



Climate Change Central

**MANURE MANAGEMENT AND
GREENHOUSE GAS MITIGATION
TECHNIQUES:
A COMPARATIVE ANALYSIS**

DISCUSSION PAPER C3 – 013

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RESULTS IN BRIEF

Alberta is the second largest agricultural producer in Canada, just slightly behind Ontario in terms of farm cash receipts. The livestock industry in Alberta, which accounts for 62% of the provincial farm cash receipts, is a large and growing business worth over \$5 billion per year. What used to be a diverse industry, where farmers kept a variety of different types of livestock, has transformed into a much more specialized business, with farmers maintaining large numbers of a single animal type. As the Alberta livestock industry increases in density and size, several factors are driving the need for more advanced manure management systems. These drivers include the following:

- Trend towards confined feeding operations (CFOs) is creating large, concentrated quantities of manure.
- The public perception of CFOs, particularly after the Walkerton disaster in Ontario.
- The implementation of provincial legislation regulating the expansion and construction of CFOs.
- The ratification of the Kyoto Protocol by the federal government in late 2002 has raised interest in the development of improved manure management systems that can reduce greenhouse gas (GHG) emissions.
- Rising energy costs have heightened interest in manure management systems that facilitate “waste to energy” practices.

Liquid manure management systems, such as those used by swine operators and large dairy barns, have the highest methane emission factors (kg/head/year), and contribute over 80% of the total methane emissions from livestock manure in Alberta. However, there is no one solution to mitigate GHG emissions for all types of livestock manure.

This discussion paper identifies and analyses three manure management techniques that, while addressing some of the social and environmental issues raised by the general public and the provincial government, can be used to mitigate GHG emissions. These techniques include bio-digesters, gasification systems and composting.

Climate Change Central’s vision to eliminate Alberta’s net greenhouse gas emissions while enhancing the economic performance of the province is supported by a set of priorities that includes emissions offset development. The following recommendations have been made so that Climate Change Central can establish a strategy that supports emissions offset development and maximizes the reduction of methane emissions from all the major components of the livestock industry in Alberta. The recommendations are described in order of priority.

1. It is recommended that Climate Change Central concentrate on the implementation of bio-digester technology with a focus on the swine industry, as this has the largest potential for methane emission reductions.
2. It is also recommended that Climate Change Central pursue the implementation of a gasification pilot project for poultry manure. Because bio-digesters are not suitable for use with chicken manure, gasification systems provide another alternative that allow energy to be captured from chicken manure while simultaneously reducing methane emissions.
3. Finally, it is recommended that Climate Change Central assist with or establish public outreach programs that promote the composting of cattle manure for both beef feedlots and older style dairy barns.

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1.0 INTRODUCTION

Manure management, as it pertains the livestock industry, can be described as the collection, storage and disposal of animal waste. The techniques used to manage manure vary by animal type as well as by the way that the livestock are raised. The trend towards confined feeding operations (CFOs) in the developed world, where animals are raised in a controlled environment to maximize growth potential and minimize production costs, necessitated the development of manure management techniques to maintain a healthy environment for the livestock. As the livestock industry in both North America and Alberta continues to increase in density and size, several other factors are now driving the need for more advanced manure management systems.

The trend towards confined feeding operations has resulted in large, concentrated quantities of manure that cannot easily be disposed of, and has raised public concern over the social and environmental impact of livestock operations. As a result, the public perception of CFOs, particularly after the Walkerton disaster in Ontario, is driving both the government and the livestock industry to make changes to the way that manure is handled. New legislation implemented by the Alberta government regulating the expansion and construction of CFOs does not explicitly specify manure management techniques that must be used, however it is clear that technology can mitigate the requirements of a CFO approval or registration.

Over the past few years, many CFO operators in Alberta have seen significant rises in energy costs, which is heightening interest in alternative sources of energy. This, in combination with the ratification of the Kyoto Protocol by the Federal government in late 2002, has been a driver behind the development of improved manure management systems that can facilitate “waste to energy” practices while reducing greenhouse gas (GHG) emissions.

While the legislation is not currently in place, the provincial and federal GHG emission reduction plans will likely depend upon the establishment of an emissions trading program as an instrument to reduce emissions. This type of program will allow large industrial emitters of GHGs, such as TransAlta and EPCOR, to meet their mandatory GHG constraint by purchasing emissions offsets. The agriculture industry, and in particular the livestock industry, is thought by many to be a source of inexpensive emissions offsets, as many initiatives that reduce GHGs on the farm have other ancillary benefits like on-site electricity generation that can serve to reduce operating costs as well as mitigate the social and environmental impact of agricultural operations.

1.1 Scope

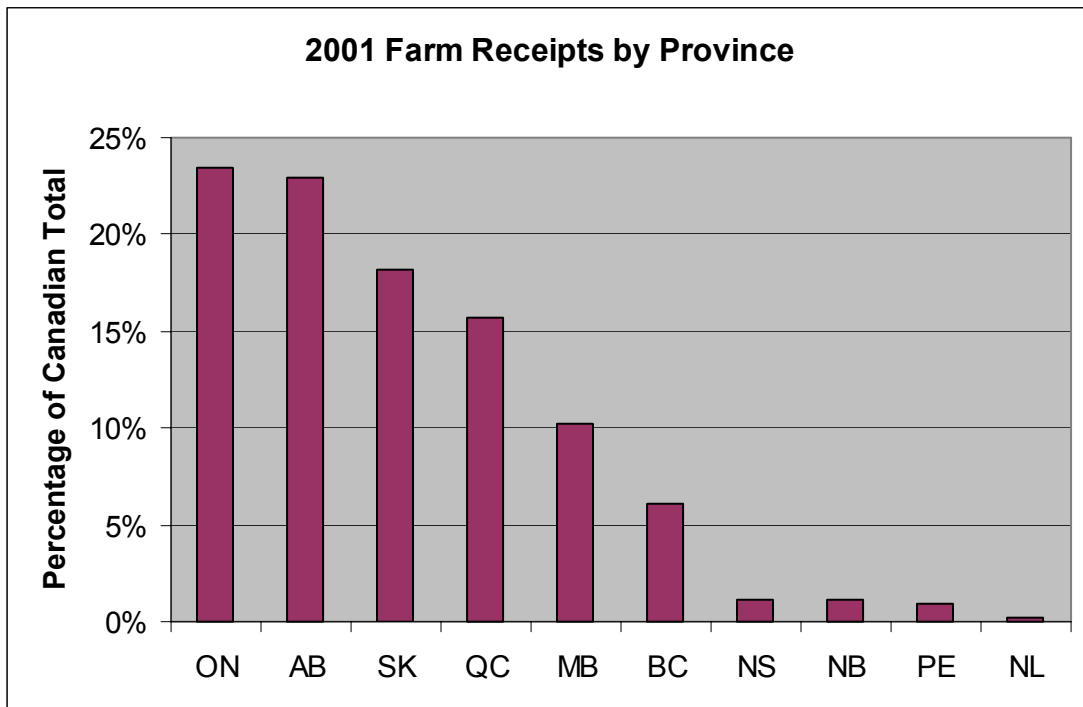
This report examines the swine, cattle and poultry industries in Alberta for density, size and fit with manure management opportunities that reduce GHG emissions. In addition, because the value of electricity and heat can counter balance some development and operating costs, this report emphasizes those technologies that have the potential for combined heat and power (CHP). Specifically, this report reviews current manure management practices and provides a comparative analysis of new technologies as they pertain to the different types of confined feeding operations. The conclusion and recommendations provided enable Climate Change Central to establish a strategy that works toward maximizing the reduction of methane emissions from the manure produced by the growing Alberta livestock industry.

2.0 BACKGROUND

2.1 Livestock in Alberta

Alberta is the second largest agricultural producer in Canada, accounting for approximately 23% of the national farm cash receipts generated from primary agriculture in 2001 and 2002 (Agriculture Facts, 2003). Figure 1 illustrates the distribution of these farm cash receipts by province in 2001.

Figure 1: 2001 Farm Receipts by Province



Source: Statistics Canada

In Alberta, agri-food industries contributed 3.9% to the total provincial GDP in 2001, of which 2.3% came from primary agriculture operations. While the agriculture sector represents a small fraction of the economic activity in Alberta, livestock and livestock products accounted for almost 62% of the Alberta farm cash receipts in 2002, totaling over \$5 billion (Agriculture Statistics Factsheet, 2003). Cattle and calves represent the most significant form of livestock in terms of both population and total farm receipts, however, the swine and poultry sectors are also important contributors. These three livestock sectors will be discussed in more detail in the following sections, however, Table 1 summarizes the livestock industry in Alberta, providing both the size and value of the various livestock types.

Table 1: Livestock in Alberta

LIVESTOCK IN ALBERTA				
Type	Head	% of Canadian Total	Farm Receipts (millions)	% of total Farm Receipts
Cattle and Calves	5,092,000		\$3,889.2	47.3%
		39.0%		
Dairy Cattle and Dairy Products	128,000		\$366.8	4.5%
Hogs	2,139,900	14.6%	\$521.6	6.3%
Sheep and Lambs	187,000	19.2%	\$17.0	0.2%
Poultry and Poultry Products	13,259,607	9.5%	\$188.8	2.3%
Other	--	--	\$109.8	1.3%
TOTAL			\$5,093.2	61.9%

Source: Alberta Agriculture, Food and Rural Development

2.1.1 Cattle

Alberta is the largest beef-producing province in Canada, and leads the nation in cattle and calf inventories with over five million head (Agriculture Facts, 2003). The beef industry accounts for over 47% of the farm receipts in the province, indicating the importance of the cattle industry to the agriculture sector (Agriculture Statistics Factsheet, 2003). However, the recent drought in Western Canada has had a negative impact on the growth of the beef industry, as feed is more difficult and more expensive to obtain. This, in combination with the impact of the recent BSE scare, may shrink the Alberta beef industry even further.

A majority of the cattle inventory is found on ranches, however 20% of the population are maintained in confined feeding operations, such as feedlots and dairy barns. Over 60% of the cattle in Alberta can be found in the south and central regions of the province, with a particularly high concentration in Lethbridge County. Table 2 highlights the top six concentrations by county.

Table 2: Alberta Cattle Concentrations

CATTLE CONCENTRATIONS	
County	Inventory
Lethbridge County	583,531
Newell County No. 4	267,255
Ponoka County	244,063
Foothills County No. 31	238,917
Red Deer County	238,561
Wheatland County	208,903

Source: Alberta Agriculture, Food and Rural Development, Agricultural Census 2001

2.1.2 Swine

In January 2003, swine inventories in Alberta stood at over 2.1 million head, ranking fourth in the country, and accounting for 14.6% of the total Canadian inventory (Pigs on Farms, 2003). While the Alberta pork industry only accounted for 6.3% of the total farm receipts (\$522 million) in 2002, the industry has seen slow but steady inventory growth, averaging 2.9% per year since 1997.

Due to the extreme temperatures in Alberta, swine are housed in barns all year round. Over 70% of the swine population can also be found in the south and central regions of the province, with the highest concentrations found in the Red Deer area. Table 3 highlights the top five concentrations by county.

Table 3: Alberta Swine Concentrations

SWINE CONCENTRATIONS	
County	Inventory
Lacombe County	164,821
Wheatland County	149,329
Lethbridge County	132,195
Red Deer County	107,865
Kneehill County	104,930

Source: Alberta Agriculture, Food and Rural Development, Agricultural Census 2001

2.1.3 Poultry

The poultry inventory in Alberta was over 13.2 million birds in 2001, which also ranked fourth in the country, however this accounted for less than 10% of the total Canadian inventory. While predominantly hens and chickens, there are turkeys, ducks, geese, and other birds

bred in the province, although they only make up 8% of the poultry inventory (2001 Census of Agriculture – Alberta Poultry Inventory, 2002). Poultry and eggs accounted for 2.3% of the 2002 farm receipts in Alberta (Agriculture Statistics Factsheet, 2003). Based on the 2001 Agricultural Census, the poultry industry as a whole has seen an average annual growth in inventory of 4.6% since 1996, although most of this growth can be attributed to hens and chickens, as the growth in turkey and other poultry production has remained relatively flat during this time.

Intensive poultry production facilities use heated and ventilated barns to house birds all year round. Unlike the swine and cattle populations that are concentrated in the south and central regions of the province, the poultry population is relatively evenly spread out across all regions except for the Peace region, with the highest concentrations found near the major centers. However, the highest concentration in the province can be found near Lethbridge, which accounts for almost 12% of the provincial population. Table 4 highlights the top five concentrations of chicken and hens by county.

Table 4: Alberta Chicken and Hen Concentrations

CHICKEN and HEN CONCENTRATIONS	
County	Inventory
Lethbridge County	1,434,028
Sturgeon County	1,297,666
Kneehill County	975,070
Camrose County No.22	972,700
Foothills County No. 31	683,317

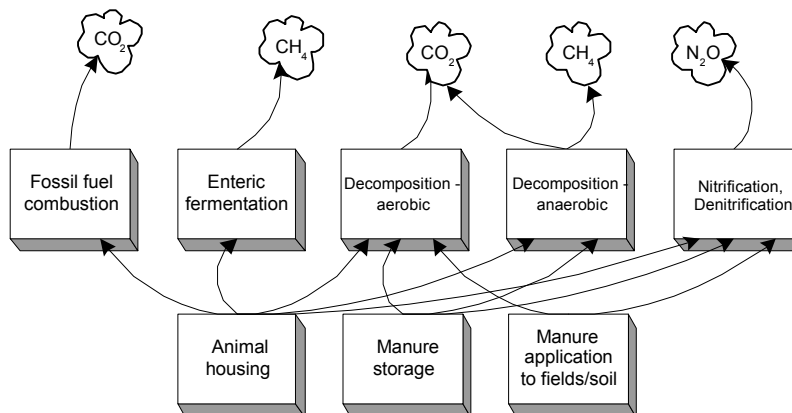
Source: Alberta Agriculture, Food and Rural Development, Agricultural Census 2001

2.2 Livestock and GHG emissions

The Alberta agriculture sector contributes approximately one third of the total agriculture GHG emissions in Canada and approximately 10% of the total provincial GHG emissions. The reason for the high proportion of Alberta's agricultural emissions relative to the rest of the country is due to the intensity of the livestock industry in Alberta, and in particular, the beef industry.

The GHG emissions from the agriculture sector are slightly unique, as 97% of the emissions from farms are in the form of methane (CH₄) and nitrous oxide (N₂O), rather than carbon dioxide (CO₂) (Agriculture and Agri-Food Climate Change Foundation Paper, 1999. pg3). This is especially true in the case of livestock operations, as there are a few specific sources of methane and nitrous oxide that are unique to livestock. Figure 2 illustrates the sources, processes and types of gases that are emitted from livestock operations; however, the quantity of gas produced from each process will vary widely by the type of animal being farmed. The most significant sources of GHG emissions from livestock operations include enteric fermentation and manure management (manure storage and the application of manure to the land).

Figure 2: Sources of GHG Emissions from Livestock Operations



Source: Climate Change Central, Greenhouse Gas Emissions and Opportunities for Reduction From the Alberta Swine Industry – Discussion Paper, 2003.

2.2.1 Enteric Fermentation

All animals produce methane when they digest feed through an anaerobic microbial process called enteric fermentation. However, the quantity of methane produced is dependant upon the type of animal. Ruminants, such as cattle, sheep and goats, are animals with a rumen or a fore-stomach, and they produce significantly higher quantities of methane during the digestion process than do non-ruminants, such as pigs and chickens. Because of the pre-digestion process that occurs in the rumen, ruminants are capable of efficiently digesting course feeds.

There are several factors that affect the rate of methane emissions from the enteric fermentation process, but the quality of feed and the quantity of feed are the two most important. Diets that increase the rate of digestion typically reduce the level of methane emissions, as the feed spends less time being digested under anaerobic conditions in the animals rumen or stomach. When the intake of feed is raised above maintenance levels, the efficiency of feed utilization is increased. While the absolute quantity of methane emitted will increase under elevated feed intake conditions, the emissions per unit of product are usually reduced.

2.2.2 Manure Management

Another major source of methane from livestock operations is the manure that animals excrete. Manure, like other organic materials, immediately begins to decompose, converting the carbon in the waste to either CO₂ or CH₄. Under well-aerated conditions, the decomposition process will release the carbon in the manure as CO₂, but under anaerobic conditions, where there is an oxygen deficiency, the decomposition process generates significant quantities of methane.

Intensive livestock operations that have a liquid manure storage system, such as a hog operation, use water to wash the manure from the barns into outdoor lagoon. Because of the lack of available oxygen in the liquid manure, anaerobic decomposition takes place, emitting significant quantities of methane and only small quantities of CO₂. Solid manure storage systems, such as those found at cattle feedlots, typically pile the manure in an outdoor storage yard until it can be spread on the local fields. While this type of manure storage is significantly dryer than the liquid systems, a majority of the manure still decomposes under anaerobic conditions and produces methane.

The application of manure to the field can be a significant source of both nitrous oxide as well as methane. While plants need nitrogen (from manure or chemical fertilizer) in order to grow, applying more manure to the land than the plants are capable of absorbing will result in a loss of nitrogen to the atmosphere in the form of nitrous oxide. Considerable amounts of N₂O can be produced by manure application through the process of denitrification, a process that is augmented by anaerobic conditions and the high levels of available carbon in manure. The application of manure to wet fields can further exacerbate the GHG emissions by providing anaerobic conditions that augment both methane and nitrous oxide production.

3.0 INTENSIVE LIVESTOCK OPERATIONS

Intensive livestock operations, otherwise known as confined feeding operations (CFOs) have become significantly more popular since the early 1990's due to an increasingly competitive market for livestock (Cahoon, 2003). CFOs for beef cattle, dairy cattle, pigs and poultry are now common in the agriculture industry and offer farmers a cost-effective method for raising large numbers of animals without requiring a large land base. A CFO is defined by Alberta Agriculture as a fenced or enclosed area where livestock is confined for the purpose of growing, sustaining, finishing or breeding by means other than grazing. Typically, the animals are kept in pens or barns, where the farmer supplies their feed and water. This technique allows complete control over the animals' feed intake and produces optimal growth and development rates.

3.1 Trends

Over the last decade, Alberta has seen its livestock industry change quite significantly. What used to be a diverse industry, where farmers kept a variety of different types of livestock, has transformed into a much more specialized industry, with farmers maintaining large numbers of a single animal type. The number of farms in Alberta that keep livestock has declined since the early 1990's, however, over the same time period, the population of livestock in the province has increased. This trend to a smaller number of larger farms is evident for most types of livestock and coincides with the migration to specialized confined feeding operations by many livestock operators in the province.

Between 1993 and 1996, cattle prices dropped 30% in Alberta, forcing livestock operators to find new ways to remain competitive in an increasingly challenging market (Agriculture Statistics Yearbook – Alberta Livestock Industry, 2002). The production efficiency associated with confined feeding operations for all types of livestock was a significant factor in the change of livestock farming practices and the increase in the number of CFOs during the early to mid 1990's.

3.2 Types of CFOs

The concept of the CFO has been applied to many types of animals, however, the most common types in Alberta include beef cattle, dairy cattle, hogs and poultry, which includes both chickens and turkeys. While the concepts are similar for each type of animal, the specifics of a confined feeding operation varies from animal to animal. Table 5 illustrates the typical types of confined feeding operations found in Alberta.

Table 5: Alberta Confined Feedlot Operations

CONFINED FEEDING OPERATIONS IN ALBERTA			
Animal	Type of CFO	Manure Mangement System	Comments
Beef Cattle	Open, outdoor pens	Solid	Pens periodically “mucked out” with a front end loader or backhoe. Cattle typically spend 60-120 days in a feedlot, prior to being sold to meat processors.
Dairy Cattle	Barn	Liquid and solid systems	Larger operations use liquid systems, but solid “scrape and haul” systems also exist
Hogs	Barn	Liquid	Manure is flushed using water and stored in an outdoor lagoon. Special pens for sows and piglets. Different types of operations include Farrow to Finish, Farrowing, and Finishing.
Poultry (Chickens and Turkeys)	Barn	Solid	For broilers, barn is cleaned after each flock (8 week cycle).

3.3 Energy Requirements at Confined Feeding Operations

To maintain a highly efficient livestock operation, a variety of technologies are used to facilitate handling the large number of animals as well as to keep the animals comfortable and highly productive. The quantity of energy required to drive the technologies commonly used by CFO operators varies by animal type, and can be a significant component of the operating costs.

The energy consumed by heating, ventilation and air conditioning (HVAC) systems typically accounts for the largest quantity of energy that is used at a swine or poultry operation, however this is not the case for beef or dairy cattle operations. Because beef cattle are held in outdoor pens, HVAC systems are not required, although a small amount of energy may be used to prevent the animals’ drinking water from freezing in the winter. Dairy cattle require the shelter of a barn, but do not need the facilities to be heated, as the animals remain comfortable in temperatures below freezing. However, the milking center in a dairy barn is heated, and depending upon the design, the whole barn may need to be ventilated during the summer months to prevent the barn from getting too hot.

By maintaining the high levels of productivity through the use of technology, swine, poultry and dairy operations can consume large quantities of electricity and natural gas. This is of particular concern to CFO operators in Alberta, as energy prices have increased quite significantly over the past few years, and is thinning profit margins in an already highly competitive industry. Table 6 summarizes the energy requirements of each type of CFO.

Table 6: Alberta Confined Feedlot Operations

CFO ENERGY REQUIREMENTS		
Animal	Type of CFO	Direct Energy Requirements
Beef Cattle	Open, outdoor pens	Direct energy requirements are quite low, as animals are kept outdoors all year round. May require some heat to keep drinking water from freezing during the winter. Some operators spray water over the pens during the summer to keep the dust levels down.
Dairy Cattle	Barn	Modern dairy barns are not heated, but may be ventilated during the summer. The milking center is heated with radiant heating elements. Milk is collected and moved using a vacuum system.
Hogs	Barn	Barns are heated and ventilated.
Poultry (Chickens and Turkeys)	Barn	Barns are heated and ventilated. Barns must be cooled when outside temperatures exceed 27°C. Lighting control is very important to optimize egg production in layers.

4.0 MANURE MANAGEMENT

The improved efficiency of confined feeding operations have undoubtedly enabled the livestock industry to produce more meat at a lower cost, but the manure that these operations generate has created a variety of issues in terms of air and water quality as well as GHG emissions. While confined feeding operations and manure management practices in Canada have been largely unregulated until recently, the experiences of other regions with intensive livestock operations, such as North Carolina, have prompted the implementation of legislation to mitigate the issues as additional CFOs are constructed.

The technique used for managing manure at a CFO varies by animal type. The following sub-sections describe the methods that are used for the most common forms of livestock.

4.1 Beef Cattle

As described in the previous section, beef cattle are kept in outdoor pens, where the livestock operator can control their feed intake. The pens are usually earthen floor areas with sturdy wooden fencing around the perimeter. Beef cattle spend between 60 and 120 days in the feedlot before being sold to processors for slaughter. During this time, manure is deposited onto the earthen floor until it is periodically removed using a front-end loader or a backhoe. This technique is classified as a solid manure management system. A single typical finisher is capable of producing 180 kg of manure per month.

Once removed from the pen, the manure is either applied directly to the surrounding fields to replace the nutrients lost during cropping activities, or it can be stored in windrows for composting.

4.2 Dairy Cattle

Dairy farmers house their cattle in barns, which contains the feeding pens or stalls, as well as the milking center. The newer, more efficient operations, use a liquid manure management system, where water is used to wash out the manure on a daily basis. The liquid manure is then pumped outside for storage in either an earthen lagoon or a metal or concrete tank. A few times a year, the liquid manure is agitated and then applied to local agricultural land with a manure spreader or an irrigation system. The liquid that is applied to the fields has a high nutrient content, and help to replace the nutrients lost from the soil during the cropping process. This technique is similar to the systems used in swine barns.

Older operations continue to use a solid manure management technique, known as “scrape and haul”, instead of the liquid systems. On a daily basis, the manure is scraped out of the stalls, and hauled outside where it is stockpiled until it can be applied to the local fields. While the scrape and haul technique is still fairly common amongst smaller operations, only about 25% of the dairy cattle manure in Alberta is handled in this fashion, with 75% being handled by the more efficient liquid manure management systems.

4.3 Swine

Swine CFOs use barns to house the animals year round. The manure that is generated is washed out from the pens using water, and is collected in a sump in the barn before being pumped outside for storage in an earthen lagoon. Once in the lagoon, the solids in the manure settle out, leaving a liquid manure that can be pumped out of the lagoon for spray application to the surrounding fields. The solids that collect on the bottom of the lagoon are dredged out a few times a year, and are also applied directly to the surrounding fields. Both the solid and the liquid that are removed from the lagoon have a high nutrient content, and help to replace the nutrients lost from the soil during the cropping process.

4.4 Poultry

Poultry farm operators use barns to house their birds at all times of the year. Poultry manure is quite dry, and is only removed periodically from the barn. When cleaning occurs, the manure is scraped out of the coops, and hauled outside where it is either composted or stockpiled.

5.0 REGULATIONS AFFECTING CFO'S

Prior to January 1, 2002, the development or expansion of a CFO in Alberta was regulated at a municipal level. However, the rules varied from one municipality to another, and some municipalities did not even require a development permit for new or expanding CFOs until the mid 1990's. As a result, it is estimated that there are several hundred existing CFOs that did not require municipal development permits when they were built or expanded.

In mid 2001, after several years of public consultations, the Alberta Government announced its decision to assume legislative responsibility for CFOs. On January 1, 2002, amendments to the Agricultural Operation Practices Act (AOPA) were proclaimed, enabling the provincial government to regulate new and expanding CFOs through a framework that included:

- A provincial approval process

- Technical standards, ongoing monitoring and enforcement
- Provincial approval authority for the siting of CFOs

The amendments to AOPA impacted the entire agriculture industry, including existing operations, in three major areas. First, the amendments have enhanced the province's ability to deal with nuisance, such as odour, noise, dust, smoke or other disturbances resulting from an agricultural operation by establishing a series of provincial standards. Secondly, the new legislation provides producers and other stakeholders with a "one-window" process for the siting of new and expanding CFOs. This approach alleviates the need for the producers and other stakeholders to deal with multiple municipalities during the permitting process. Finally, the Act lays out a set of clear standards for manure storage and application for all farming and ranching operations.

The trend towards larger, more specialized livestock operations in conjunction with the growth in livestock populations has led many operators to build new CFOs or expand their existing operations. However, operators wishing to capitalize on the expanding livestock industry must meet several siting requirements and manure management standards under AOPA. In order to minimize the odour nuisance associated with a CFO, a buffer, known as the Minimum Distance Separation (MDS) must be established between the CFO facility and adjacent properties. While this distance will never be less than 150 metres, it could be as high as 7000 metres, depending on the size and type of the CFO, as well as the land use of the adjacent property. This buffer requirement could have a serious impact on the ability of a livestock operator to expand an existing operation. Several factors related to odour potential are used to calculate the MDS, including a technology factor. This technology factor considers the effect that the manure management system has on reducing the odour nuisance level, and has the capability to significantly reduce the final MDS requirement.

AOPA also includes standards specifically for the siting and construction of solid and liquid manure storage facilities. The objective of these standards is to ensure that manure is handled in a socially and environmentally responsible manner by reducing the risk of contamination in both surface run-off and ground water, and through standards to control the levels of dust and fly infestations.

These provincial regulations that have been recently introduced, have established a foundation for the long-term environmental, social and economic sustainability of the Alberta's livestock industry. However, the impact of this legislation has resulted in an increasing need for innovative technology to mitigate odour and other environmental and social liabilities that are associated with CFOs. As the livestock industry expands and the population pressures increase, the application of technology may, in fact, be the only way that some operations receive regulatory approval or registration.

6.0 GHG EMISSIONS: MITIGATION TECHNIQUES

As discussed in section 2.2, GHG emissions from the livestock industry are primarily in the form of methane and nitrous oxide. While enteric fermentation is a significant source of methane, this discussion paper focuses on GHG emission mitigation techniques with reference to manure management practices. This is of particular interest, as the global warming potentials of methane and nitrous oxide are 21 and 310 times that of CO₂, respectively. As a result, reducing methane and nitrous oxide emissions in favour of CO₂ emissions can significantly reduce the overall impact of the GHG emissions from manure management practices.

Traditional manure management techniques, such as the direct application of beef cattle manure to agricultural land or the collection of swine manure in open earthen storage lagoons, have social and environmental problems associated with their use. While several advanced technologies are currently being tested for practicality in reducing the environmental impacts of livestock waste, including thermal depolymerization, ultrasonic plasma resonator systems and upflow biofiltration, their ability to specifically reduce GHG emissions while enhancing the economic performance of the livestock industry is unknown.

Bio-digester systems, gasification systems and composting are three manure management techniques that potentially meet both the environmental and economic criteria that have been established and have therefore been selected for further analysis.

6.1 Bio-Digester Systems

Bio-digester systems are designed to maximize the methane produced from organic waste products, such as manure, through anaerobic decomposition. While this may seem to contradict the focus of reducing GHG emissions, a bio-digester system captures the methane that is generated, preventing release of the gas into the atmosphere. The methane that is captured can then be flared or burned to provide electricity or heat. Whether flared or burned to produce energy, the combustion process converts the GHG emissions from methane to CO₂, which has a global warming potential 95% lower than that of methane. A bio-digester system consists of four main components: the digester, the gas storage and handling system, the gas consumption (conversion) system, and the effluent storage facility.

6.1.1 Digesters

The primary function of the digester is to augment methane production by providing ideal conditions for the anaerobic decomposition of manure. Under anaerobic conditions, the carbon in the organic portion of the manure will be released in a combination of gases known as biogas. The biogas produced in an on-farm digester is typically 60-70 percent methane (CH₄), with the remainder being CO₂ and trace organic gases (Jones et al, Perdue University).

Methane generation requires two main groups of anaerobic bacteria: the acid formers, and the methane formers. These bacteria can produce significant quantities of methane gas at two distinct temperature ranges: the mesophilic range (32°C - 43°C) and the thermophilic range (49°C - 60°C). Although research is being conducted on thermophilic digestion, the lower methane content of the gas that is produced and the additional heat required to maintain the higher temperature of the process do not currently offset the advantages associated with this type of digestion. As a result, most heated digesters operate in the mesophilic range, at an ideal temperature of approximately 35°C.

There are three main types of digesters that can be used in manure management applications, ranging from the simple covered lagoon to the more complex plug flow and complete mix digesters. The type of digester that is used in any given application is based largely on the manure management method, and the total solids content of the collected manure (AgSTAR Program, 2002). Depending on the type of animal, manure as it is excreted, has a total solids content between 8% and 22%. However, liquid manure management systems, such as those typically used in hog barns, use water to wash the manure out of the barn, which dilutes the manure and therefore reduces the solids content. Solid manure management systems, such as those used at cattle feedlots, tend to have bedding material, such as straw, mixed in with the manure, which increases the total solids content. Because the characteristics of these two manure products are so different, different types of digesters must be used.

Manure with a total solids content of 3% or less are ideally suited to a covered lagoon type digester, as the system is capable of handling the large volumes associated with the low solid

content. This type of digester can be constructed inexpensively by building an earthen storage lagoon, and fitting a membrane over the top to collect the biogas that is produced by the manure. This type of digester typically is not heated, and does not have any type of mechanical agitator to continuously mix the contents of the lagoon. As a result, the level of methane production from the covered lagoon digesters is lower than the more complex digesters, especially in the colder Canadian climate.

Complete mix digesters are heated tanks that are constructed either above ground or sunk partially into the ground and are typically made of either concrete or steel. The tanks are insulated to help maintain the elevated temperature that is required to maximize biogas production. The digester is capped with a variable volume gas-tight cover that facilitates short-term gas storage. Inside the digester, there is a paddle or a pump that periodically mixes the contents of the digester to ensure an even temperature distribution in the liquid. While decomposition of the manure under anaerobic conditions will continue on for quite some time, the rate of methane production drops below the point at which it is economic to recover after approximately 15-20 days. As a result, the tanks are sized to hold 15-20 days worth of manure at any given time. The complete mix digesters work best with manure in a slurry form, with a total solids content of 3 to 10%.

The plug flow type digesters are also heated tanks, but are long and narrow in shape, and are typically built into the ground. These are also capped with a gas-tight cover, but they do not have any type of agitator to mix the manure. This is because the solids content of the manure in a plug flow digester is in the 10-13% range, which is too thick to mix without expensive heavy duty mixing systems. This type of digester is commonly used for dairy cattle, where manure is collected through a scraping process.

6.1.2 Gas Storage and Handling

The sophistication of the gas storage and handling system is dependent upon the type of digester being used, and the end-use of the biogas. However, all of the systems should be designed with variable volumes that can adjust for differences in the rate of gas production and consumption while maintaining uniform pressure (Jones et al, Perdue University). A large number of digesters have gas collection systems that double as a gas storage system. For example, the membrane used to collect methane in a covered lagoon digester, can be designed to store the biogas by expanding like a balloon, until the gas is drawn out for consumption. As a result, gas stored in this method is low pressure, and will only involve short-term accumulations.

High-pressure gas storage is possible, but is quite expensive for on-farm use, as methane does not liquefy under reasonable pressures and temperatures. Unlike other gaseous fossil fuels, such as propane, methane will not liquefy if the temperature of the gas is greater than -106°C, resulting in the need for very high pressures. Because of the cost of the vessels required to store gas at pressures as high as 375 atmospheres (5500 psi), as well as the low heat content of biogas, long-term, high pressure storage is not practical for on-farm applications.

From the gas storage facility, the biogas must be piped to the end-use application, whether this be a waste gas flare, a boiler or an engine-generator set. For the boiler and engine-generator set applications, the continuity of the gas supply is very important, reinforcing the need for short-term gas storage facilities.

6.1.3 Gas Consumption

Because the bio-digester is designed to capture the biogas generated by the anaerobic decomposition of manure, rather than releasing it directly into the atmosphere, the biogas can be consumed in several different ways. The simplest method of consuming the biogas is to periodically flare the gas. While the available energy in the biogas is not harnessed by

flaring, the combustion process converts the methane to CO₂, therefore reducing the impact of the GHG emissions from manure.

The equipment for flaring the biogas is inexpensive to set up, but does not take advantage of the energy content of the gas. As a result, it is possible to use the biogas in a boiler to produce hotwater or steam for heating or another process, or to it can be used to produce electricity through a variety of different technologies. Electrical power generation units can be configured to produce electricity, while the waste heat from the combustion process can be captured to provide hot water. This process, called cogeneration, maximizes the use of the available energy in the biogas by creating both heat and power simultaneously.

In order to provide a reliable and useable source of electricity and heat, it is essential to have a steady supply of biogas. This requirement drives the digester design and management to some degree, as a poorly designed and managed digester will have a non-uniform release of methane that is difficult to use.

6.1.4 Effluent Storage Facility

The anaerobic decomposition process does not reduce the volume of waste to be handled, however, it does reduce the solids content of the waste. As a result, an equal volume of liquid must be removed from the digester when fresh manure is added. The material that is removed from the digester, referred to as the digester effluent, is virtually odour free, but is not suitable for discharge into a watercourse due to the high nutrient levels. The effluent must be stored until it can be used for irrigation or otherwise applied to the land.

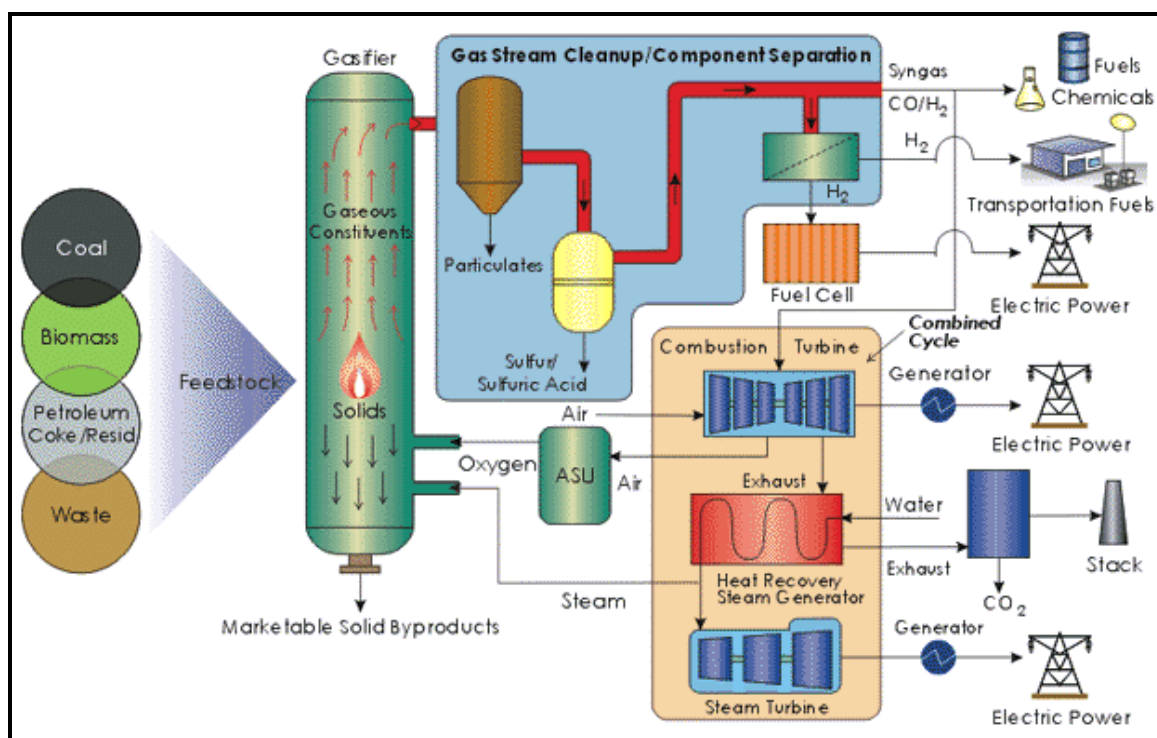
The effluent is typically stored in a lagoon before it is applied to the land, but depending upon the design of the digester, the tank must be dredged out periodically to remove the sediment that accumulates.

6.2 Gasification

Gasification is relatively old technology, and has been in commercial use for over 50 years. The gasification process converts any carbon-containing material into a synthesis gas, referred to as “syngas” which is composed primarily of carbon monoxide and hydrogen. Syngas can be used as a fuel to generate electricity or steam or used as a basic chemical building block for a large number of processes in the petrochemical and refining industries.

While the technology used in gasification systems varies widely, they all share certain general production characteristics. Rather than burning a carbon-based material, such as wood, coal or even manure, the gasification process reacts the material with steam and carefully controlled quantities of oxygen under high temperatures and pressures. The heat and pressure break apart the chemical bonds in the material’s molecular structure, setting into motion chemical reactions with steam and oxygen to form a gaseous mixture, typically hydrogen and carbon monoxide (How Gasification Power Plants Work, U.S. Department of Energy). The process, taking place at temperatures over 800°C, yields energy in the form of hydrogen gas, and waste mineral ash, while completely disposing of the original material. In the case of manure gasification, there is little or no odour produced during the process, as it is a closed system, and the reaction temperature is high enough to destroy any pathogens that may be present, yet low enough to ensure that dioxins are not produced. Because of the temperature of the reaction, the syngas and the waste ash are sterile. Depending on the sulfur and nitrogen content of the material used as a feedstock, the syngas will contain NO_x and SO_x, although post-processing of the gas can separate out these components. As much as 99% of sulfur and other pollutants can be removed from the syngas and processed into commercial products such as chemicals and fertilizers. Figure 3 illustrates the gasification process, as well as the potential end uses for syngas.

Figure 3: Gasification Process



Source: U.S. Department of Energy, Office of Fossil Energy

As illustrated in Figure 3, the gas produced from the gasification process can be separated into its raw components, thus producing pure hydrogen for use in fuel cells. The details of fuel cells will be discussed more completely in Section 11.5, however the fuel cell is used to generate electricity. The syngas, a mixture of primarily carbon monoxide and hydrogen can also be used to fuel a variety of prime movers, such as a combined cycle gas turbine, as is illustrated in Figure 3 or in a wide variety of petrochemical and refining processes.

Because the gasification process requires a feedstock that is dry, and has a moisture content between 5% and 30%, liquid, slurry and even semi-solid manure is not suitable for use in a gasification process. As a result, swine and cattle manure cannot be used as a feedstock for a gasifier without first being dried. This would add cost and complexity to the manure management process, and would likely not be feasible. However, chicken manure is typically very dry, and is much better suited to the gasification process.

6.3 Composting

Composting is a natural biological process, carried out under controlled conditions, which converts organic material into a stable humus-like product called compost. During the composting process, various microorganisms, including bacteria and fungi, break down organic material under aerobic conditions into simpler substances (Composting Council of Canada, www.compost.org)

Composting is a widely recognized process that many people associate with kitchen and garden waste, and can take place either in the backyard or at a municipal landfill site. However, the process is gaining popularity amongst livestock producers as a way to manage the manure that is produced on their farms. Although moisture is a critical ingredient to

successful composting, liquid manure, such as swine manure is too wet to compost in its raw state. The high moisture content of liquid manure would prevent the development of the aerobic microorganisms necessary for composting. As a result, the process is better suited to dryer materials, such as cattle manure, with beginning moisture content of approximately 60% (Hastie, 2003).

Another important issue that must be addressed in order to optimize the composting process is maintaining a proper carbon to nitrogen balance. If the ratio of carbon to nitrogen is too high or too low, the composting process can be slowed down significantly, and can also affect the quality of the end product. As a result, cattle producers who are composting their manure use wood chips in the bedding pack to help maintain an optimal C:N balance. Once the manure and woodchip mixture is loaded out of the pen, it is typically placed in long windrows so that the pile can be turned using a windrow turner. The purpose of turning the pile is to ensure that the manure stays aerated, thus allowing the aerobic microorganisms to breakdown the organic matter. The grade of compost that is desired, will dictate the number of times that the pile must be turned, with more turns typically yielding a higher grade of compost material.

Finished compost can be applied to soils as a fertilizer, as it contains nitrogen, phosphorous and potassium in forms that are readily available to plants. The organic matter also enhances the soil's water-holding ability, meaning that water is held in the root zone for plant use. Because the composting process takes place in the thermophilic range (49°C - 60°C), pathogens and weed seeds that might originally be contained in the manure are destroyed. As a result, the compost material is ideally suited for spreading on agricultural lands or for use in cultivated gardens.

Due to the high moisture content, it is not economical to haul raw manure over distances greater than about 15 km (Larney, 2003). As a result, manure is spread on land close to the source at high application rates. The composting process reduces the moisture content of the manure to approximately 25% and also reduces the carbon content of the manure through CO₂ emissions, thus greatly reducing the volume of the original material. The more homogenous nature of the composted manure in combination with reduction in volume and moisture content improves the haul cycle economics, and therefore enables nutrients to be applied over a larger area, reducing the high application rates that are associated with raw manure. Because composting is an aerobic process rather than an anaerobic process, odours associated with decomposing manure are virtually non-existent which is advantageous in terms of both manure storage and land application.

7.0 COMPARATIVE ANALYSIS

To evaluate each of the manure management methods and facilitate a comparative analysis of the various technologies, a series of qualitative and quantitative criteria was established. The criteria were developed to specifically evaluate the social, environmental, technical and economic objectives that are important to the stakeholders, which include the CFO operator, Climate Change Central and the general public. The criteria used for the analysis include:

- Applicable animal types
- Maturity of technology
- Use of technology in Alberta
- Magnitude of GHG reduction
- Cost of GHG reduction (\$/tonne)
- Economic viability
- Project replication

- Minimum efficient scale
- Number of potential sites for application
- Environmental controls
- Nutrient by-product
- Energy by-product
- Complexity of technology
- Potential impact of GHG reduction

7.1 Applicable Animal Types

Because of the processes involved, each of the different manure management techniques is suitable to specific types of manure, and therefore applicable only to specific types of animals. Because there are several different bio-digester designs, the systems are capable of handling a variety of different manure consistencies, from liquid to semi-solid. Based on the manure management techniques used in Alberta, bio-digester technology is suitable for swine and some dairy cattle manure, although a pilot project using beef cattle manure is scheduled to begin in the fall of 2003. The higher concentration of fine solids in poultry manure can cause problems in a digester, and is therefore better suited to other treatment methods.

Because of the low moisture content of the feedstock that is required for a gasification system (5 – 30%), poultry manure is ideally suited to this process. Other types of manure, such as swine and cattle manure are too moist to be used in a gasification system without first being dried, which is costly and adds complexity to the system. Composting is suitable to slightly more moist materials, and can be successfully implemented with cattle and poultry manure.

7.2 Maturity of Technology

The maturity of the technology associated with various manure management techniques helps establish the ease in which a manure management system could be implemented on a commercial scale. While modifications to the technology may be required to meet the requirements of Canadian CFOs, due mainly to our harsh climate, the use of similar systems in other countries or industries significantly reduces the barriers typically associated with untested technology.

The technology associated with bio-digesters, gasification systems and composting is relatively mature, however, research continues to improve the efficiency and expand the application of the various processes. Bio-digester technology is well established in Europe, and has been adapted for use in the United States, where there are over 30 operating digesters. Due to a variety of factors, including climate and less stringent environmental regulations in the past, digesters are not common in Canada.

Gasification technology is also well established and is used around the world to make chemical building blocks for a large number of processes in the petrochemical and refining industries. The feedstock for these processes is typically a high-energy material such as coal or petroleum by-products, and as a result, gasification systems built for manure management purposes are not very common.

Manure composting techniques, typically associated with beef and poultry manure, are well developed in North America. Despite the comparatively widespread use of manure composting, research is still being performed by a variety of organizations, including Agriculture and Agri-Food Canada and the Alberta Agriculture Research Institute, to identify the most cost-effective methods of commercialization without sacrificing the quality of the end product.

7.3 Use of Technology in Alberta

The level of use of the three manure management techniques that have been discussed indicates the degree to which the technology has already been introduced to the agriculture industry in Alberta. Value is recognized if technology implementation can be used to establish a leadership role that increases public awareness and encourages additional operations to adopt the technology.

As mentioned previously, the use of bio-digesters is not common in Canada. However, there is at least one production scale digester system operating in Alberta on the Iron Creek Hutterite colony near the town of Viking. This system was designed and built for a 1200 sow hog operation, and generates both heat and electricity that is consumed by the colony (MacArthur, 2003). In addition to this, a unique bio-digester project has been proposed to handle drier beef cattle manure from a feedlot near Vegreville, and is scheduled for construction in late 2003 and early 2004.

While gasification systems are widely used in the petrochemical industry, there are no known commercial scale manure gasification systems currently operating in Alberta or in the rest of Canada. However, a poultry operator in southern Alberta has expressed interest in this technology, but no formal project proposal has yet been made.

Manure composting techniques, typically associated with beef and poultry manure, are well established in North America. Several feedlot operators in Alberta are using composting techniques to help reduce the volume of manure that must be handled during land spreading as well as to provide additional sources of revenue.

7.4 Magnitude of GHG Reduction

Each of the three technologies that have been discussed is an effective method of reducing GHG emissions, however, the magnitude of the reduction varies based on the chemical and physical processes involved.

The bio-digester systems are designed to augment methane production from the anaerobic decomposition of the manure, while an airtight cover captures the biogas that is produced. The biogas is then reacted with oxygen in a combustion process that converts the methane to CO₂ and H₂O before it is released to the atmosphere. The composting process also decomposes manure, but under aerobic rather than anaerobic conditions. Due to the presence of oxygen during the decomposition process, composting primarily generates CO₂ instead of CH₄, therefore reducing the impact of the GHG emissions on the environment.

As with the anaerobic decomposition process found in a bio-digester, the gasification process also takes place in a closed system. Through a reducing reaction involving heat and pressure, organic material that is fed into the process is converted primarily into a gas made up of CO and H₂. Neither the gasification process nor the combustion of the resulting syngas generates any significant quantities of GHGs. Under ideal conditions, the gasification process is effective at virtually eliminating all GHG emissions from livestock manure, however this comes at a cost.

7.5 Cost of GHG Reduction

To build and maintain the infrastructure for either a gasification system or a bio-digester is an expensive endeavour, with the capital cost alone easily reaching into the hundreds of thousands of dollars. However, the potential of each technique to reduce emissions must also be considered. Based on the manure management methods that are currently being practiced in North America for each type of animal, the methane potential from manure varies. The Intergovernmental Panel on Climate Change (IPCC) has established factors for

methane emissions from manure management for common types of livestock. Table 7 lists the various IPCC emissions factors for common types of livestock.

Table 7: IPCC North American Methane Emissions Factors

METHANE EMISSIONS FACTORS FOR COOL CLIMATE	
Livestock Type	Emissions Factor (kg/head/year)
Dairy Cattle	36
Beef Cattle	1
Swine	10
Poultry	0.078

Source: IPCC Guidelines for National Greenhouse Gas Inventories

The emissions factor is so low for beef cattle due to the assumption that the manure is managed as a solid, and is deposited on pastures or ranges, resulting primarily in aerobic decomposition. This is not entirely true for feedlot animals, as the higher concentration of manure in a smaller area likely leads to slightly higher levels of anaerobic decomposition. In order to remain conservative, it is assumed that the methane emissions factor for beef cattle of 1 kg/head/year is the weighted average emission of range cattle and feedlot cattle. Therefore, let us assume that 80% of the beef cattle in Alberta that are not kept in a CFO have a slightly lower emissions factor of 0.9 kg/head/year. In order to maintain the average of 1 kg/head/year, the emissions factor for the 20% of the beef cattle that are kept in a CFO can be calculated to be 1.4 kg/head/year

Using the methane emissions factors, including the revised factor for feedlot cattle, as well as the estimated capital cost of the technology used to mitigate GHG emissions, the estimated cost per tonne of emission reduction can be calculated for operations of a similar scale. Table 8 summarizes the methane potential, capital costs and the costs of methane reductions based on specific types of livestock and manure management technology.

Table 8: Estimated Costs of Emission Reductions for CFO Livestock

ESTIMATED COSTS OF EMISSIONS REDUCTIONS					
Livestock Type	Head¹	Methane Potential (t/year)	Technology Required	Capital Cost (\$ 000's)	Cost of CO₂e Reduction² (\$/tonne)
Beef Cattle (feeders)	20,000	28 ³	Windrow Turner and Dump truck	250	\$ 28
Swine (feeders)	50,000	500	Bio-Digester and Generator	4,500	\$ 29
Poultry	125,000	9.75	Gasification System and Generator	275 ⁴	\$ 90

7.6 Economic Viability

As can be seen in Table 8, even though gasification systems are very good at reducing GHG emissions, they are the most costly to implement on a capital cost per tonne of direct reduction basis. Because there is no legislation that requires a livestock operator to use any of the manure management technology that has been discussed, the revenue streams that can be generated from the technology must offset both the capital costs and the operating costs of any manure management technology. Bio-digester systems can produce power and heat as well as bio-fertilizer products that can offset the cost of implementing the technology. However, power generation provides the largest revenue stream, and as a result, the economic viability of a biodigester is linked directly to the current prices of natural gas and electricity. Based on the current energy prices in Alberta and the risk associated with predicting future energy prices, a bio-digester project would provide only a minimal return.

Because gasification systems can also be used to produce electricity and heat, the economic viability of these systems is also linked to current energy prices. However, the gasification technology is not as well established for use with a manure-based feedstock, and there is less information available to determine whether a project would be economically viable. As a result, it is suspected that like the biodigester systems, a gasification system would also only provide a minimal return.

Composting techniques generate a dry, stable, nutrient rich material that can be spread on local fields or sold commercially to golf courses, sod farms, as well as to individual consumers to enhance soil quality. Because the compost material is dryer and has better spreading characteristic than raw manure, there is an economic advantage to livestock operators, as the nutrients from manure can be spread more easily, and can be distributed further from the source. This handling advantage in combination with commercial sales of

¹ Number varies by livestock type, but is based on 10,000 “animal units” (where possible), as defined in the AOPA.

² Based on a 15-year project life cycle, and 100-year Global Warming Potential for methane of 21.

³ Based on revised methane emission factor of 1.4 kg/head/year for feedlot cattle.

⁴ Currently, the estimate for a project of this magnitude is in the \$550,000 – \$750,000 range, however, once the technology becomes more established, it is assumed that the capital cost could be reduced to the \$275,000 range.

horticultural grade compost can produce a slightly positive return from a compost project when it is analyzed on a “whole farm” basis.

7.7 Project Replication and Minimum Efficient Scale

Another advantage of composting as a technique to reduce GHG emissions is the ability to replicate the concept amongst multiple operators. Because the minimum efficient scale is fairly small, and the equipment that is required is available in a variety of different sizes and levels of complexity, it is relatively easy to scale composting to almost any size of operation and still maintain a positive return on investment.

Bio-digester and gasification systems are also replicable, but not to the same degree. Because of the complexity of the systems and the capital cost involved, the minimum efficient scale of a bio-digester or a gasification system is considerably larger than it is for composting systems. These more complex systems both require certain components, such as electronic control systems, motors and pumps that have a non-linear relationship between cost and capacity. For example, the cost of the electronic control system required for a 20,000 hog capacity bio-digester may only be 25% higher than the cost of the control system for a 10,000 hog capacity unit, despite the fact that the capacity of the bio-digester system has increased by 100%. As a result, the capital cost per head grows exponentially as the capacity of the unit is reduced.

7.8 Number of Potential Sites for Application

The number of potential sites for the application of manure management techniques such as bio-digesters and gasification systems, is a factor in determining both the potential impact of these systems and the areas of potential research. This criterion is tied closely to the minimum efficient scale of the technology as well as the distribution of livestock in the province.

It is estimated that at best, bio-digesters are currently applicable to only 3.5% of the swine farms in Alberta that have over 4,685 head. Although this percentage may seem low, these larger operations account for 40% of the swine population in the province (Alberta Agriculture, Food and Rural Development, 2003). Gasification systems would be disadvantaged in the same way, applying only to a small number of poultry farms that could achieve the minimum efficient scale in terms of the number of chickens.

Composting, due to the smaller minimum efficient scale that can be achieved, could likely be applied to beef cattle feedlots with as less than 1,000 head of capacity. This would account for a large portion of the feedlot operations in Alberta, and would likely include over 90% of total population of feedlot cattle.

7.9 Environmental Controls

With increasingly rigorous environmental regulations and permitting requirements facing confined feeding operations, including the amendments made to AOPA in 2002, concerns around air quality (odour control) and water quality are influencing and controlling the construction and expansion of CFO's. As a result, any improvement in air and water quality that a manure management system can impart is considered to be advantageous.

One of the ancillary benefits of all three techniques for mitigating GHG emissions, is that they virtually eliminate the odour associated with manure management. In the case of bio-digesters, the manure is decomposed in a closed environment, with a sealed cap to collect the biogas that is produced. The biogas is combusted in a generator or a boiler, and the exhaust gas is primarily CO₂, which is odourless. The gasification process is similar, in that the manure is reacted in a closed system until it is broken down into gaseous constituents,

made up primarily of CO and H₂, which are both odourless gases. Composting, while not a closed system, is an aerobic process and virtually eliminates the odour associated with the anaerobic decomposition of manure.

These manure management techniques can also help to improve water quality in terms of ground water and surface run-off. In the case of composting, surface run-off will not be prevented, however, the elevated temperature and duration of the composting process eliminates pathogens that could contaminate surface run-off. This is particularly true where compost is spread on agricultural lands, in place of raw manure. The more complex biodigester tanks used with the complete mix or plug flow digesters can be constructed either above ground, or sunk down into the ground, but are generally steel or concrete structures. As a result, barring any crack in the structure, the digester tanks eliminate any groundwater contamination. The duration and temperature of both the thermophilic and the mesophilic digestion processes are also capable of eliminating pathogens from the manure, and the effluent from the digester contains nutrients in a form that are more accessible to plants. As a result, this significantly reduces the contamination of surface run-off when the effluent is applied to agricultural lands. Gasification systems also operate at high temperatures, therefore eliminating any pathogens that might be present by reacting manure with limited quantities of oxygen at high temperatures.

7.10 Nutrient By-Product

Because of the high concentration of livestock at a CFO, the local agricultural land must be used to grow feed to sustain the large number of animals that are being raised. Before the advent of the more advanced manure management techniques, livestock manure from CFOs was eventually spread on the adjacent land, returning the unused nutrients back to the soil from which they originally came. This process is very important, as it helps to ensure that the land will continue to be productive in the future. However, many advanced manure management techniques require livestock manure to be processed, which means that it can no longer be applied as raw manure to the local agricultural land. As a result, it is important that any manure management technique used to reduce GHG emissions have a nutrient by-product that can be used to return unused nutrients to the local soils.

The effluent from a bio-digester and composted manure both contain all of the nutrients that were present in the raw manure, and can be applied directly to agricultural land. After processing the manure with a bio-digester or through composting, the nutrients are in a form that is more available to plants, thus making these manure management techniques advantageous.

The residual ash from a gasification process also contains nutrients, but it must be processed into a fertilizer product before it can be applied to agricultural soils. This is partly due to the difficulty associated with spreading ash as well as ensuring that the ash binds to the soil. As a result, the gasification process requires an extra step to ensure that a useable nutrient by-product is available.

7.11 Energy By-Product

The capital cost and operating cost associated with manure management techniques like bio-digesters, gasification and composting means that a revenue stream must be generated to ensure a positive return on the project. Given the rising energy costs that agricultural producers in Alberta are facing, an energy by-product, such as a combustible gas that can be used to power an electrical generator or a boiler is considered to be advantageous. Additionally, the use of combined heat and power (CHP) systems (see Section 11.0), allows for increased energy efficiency, as waste heat from an electrical generator can be captured to supplement local heating demands.

Bio-digesters and gasification systems both produce low energy combustible gas (biogas and syngas) products. While the gases cannot easily be stored in the long term, the ability to use the captured gases to generate electricity and produce heat are distinct advantages that have the potential to produce significant streams of revenue. While composting is also capable of producing a revenue stream from the sale of horticultural grade compost, the technique does not generate any form of energy that can be easily captured and used to offset power and heating costs associated with the operation.

7.12 Complexity of the Technology

CFO operators specialize in the production of livestock that meets specific market requirements at the lowest possible cost. While technology is used to maximize productivity, the agricultural community is slow to adopt new technology that is unproven, particularly if it is complex in nature. As a result, despite the advantages associated with some manure management techniques, the complexity of the associated technology may provide a barrier to its widespread use if an appropriate demonstration is not established.

Composting is likely considered the least complex of the three manure management techniques in terms of technology. While the science behind good composting is no less complex, the only special equipment that is required is a windrow turner. These vary in size from tractor attachments that are PTO-driven to large, self-propelled windrow turners that are capable of turning piles up to 10 feet in height. In comparison, the complexity of the control systems, pumps, generators, heat recovery systems and mixing systems of a biodigester or a gasification system requires higher levels of operator expertise in terms of both proper operation to maximize performance and ongoing maintenance.

7.13 Potential Impact of GHG Reduction

Based on the combination of many of the criteria discussed in this analysis, the potential impact of the GHG emission reductions can be evaluated for each of the different manure management alternatives. The biodigester has a fairly large potential impact, as it can be applied to the liquid manure management systems used for swine and some dairy cattle, as well as potentially beef cattle. Of the CFO's that are potentially large enough to apply the various technologies, swine account for 73.1% of the methane emissions from CFO livestock manure in Alberta. As a result, any technology that can be used to mitigate these emissions will have a significant impact. Table 9 illustrates the contribution of methane emissions from CFO livestock manure by livestock type.

While gasification virtually eliminates all GHG emissions, the technology can only be applied to poultry manure because of the low moisture content that is required. Despite having approximately 13 million chickens in the province, methane emissions from CFO poultry manure only accounts for 3.8% of the total from CFO livestock in Alberta. As a result, the potential impact of GHG emission reductions from gasification systems is quite low. The composting of manure can be applied to beef cattle, poultry and dairy cattle when the manure is not handled with a liquid manure management system. Despite the broad potential application for composting, the manure that can be composted accounts for less than 20% of the methane emissions from CFO-based livestock manure, as the larger dairy barns use liquid manure management systems.

Table 9: Contribution of Methane Emissions from Applicable CFO Livestock

CONTRIBUTION OF METHANE EMISSIONS FROM APPLICABLE CFO'S				
Livestock Type	Emissions Factor (kg/head/year)	Applicable Population⁵	CH₄ Emissions (tonnes/year)	Contribution by Livestock Type
Dairy Cattle	36	76,800	2,765	15.7%
Beef Cattle	1.4 ⁶	916,560	1,283	7.3%
Swine	10	1,283,940	12,839	73.1%
Poultry	0.078	8,618,745	672	3.8%
TOTAL			17,559	

7.14 Summary

A summary of the preceding comparative analysis can be found in Table 10.

⁵ Assumes 60% of the dairy cattle and swine, 65% of the poultry and 18% of the beef cattle in Alberta are maintained on CFO's that are large enough to apply the various technologies being discussed.

⁶ Revised methane emission factor of 1.4 kg/head/year for feedlot cattle.

Table 10: Summary Table of Comparative Analysis

COMPARATIVE ANALYSIS SUMMARY			
	Bio-Digester	Gasification	Composting
Applicable animal types	Swine Dairy cattle Testing for beef cattle	Poultry	Beef cattle Poultry Dairy cattle – dry systems
Established Technology	Yes. Technology is well established in Europe and is used to some degree in the U.S.A.	Gasification technology is well established, but not widely used for manure management.	Yes. The process of composting manure is well established.
Existing Projects in Alberta	Iron Creek Hutterite Colony IMUS (project to begin in fall 2003)	No	EcoAg Initiatives at Roseburn Ranches Porcupine Corral Cleaning
Magnitude of GHG reduction	Virtually eliminates all CH ₄ emissions from anaerobic decomposition of manure, as process captures the gas. Captured CH ₄ is typically combusted, producing CO ₂ .	Eliminates all GHG emissions. Process generates CO and H ₂ .	Eliminates virtually all CH ₄ emissions, as manure is maintained in a aerobic state that produces only CO ₂
Cost of GHG reduction (\$/tonne basis)	Low	High	Low
Economic viability	Marginally positive with current energy prices.	Unknown, although suspected to be marginal. Linked to current energy prices	Slightly positive return when evaluated on a whole farm approach. Composting allows nutrient rich manure to be hauled further for land application and can also be sold commercially.
Project replication	Technology is replicable, but a minimum efficient scale is a limitation.	Technology is replicable, but a minimum efficient scale is a limitation.	Technology is easily replicable.
Minimum efficient scale	Limited to use on medium to larger sized operations (i.e.: swine operations with more than 4,650 head)	Limited to large sized operations (i.e.: chicken farms with more than 100,000 birds)	Technology can be used for virtually all sizes of operations
Number of potential sites for application	Low, due to minimum efficient scale that is required	Low, due to minimum efficient scale that is required	High, due to small minimum efficient scale that is required

COMPARATIVE ANALYSIS SUMMARY

	Bio-Digester	Gasification	Composting
Environmental controls	<p>Controls odour</p> <p>Heated biodigester processes destroy pathogens</p> <p>Minimizes/eliminates contamination of groundwater and surface run-off</p>	<p>Controls odour</p> <p>Process destroys pathogens and prevents development of dioxins</p> <p>Eliminates contamination of groundwater and surface run-off</p>	<p>Controls odour</p> <p>Process destroys pathogens</p> <p>Eliminates pathogen contamination of surface run-off.</p>
Nutrient by-product	Yes, bio-digester effluent is nutrient rich.	Yes, but ash must be processed into fertilizer product.	Yes, compost is nutrient rich.
Energy by-product	Yes, biogas contains 60-70% CH ₄	Yes, syngas is a mixture of CO and H ₂	No
Complexity of technology	Medium - High	Medium - High	Low
Potential impact of GHG reduction	High, as this technique can be applied to a variety of different livestock types, including swine.	Low, as this technique really only applies to poultry. CH ₄ emissions from poultry manure make up a small component of the total emissions from the livestock industry (see Table 9).	Low, as this technique applies primarily to beef cattle manure, which has low methane potential given the current manure management techniques.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The primary concern of a CFO operator prior to making any investment in technology, whether it is for manure management or another purpose, is the economic benefit associated with implementing the technology. As with any successfully run business, the project must have a positive return, otherwise the investment should not be made. Without going into a detailed cost-benefit or financial analysis, the comparative analysis suggests that the economic return for each of the different manure management technologies is marginally positive given current energy prices. This implies that a CFO operator could successfully implement any of the three systems, depending on the type of livestock that is being raised. However, based on the other criteria that were used to evaluate the various systems, the bio-digester appears to be the most advantageous technology to pursue when examining biowaste opportunities for GHG emission reductions and potential distributed electricity generation.

Aside from the marginal economics of a bio-digester project, the technology has a number of positive characteristics. Bio-digesters are the very efficient in terms of GHG emissions reduction, as the cost per tonne of CO₂e emissions reduction is comparatively low. This means, for example, that the bio-digester technology can effectively reduce methane emissions by more, for every dollar that is invested, than that of a gasification system. Additionally, the bio-digester has the largest potential impact in reducing GHG emissions, as they can be used to process swine manure, which accounts for 73.1% of the methane emissions from applicable CFO livestock manure in Alberta.

Despite the apparent advantages of the bio-digester, the technology is already fairly well established, with at least one system developed and operating in Alberta. There are at least two other large-scale projects that have been proposed, one in Alberta and one in Saskatchewan, which will likely be constructed in late 2003 and early 2004. As a result, the value of sponsoring a bio-digester pilot project may be questionable at this point, unless the technology can be geared specifically toward the small to medium sized operations. These smaller operations, which account for 20-30% of the Alberta livestock population, typically cannot achieve the minimum efficient scale that is required to build a biodigester, resulting in lost potential for methane emission reductions.

While the bio-digester technology appears attractive, it must be recognized that none of the manure management technologies discussed are capable of handling all types of manure. As a result, there is clearly no one right answer when it comes to selecting the best technology. By establishing a three pronged approach, and acting on the following recommendations, Climate Change Central can establish a strategy that works toward maximizing the reduction of methane emissions from all the major components of the livestock industry in Alberta. The recommendations are described in order of priority.

8.1 Development of Bio-Digester Technology for Swine Manure

It is recommended that Climate Change Central concentrate on the implementation of bio-digester technology with a focus on the swine industry, as this has the largest potential for methane emission reductions. The current minimum efficient scale of the bio-digester means that the technology only applies to about 40% of the swine population in Alberta. By focusing additional efforts on reducing the minimum efficient scale that is required, the application of the bio-digester could be expanded, potentially including another 25 – 30% of the swine population.

Further research should also be conducted on the impact of adding other waste products to the bio-digester waste stream. The addition of other waste products, such as livestock mortality or supermarket meat waste, while increasing the complexity of the system could

increase the quantity of methane that is produced by the bio-digester, and therefore the quantity of electricity that could be generated. This would improve the economics of a bio-digester system, potentially making the investment in the technology more attractive.

While bio-digesters already exist or have already been proposed in Alberta and elsewhere in western Canada, further development of this technology will likely improve the acceptance of bio-digesters amongst CFO operators, as well as lead to improvements in system efficiencies. This has the potential to reduce the capital cost and operating costs involved with implementing a project of this magnitude, ultimately reducing the risk associated with the technology.

8.2 Chicken Manure Gasification Pilot Project

It is also recommended that Climate Change Central pursue the implementation of a gasification pilot project for poultry manure. Because bio-digesters are not suitable for use with chicken manure, gasification systems provide another alternative that allows energy to be captured from chicken manure while reducing methane emissions. The first step will be to establish that a positive energy balance can be achieved, meaning that more energy can be produced than is required by the system. Once this is established, efforts should be focused on reducing the minimum efficient scale of the technology, therefore making the systems available to not only the large poultry operations, but the medium sized operations as well.

Gasification technology is not widely used for manure management, and the potential for methane emissions reductions through the implementation of this technology is currently quite small; the applicable poultry population accounts for less than 4% of the methane emissions from livestock manure in Alberta. However, the average annual growth rate of the poultry population in Alberta between 1996 and 2001 was over 5%, a trend that is likely to continue. This, in combination with the increasing pressures to reduce the impact of CFO's on the environment in terms of air quality (odour) and water quality, suggests that the potential application of this technology is increasing.

Further research should also be conducted on the impact of supplementing the feedstock with other waste products. The addition of other waste products, such as straw, woodchips or potentially livestock mortality, while increasing the complexity of the feedstock delivery system, could increase the quantity of syngas that is produced by the gasification system, and therefore the quantity of electricity and heat that could be generated. This would improve the economics of a gasification system, potentially making the investment in the technology more attractive.

By establishing a pilot project, it is anticipated that the risk to the CFO operator associated with the implementation of new technology will be mitigated to an acceptable level. As a result, the proliferation of this technology amongst poultry CFO operators will be dependent upon establishing an operational commercial scale system that provides a visible positive financial return.

8.3 Promotion of Cattle Manure Composting

Finally, it is recommended that Climate Change Central assist with or establish public outreach programs that promote the composting of cattle manure for both beef feedlots and older style dairy barns. This would include providing information on composting techniques that are currently in use in Alberta, providing easy access to research that has been conducted and showcasing of existing composting operations.

Because manure composting is currently being practiced in Alberta by at least two beef cattle operations and is providing those operations with an additional revenue stream, the public outreach program must be carefully designed so as not to promote specific providers of

manure compost. Instead, the concept of composting must be promoted by describing the generic benefits associated with composting based on the whole farm approach.

As with the poultry manure gasification systems, the potential for methane emission reductions from manure composting is not enormous, but if it can be demonstrated that there are a variety of benefits, including a reduction in methane emissions, the technology may be adopted by more feedlot and dairy barn operators.

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10.0 APPENDIX A – SUMMARY OF MANURE MANAGEMENT TECHNIQUES

Table 11: Advantages and Disadvantages of Manure Management Techniques

MANURE MANAGEMENT TECHNIQUES		
Livestock Type	Advantages	Disadvantages
Bio-digester	<ul style="list-style-type: none"> Ability to stabilize raw manure (effluent is virtually odour free) Almost complete retention of fertilizer nutrients Can stabilize more waste per unit volume than other treatment facilities Ammonia control GHG reduction Water quality protection Facilitates the capture of energy from a waste product 	<ul style="list-style-type: none"> High capital cost Economic viability is dependent upon current energy prices System requires additional expertise to ensure proper operation. The minimum efficient scale is quite large
Gasification	<ul style="list-style-type: none"> Eliminates almost all GHGs by breaking manure down into gaseous constituents. End products (gases and solids) are free of pathogens and dioxins. Facilitates the capture of energy from a waste product. Other waste, such as wood chips, can be added to the feedstock to increase the energy potential of the system. 	<ul style="list-style-type: none"> High capital cost Economic viability is dependent upon current energy prices System requires additional expertise to ensure proper operation Positive energy balance must be confirmed. CO is a waste product of the gasification process. While this is not a GHG, it is poisonous to humans and generates ozone.
Composting	<ul style="list-style-type: none"> Relatively inexpensive to set up Minimum efficient scale is quite small Process eliminates pathogens and weed seeds Compost is easier to handle and spread on agricultural land 	<ul style="list-style-type: none"> No energy harnessed from the composting process

11.0 APPENDIX B – CHP TECHNOLOGY

Combined heat and power (CHP), or cogeneration, is a process that allows the capture of both electrical output and heat from an electrical generator. With the exception of fuel cells, electrical generators consist of two main components: a prime-mover which provides energy input, and a generator which provides energy output. The prime-mover, powered by either steam or a fuel such as diesel or natural gas, turns a shaft that is connected to the generator. As the generator shaft rotates, electrical current is produced, and it is transmitted to the location where the power is needed through electrical power lines.

The CHP process applies to systems that are equipped with a fuel burning prime-mover, such as a diesel or natural gas powered reciprocating engine, or a natural gas powered industrial turbine or micro-turbine. In a CHP system, the prime-mover generates electricity by mechanically turning the generator shaft, but the waste heat created by the internal combustion process of the prime-mover is also captured and used locally. For example, consider a university campus where a gas turbine CHP system is used to generate power to meet the electrical demands of the campus instead of relying on grid-supplied power. The waste heat generated by the combustion process in the gas turbine can also be captured and used to heat the buildings on campus through a central heating system.

The delivered efficiency of a generator, or the measure of electric energy that is produced divided by the total fuel energy consumed, varies on the type of technology that is used. The coal-fired generators that provide a majority of the electricity in Alberta have a delivered efficiency of approximately 35 percent, while the efficiency of reciprocating engines ranges between 28 and 42 percent. By capturing the waste heat produced by a combustion process, the delivered efficiency of a CHP system can reach over 80 percent. Of course, the delivered efficiency of a CHP system is dependent upon the fact that there is a need and a use for the waste heat. Capturing the waste heat from a large centralized coal-fired generating station may not be useful, as the supply of heat would likely exceed the local demand. As a result, the concept of CHP is usually associated with distributed generation facilities.

11.1 Distributed Generation

Distributed Generation (DG) is broadly defined as the production of electricity near the point of use, and is typically associated with small-scale power generation facilities. Although large, centralized generation facilities can often provide more power at a lower cost, some utilities see that DG can shore up weak transmission systems, delay or defer new transmission lines or power plants and improve the reliability and power quality for customers (Steve Blankinship, Power Engineering).

In Alberta, the combination of increasing demand for power, de-regulation of the power generation industry and environmental concerns have made DG an attractive alternative to the development of additional centralized power generation facilities. Advancements in both engine technology and remote monitoring systems have increased the reliability and efficiency of DG systems making them viable alternative during peak demand hours. DG systems can be operated either off the grid, supplying power to local consumers through a localized distribution network, or they can be interconnected to the provincial grid, where a process called “net-metering” allows distributed generators to receive credit for power that they supply to the grid.

In the case of livestock producers, GHG mitigation techniques that generate methane or hydrogen, such as bio-digesters or gasification, can provide the fuel for DG applications. The quantity of manure and the efficiency of the digester or gasification process will dictate the quantity of gas that can be produced, and therefore the size of the DG application. While prime-movers and electrical generators can be purchased in a variety of capacities, the

minimum quantity of electricity that is useful for DG applications appears to be in the 30-40 kW range. This translates to approximately 5000 head of swine to achieve the minimum efficient scale.

In order to maximize the return on DG investments, monitoring the price of power is very important. The price per kWh of electricity varies on the type of technology employed, but by having the DG facility interconnected to the provincial grid, the maximum return can be realized. When the price of power from the grid is higher than the cost to produce power from the DG asset, the DG asset should be operating, thereby providing the user with lower cost electricity. When the price of power from the grid is below the cost of producing it with the DG asset, the DG asset should be turned off, and power should be purchased from the provincial grid. Typically, the price of power is higher during the day, but can drop as low as \$0.01 per kWh overnight. As a result, it is important that any gas producing system have the capability to store up to 12 hours of gas so that maximum return can be achieved on the DG asset by running the system during the day.

If CHP technology is employed, it is important to realize that when the DG facility is not operating, heat will not be available. As a result, the requirement for a constant supply of heat may dictate that the DG facility be either operated around the clock, despite the higher costs, or an alternate source of energy be used to supplement the heating requirements while the DG asset is not operating.

There are a variety of technologies that can be employed in DG applications, each with their own advantages and disadvantages. The following sections identify the details of each of the mainstream technologies, citing the positive and negative aspects of each.

11.2 Reciprocating Internal Combustion Engines

Reciprocating internal combustion engines, otherwise known as conventional piston engines are by far the most common type of prime-mover used in DG applications. While piston engine technology is always advancing, the core concept has been in use for over 100 years. In DG applications, these engines are typically fuelled with either diesel or natural gas and range in size from just a few horsepower to over 2500 horsepower. These larger piston powered generators, with rated electrical capacities of over 1.5 MW, have a delivered efficiency, without CHP, in the range of 37 – 40%. However, three engine manufacturers have embarked on a cooperative venture with the US Department of Energy to improve efficiency and reduce the environmental impact of large, natural gas-fired engines. These engines are targeted to reach delivered efficiency levels of up to 50% without CHP, which is very close to the efficiency of a combined cycle gas turbine generator.

Because of the number of moving parts in a reciprocating engine, regular scheduled maintenance is required to ensure that the expected life cycle of the equipment is reached. Despite the need for regular maintenance, the installation cost per kW is the lowest amongst all of the different DG technologies.

11.3 Microturbines

A microturbine is a compact turbine generator that delivers both electricity and heat close to the point where it is needed. This form of distributed generation technology is relatively new, making its commercial debut in 1998. The electrical generating capacity of these units is quite small, with popular models available at 30 kW and 60 kW capacities.

The microturbine is capable of operating on a variety of gaseous and liquid fuels, including low energy fuels, such as the biogas generated from a bio-digester. However, due to the high speed of the turbine components, it is important that the fuel be free of any particles, such as water droplets, to prevent damage to the system. The delivered efficiency of the

microturbine is quite low at 25-28%, however, with CHP technology to capture the waste heat generated by the combustion process, the combined efficiency can reach 80%.

Due to the nature of turbine engine design, the microturbine has only one moving part, a significant reduction when compared to the conventional reciprocating engine, which results in a generating system that requires very little maintenance. Cummins claims that scheduled maintenance on their microturbine systems is only required once every 8000 operating hours. As a result, the operating costs of a microturbine powered DG system are significantly lower than that of conventional piston powered systems. Another advantage of the microturbine is the low emissions levels that can be achieved under a variety of load conditions, enabled by the continuous-combustion characteristics of the gas turbine engine.

Despite the apparent advantages of the microturbine, the technology is complex and relatively sensitive to its operating environment when compared to conventional piston engines. The microturbine is also relatively new technology, and does not yet have a large installed base. As a result, the installed cost per kW is considerably higher than more conventional systems.

Advantages:

- Can use a wide variety of gaseous and liquid fuels, including low BTU fuels such as bio-gas
- Low emissions
- Few moving parts, requires less maintenance (scheduled maintenance every 8000 hours)
- Quiet operation
- Compact design

Disadvantages

- New technology is not totally proven
- Fuel cannot contain any solids or liquids (water droplets, etc.)
- Low delivered efficiency (25-28%)
- High capital cost

11.4 Industrial Turbines

Industrial turbines are significantly larger than microturbines, and have been commercially available for over 40 years. Mid-sized industrial turbines, used primarily for oil and gas production as well as transmission and power generation, have output capacities above that which can be achieved with a conventional piston engine. In terms of electrical power generation, the capacity available from mid-sized industrial turbines ranges from 1 MW to 15 MW, where the largest reciprocating engines are only capable of producing about 2 MW. The industrial turbine is therefore used only in larger applications.

The delivered efficiency of mid-sized industrial turbines ranges from about 22% to 37%, and is dependent upon the size of the unit. However, the application of CHP technology raises the overall efficiency to as much as 80%. Typical applications for this technology include larger institutional and industrial sites, such as hospitals, universities and manufacturing plants where there is demand for both electric power and heat. The number of moving parts is also very low in an industrial turbine, which results in relatively low operating costs. However, due to the significant size and complexity of the equipment, the installed cost per kW is still higher than that of the conventional reciprocating DG technology.

11.5 Fuel Cells

Unlike all of the other DG technologies that have been discussed, the fuel cell does not have a prime-mover and generator. Instead, a fuel cell is an electrochemical device that combines hydrogen fuel and oxygen from the air to produce electricity, heat and water. Fuel cells operate without combustion, as the fuel is converted directly to electricity through a series of chemical processes. As a result, the fuel cell itself has no moving parts, making it a quiet and reliable source of power. The CO₂ emissions from a fuel cell are very low, being 50% lower than the emissions associated with centralized power production in Alberta.

The electrical generating capacity of the fuel cell is slightly higher than that of the microturbine, but still well below the industrial turbines and larger reciprocating engines. Commercial systems are available with a 200 kW generating capacity. Although the fuel cell actually uses hydrogen in the chemical processes to generate electricity, commercial fuel cells can be fuelled with natural gas or other lower energy gases, such as biogas. The delivered efficiency of the electric power generated by a fuel cell ranges from 37-40%, considerably higher than any of the other technologies at the same output level. However, even though there is no combustion process in a fuel cell, one of the significant by-products of the power generation process is still heat. By capturing this waste heat, fuel cells can achieve 85-87% efficiency.

A disadvantage of the fuel cell technology is the short life span of the core components when compared to the mechanical systems discussed previously. A fuel cell will need a costly overhaul of key components after about only 5 years of operation. Despite the high efficiencies achieved by the fuel cell, and the relatively low operating cost due to the lack of moving parts, when the short life span and capital cost are considered together, the installed cost per kW is quite high.