	Type of livestock	Number of pigs marketed per year	Cost in 2008 CDN$ per head per year	Reason study was selected
Tyndall, J.C. and R.C. Grala. 2008. Financial feasibility of using shelterbelts for swine odor mitigation. **Agroforestry Systems.** Published online May 2008.	Cost of site preparation, establishment, and maintenance of shelterbelts around swine operations	Iowa	Swine	1,500 2,000 2,500 10,500	$0.08 $0.11 $0.05 $0.03	It includes all identified cost drivers to estimate cost per animal; compares costs against operation size; it is peer reviewed; and in addition Iowa may experience geographic agglomeration of CFOs similar to southern Alberta.

Questions

2. **Are there any additional factors which should be considered for transferring these cost estimates to Alberta or central and northern Alberta (due to differences in climate, agricultural practices, density of farms)?**
3. **Would the cost of dead animal composting in Alberta (or central and northern Alberta) be much less, about the same, a lot more than indicated by the literature?**
4. **Are you aware of any relevant studies which would provide better benchmark cost estimates for Alberta?**
5. **Are you aware of any opportunities or barriers to adopting these practices in Alberta?**
6. **Do you have any other comments about shelterbelts that are relevant to their application in Alberta?**

Thank you for your time!

B.5 Composting

Dear:

Thank you for agreeing to participate in the study!

This information sheet summarizes the main cost and benefit drivers for composting that were found in the literature. The purpose of the interview is to identify whether the cost and benefit drivers we have identified are complete and to help us determine whether there are any additional considerations that are relevant to composting in Alberta.

Part I Identification of Cost Drivers

Manure composting is an aerobic process that facilitates rapid microbial decomposition of the manure organic matter into a stable product. It reduces NH_3 emissions compared to a mechanism where it is not composted.

Livestock management today is challenged to find new methods to dispose of dead animals to comply with environmental regulation. Various methods include composting, incineration, burial pits and freezing. We consider dead animal composting, which is an aerobic process of decomposing the animal without producing objectionable odours. Manure and dead animal composting have different cost/benefit drivers including operational and fixed costs and nutrient off-set benefits (benefits of substituting manure for inorganic fertiliser):

Questions

1. **Tables 1 and 2 broadly organise cost/benefit drivers we found for each composting type. For each please indicate whether there are any cost/benefit drivers that are missing? Please rank the top three cost drivers for each (1 being the most important cost driver)**

Table 1 Cost/benefit drivers of manure composting

Cost/benefit Drivers	Rank
Cleaning of pens	
Placing manure in windrows	
Turning	
Watering	
Fixed costs of the composting structure	
Nutrient benefit which can be valued by the market price of the product	
Other:…	
Other:…	

Table 2 Cost/benefit drivers of dead animal composting

Cost/benefit Drivers	Rank
Operating costs include labour	
Fixed costs of the composting structure	
Fixed costs of water services	
Fixed costs of machinery	

Cost/benefit Drivers	Rank
Nutrient benefit which can be valued by the market price of the product	
Other:…	
Other:…	

Part II Review of Costs Drivers

Based on a review of the literature and a suite of review criteria, which include comprehensiveness of cost drivers and geographic location of the study, we selected two or three studies for each management mechanism which are relevant to the Alberta context. Three studies were selected for providing benchmark cost estimates for implementing dust reduction mechanisms for roads in Alberta. The main features are summarized in Table 3. We assume that the quantity of manure produced by a beef cow per year is about 11 tonnes according to USDA and that a 450-lb dead sow shrunk to 1/3rd its weight when composted.

Questions

2. **Are there any additional factors which should be considered for transferring these cost estimates to Alberta or central and northern Alberta (due to differences in climate, agricultural practices, density of farms)?**
3. **Would the cost of dead animal composting in Alberta (or central and northern Alberta) be much less, about the same, a lot more than indicated by the literature?**
4. **Are you aware of any relevant studies which would provide better benchmark cost estimates for Alberta?**
5. **Are you aware of any opportunities or barriers to adopting these practices in Alberta?**
6. **Do you have any other comments about composting that are relevant to their application in Alberta?**

Thank you for your time!

Table 3 Features of the study

Study	Cost Drivers Included	Location of Study	Type of livestock	Number of animals	2008CDN$/head/year	Reason Study Selected
Smith, E., G. Card, and D. Young. 2006. Effects of market and regulatory changes on livestock manure management in southern Alberta. *Can. J. of Agric. Econ.* 54: 199-213.	Provide operating and fixed costs and nutrient benefit of windrow composting (piling manure in long rows called windrows) for beef cattle manure	Lethbridge, Alberta	Beef cattle	Not provided	$27.74	Peer Reviewed Local Study site Comparable technology (piling manure in long rows)
Foster. 1994. Cost analysis of swine mortality composting	operating and fixed costs and nutrient benefit of composting dead swine	Missouri	Swine	100 to 150	$10 to $15	The study was selected because it uses a comparable technology (an enclosed method with concrete floor), shows costs, benefits and operation size.
USDA-NRCS. 2003. Costs associated with development and implementation of nutrient management plans	Operating and fixed costs of composting dead poultry	North Carolina	Broiler	25,000	$0.05	The study was selected because it uses a comparable technology (an enclosed method using a bin) and shows net cost against operation size.
			Layer	50,000	$0.02	
			Turkey	5,000	$0.17	

B.6 Dust reduction: Unpaved roads

Dear:

Thank you for agreeing to participate in the study!

This information sheet summarises the main cost and benefit drivers for dust reduction on roadways that were found in the literature. The purpose of the interview is to identify whether the cost and benefit drivers we have identified are complete and to help determine whether there are any additional considerations that are relevant for implementing dust reduction mechanisms in Alberta.

Part I Identification of Cost Drivers

Dust reduction mechanisms for roadways work by adhering fine particles together and reducing their ability to be suspended in air by vehicle tires. We consider three types of dust reduction mechanisms: lignin sulphonate (a polymer of woody plants, with an adhesive property when moist), bitumen (a petroleum based binder), and Calcium Chloride (a type of salt that binds with dust). Each mechanism has different cost/benefit drivers including operational and fixed costs, frequency of application and road maintenance. For example the first time lignin sulphonate are applied it is cheaper than bitumen because this chemical is less expensive. However, because lignin sulphonate have to be applied twice a year and bitumen once every six years, the latter is cheaper over a six year period. We did not find the frequency of re-application of calcium chloride.

Questions

1. **Based on your knowledge of dust reduction mechanisms please rank (1 for best, 3 for worst) the mechanisms based on cost, environmental performance, and convenience of use or likelihood to be adopted by producers. Assume that the time frame for evaluating cost and performance is 10 years**

Table 1 Ranking of dust reduction mechanisms for roadways

Palliative	Cost (10 years)	Performance in Dust Abatement	Convenience/Adaptability
Lignin sulphonate			
Bitumen			
Calcium Chloride			

2. **Tables 2 broadly organise cost/benefit drivers found to be common to each of the dust reduction mechanisms. For the mechanism which is most effective at reducing dust, are there any cost/benefit drivers relevant to dust reduction mechanisms that are missing from the list? Please rank the top three cost drivers for the (1 being the most important cost driver)**

Table 2 Cost/benefit drivers for dust reduction mechanisms for roadways

Cost/Benefit Driver	Rank
Operational costs such as labour	
Fixed costs such as machinery	
Benefit of reduced road maintenance which is also a function of road traffic	
Other:…	
Other:…	

Part II Evaluation of Estimates of Costs from Literature Review

Based on a review of the literature and a suite of review criteria we selected two or three relevant studies for each mechanism which could be applied to the Alberta context. Two studies were selected for providing benchmark cost estimates for implementing dust reduction mechanisms for roads in Alberta. The main features are summarized in Table 3. We assume application for 1 km of road per feedlot with capacity of 10,000 head and 2 turns per year (Brian West, pers. comm.; Amosson et al. 2006, 2008).

Questions

3. **Are there any additional factors which should be considered for transferring these cost estimates to Alberta or central and northern Alberta (due to differences in climate, agricultural practices, density of farms and whether facilities need a permit from Alberta Transport to install dust palliatives)?**
4. **Would the cost of dust palliatives in Alberta (or central and northern Alberta) be much less, about the same, a lot more than indicated by the literature?**
5. **Are you aware of any relevant studies which would provide better benchmark cost estimates for Alberta?**
6. **Are you aware of any opportunities or barriers to adopting these practices in Alberta?**
7. **Do you have any other comments about dust reduction mechanisms that are relevant to their application in Alberta?**

Thank you for your time!

Table 3 Features of study

Study	Cost drivers included	Location of study	Type of Livestock	Type of Palliative	Cost 2008CDN$/head/year	Reason study was selected
Federation of Canadian Municipalities. 2005. Dust control for unpaved roads. www.infraguide.com	Examined costs and benefits of Calcium Chloride per km of road. Costs include operating costs, fixed costs, frequency of application and reduced road maintenance costs of Calcium Chloride.	Missoula, Montana	Beef cattle	Calcium chloride	$-0.78 to 0.28	Calcium chloride is used around municipalities and feedlots in southern Alberta
T. Becker, Operations Manager, Alberta Transportation, Lethbridge, AB, pers. comm.	Provides operating costs and fixed costs for application of lignin sulphonate and bitumen on primary highways of southern Alberta. Estimates are dependent on frequency of application	Southern Alberta		Lignin sulphonate	$0.39	Lignin sulphonate and Bitumen are used around primary highways in Southern Alberta. These are actual application costs for Southern Alberta
				Bitumen	$0.07	

B.7 Dust reduction: Beef cattle feedlots

Dear:

Thank you for agreeing to participate in the study!

This information sheet summarises the main cost and benefit drivers for dust reduction mechanisms on feedlots that were found in the literature. The purpose of the interview is to identify whether the cost and benefit drivers we have identified are complete and to help us determine whether there are any additional considerations that are relevant for implementing dust reduction mechanisms in Alberta.

Part I Identification of Cost Drivers

Dust reduction mechanisms for feedlots work by, adhering fine particles together and reducing their ability to be suspended in air by hooves of cattle or wind. We consider two types of dust reduction mechanisms: the use of water sprinklers; and the use of water trucks to sprinkle water around the facilities. The types of dust reduction mechanisms will have an impact on several cost/ benefit drivers including operational and fixed costs.

Questions

1. **Based on your knowledge of dust reduction mechanisms please rank (1 for best, 3 for worst) the mechanisms based on cost, environmental performance, and convenience of use or likelihood to be adopted by producers. Assume that the time frame for evaluating cost and performance is 10 years**

Table 1 Ranking of dust reduction mechanisms for feedlots

Palliative	Cost (10 years)	Performance in Dust Abatement	Convenience/Adaptability
Sprinklers			
Water trucks			

2. **Table 2 broadly organises cost/benefit drivers we found to be common to each of the dust reduction mechanisms. For the mechanism which is most effective at reducing dust are there any cost/benefit drivers relevant to dust reduction mechanisms that are missing from the list? Please rank the top three cost drivers for the (1 being the most important cost driver)**

Table 2 Cost/benefit drivers

Cost/benefit drivers	Rank
Maintenance	
Energy,	
Repair	
Insurance	
Fuel	
Labour	
Investment,	

Cost/benefit drivers	Rank
Interest	
Depreciation	
Other:…	
Other:…	

Part II Evaluation of Estimates of Costs from Literature Review

Based on a review of the literature and a suite of review criteria, which included comprehensiveness of cost drivers and geographic location of study, we selected two or three relevant studies for each mechanism which could be applied to the Alberta context. Two studies were selected for providing benchmark cost estimates for implementing dust reduction mechanisms for feedlots in Alberta. The main features are summarized in Table 3.

Questions

3. **Are there any additional factors which should be considered for transferring these cost estimates to Alberta or central and northern Alberta (due to differences in climate, agricultural practices, density of farms)?**
4. **Would the cost of dust reduction mechanisms on feedlots in Alberta (or central and northern Alberta) be much less, about the same, a lot more than indicated by the literature?**
5. **Are you aware of any relevant studies which would provide better benchmark cost estimates for Alberta?**
6. **Are you aware of any opportunities or barriers to adopting these practices in Alberta?**
7. **Do you have any other comments about feedlots that are relevant to their application in Alberta?**

Thank you for your time!

Table 3 Features of study

Study	Cost drivers included	Location of study	Type of Livestock	Sub-type mechanism	Number of animals	Cost in 2008 CDN$ per animal per year	Reason study was selected
Amosson, S., B. Guerrero, L. Almas. 2006. Economic analysis of solid-set sprinklers to control dust in feedlots. *Selected paper for presentation at the Southern Agricultural Economics Association Annual Meetings*. Orlando, Florida.	Estimate operational and fixed costs of using sprinklers. Operational costs include maintenance, energy, and repair and fixed costs include investment, interest and depreciation	Texas Panhandle	Beef cattle	Sprinkler	17,500	2.73	The technology was considered applicable to Alberta, the study was explicit on all cost drivers, the costs were valued against different operational sizes (and numbers of animals marketed per year)
					20,000	2.39	
					22,500	2.12	
					52,500	1.97	
					60,000	1.72	
					67,500	1.54	
					87,500	1.86	
					100,000	1.63	
					112,500	1.44	
Amosson, S., F. Bretz, P. Warminksi, T. Marek. 2008. Economic analysis of a water truck for feedyard dust suppression. *Selected paper for presentation at the Southern Agricultural Economics Association Annual Meetings*. Dallas, Texas.	Estimate operational and fixed cost of using water trucks to reduce feedlot dust Operational costs include maintenance, insurance, fuel and labour costs. Fixed costs include investment, interest and depreciation.	Texas Panhandle	Beef cattle	Water truck	17,500	2.32	The technology was considered applicable to Alberta, the study was explicit on all cost drivers, the costs were valued against different operational sizes (and numbers of animals marketed per year)
					20,000	2.03	
					22,500	1.81	
					52,500	1.87	
					60,000	1.64	
					67,500	1.46	
					87,500	1.78	
					100,000	1.56	
					112,500	1.39	

Alberta