



**Climate Change Central**

**Greenhouse Gas Emissions and  
Opportunities for Reduction From The  
Alberta Swine Industry**

**DISCUSSION PAPER C3-012**

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## EXECUTIVE SUMMARY

There is general agreement amongst the international scientific community that the increase in concentration of greenhouse gases (GHG) in the atmosphere is linked to a gradual warming trend of the earth's average surface temperature. The Kyoto Protocol, an international agreement established to reduce the release of greenhouse gases, was ratified by Canada in December 2002. Although the Kyoto Protocol may still not come into force, both the federal and provincial governments appear committed to reducing Canada's contribution of global greenhouse gases.

Environment Canada has determined that the agriculture industry contributes approximately 8.7% of Canada's total GHG emissions. However, agriculture is an important component of the Alberta economy, directly contributing 3% to the provincial GDP in 1999, and the livestock aspect of the agriculture industry, which includes swine, has seen steady growth over the last 25 years. According to the 2001 agricultural census, the Alberta pig population in 2001 was 2.027 million head, and accounted for approximately 14.5% of the Canadian pig population. Population forecasts to the middle of the Kyoto commitment period in 2010 are scarce and vary widely, ranging from 0% to 100% growth. However, based on historical population growth over the last 20 years, it is reasonable to predict the Alberta pig population to be approximately 2.4 million head by 2010.

The swine industry involves raising pigs from the newborn piglet to a marketable hog. Given the climate in Alberta, most swine are housed in heated, indoor facilities, with special care established for piglets and sows. As a result, the important greenhouse gases released from the swine industry are carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O). These gases are released from a variety of sources; the largest being the methane released from waste storage facilities. There is currently much uncertainty associated with estimating emissions from the swine industry, and as a result, there are very few published estimates of emission levels or emissions factors. The best assessment, based on the internationally accepted and reviewed Intergovernmental Panel on Climate Change (IPCC) guidelines, estimates the 2002 Alberta swine industry emissions to be 733 kT (kilotonnes) of carbon dioxide equivalent (CO<sub>2</sub>e), of which methane accounted for more than 50%. The quantity of GHG emissions from the swine industry is small when compared to Alberta's total GHG emissions, and contributed only 0.3% to the total provincial emissions in 2000.

Regardless of the absolute quantity of swine based GHG emissions, there are over a dozen technologies and strategies that can be implemented to help reduce GHG emissions from the swine industry. One of the most promising technologies is the construction and operation of waste digesters. Digesters augment the decomposition process and facilitate the capture of the methane that is released during waste decomposition. Once captured, methane can be burned to generate both heat and electricity, potentially eliminating the farm's need for external sources of energy, such as electricity and natural gas, and simultaneously reducing GHG emissions. Other lower cost options to reduce GHG emissions include improved feeding practices, increasing the frequency of waste application to fields and timing the application of waste to fields to match the nitrogen requirements of crops. Implementation of various abatement options for the swine industry could reduce GHG emissions in Alberta by as little as 20 kT or as much as 300 kT of CO<sub>2</sub>e annually.

The environmental impact of the swine industry is not limited to GHG emissions. The strong odour associated with pigs, as well as airborne emissions of particulate matter, ammonia and hydrogen sulphide, all affect air quality, and are areas of concern. The contamination of surface and ground water from manure storage, as well as the release of excess salt and nitrogen into the soil, are additional environmental issues that must be considered before implementing any GHG abatement technology.

In order to implement changes that reduce GHG emissions from the swine industry, further research must be conducted on emissions abatement technologies, as there is still significant uncertainty in the costs and benefits to the farmer associated with many of these technologies. Information regarding the possible contributions that farmers can make to help control climate change needs to be effectively disseminated through a variety of communication channels including industry associations, government agencies and environmental action groups. Barriers that will slow the adoption of emissions abatement technologies by Alberta swine farmers include small profit margins per head and the relatively low swine density in Alberta.

Through a variety of biological processes, the swine industry emits gases such as carbon dioxide, methane and nitrous oxide, all of which contribute to the acceleration of GHG concentration in our atmosphere. However, through additional research of abatement technologies and incentive programs for farmers, significant reductions in GHG emissions from the Alberta swine industry can be achieved.

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# 1. INTRODUCTION

Climate change, the variation in worldwide temperatures and weather patterns due to human induced activities, has been studied for decades. After the majority of the scientific community reached a consensus, governments began international negotiations to reduce greenhouse gas emissions. This culminated in 1997 with the signing of the Kyoto Protocol to the United Nations Framework Convention on Climate Change. There are six classes of greenhouse gases (GHG) specified in the protocol: CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, hydrofluorocarbons, perfluorocarbons and SF<sub>6</sub>. These gases have been determined to have a warming effect on the climate of the earth, though each gas affects the climate to different degrees. Canada ratified the protocol in late 2002, however the protocol still requires the ratification of either Russia or the United States in order to come into force. Should the protocol come into force, Canada would be obligated to reduce its emissions during the period from 2008 to 2012 to 6% below 1990 levels. The Alberta government is also in the process of restricting the release of greenhouse gases. The current target is to reduce the greenhouse gas intensity by 22% in 2010 and by 50% in 2020 (AG 2002 11). It would appear that at either the provincial or federal level, there will be constraints placed on the release of greenhouse gases in the future.

The agricultural industry is a moderate contributor to Canada's greenhouse gas inventory. In 2001, the industry accounted for 8.7% of Canada's total greenhouse gas emissions (EC, 2001 Third Report 23). The livestock industry falls within the larger category of agriculture and accounted for 4.0% (EC, 2001 Third Report 47)<sup>1</sup>. The swine industry is a small contributor to the livestock industry. Based on data contained within the inventory, the swine industry contributes between 10-20% of the emissions to the livestock industry (EC, 2000 Inventory 24-25).

Alberta has a large and growing swine industry, with 14.4% of Canada's swine population in 2002 (Clowes 2003). The swine industry emits multiple greenhouse gases both directly and indirectly. Direct releases of CH<sub>4</sub> and N<sub>2</sub>O occur from the enteric fermentation, anaerobic and aerobic decomposition, and nitrification and denitrification of waste. Indirect emissions of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O occur due to the purchase of off-site electricity and the transportation of raw materials and products<sup>2</sup>.

## 1.1. Scope

The focus of this report will be on the Alberta swine industry. Specifically, the analysis will include swine industry operations, from piglets to market hogs while excluding: pork processing, indirect emissions from electricity generation, indirect emissions from transportation, indirect nitrous oxide releases from soils<sup>3</sup>. Emissions from the industry are estimated based on the currently available published data. The technologies available to reduce the greenhouse gas emissions from the swine industry will also be detailed. The costs and quantification of the greenhouse gas reduction potential will be provided where possible, however, there is limited information available for most technologies. The report concludes with a description of the barriers that exist to the implementation of emission reduction technologies. A brief description of other environmental impacts of the industry can be found in Appendix C.

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<sup>1</sup> 4.0% includes all emissions associated with manure management. However, this is a cross industrial process, as manure is used as a fertilizer on agricultural fields.

<sup>2</sup> Direct releases of these greenhouse gases could occur as well if electricity is generated on-site, however, it is not believed that any farms employ on-site generation of electricity using fossil fuels such as natural gas.

<sup>3</sup> Since the pork processing industry is contained within the Food Processing classification within Environment Canada's Greenhouse gas inventory, it will be considered outside the scope of this report.

## 2. INDUSTRY OVERVIEW

There are several key findings described in this section. The current swine population in Alberta is 2.12 million head, however, the density of swine is relatively low compared to other swine production intensive areas like North Carolina. The current population is the highest population in Alberta over at least the past 20 years. There has been a 20-year trend of an increasing population, and is forecasted to grow to 2.44 million head in 2010. There has also been a noticeable trend from smaller operations to larger operations, with the average swine per farm rising from 120 to 757 between 1981 and 2001.

The swine industry is a key part of the food processing and agricultural industries within Canada. It includes managing farms and raising swine from birth to an age when they are ready for market. Sows, adult female swine, give birth to approximately 12 piglets at a time. The piglets grow quickly and reach a weight of 110 kg within 6 months (Alberta Pork, 2002). At maturity full-grown piglets are called hogs and are ready to be shipped to market. Relative to other swine production regions in North America, Alberta has a low density of swine at 8 swine per km<sup>2</sup> arable land (Golder, 1999 2-3). By comparison, North Carolina, a large swine production state in the United States, has an average of 273 swine per km<sup>2</sup> arable land (Golder, 1999 2-3).

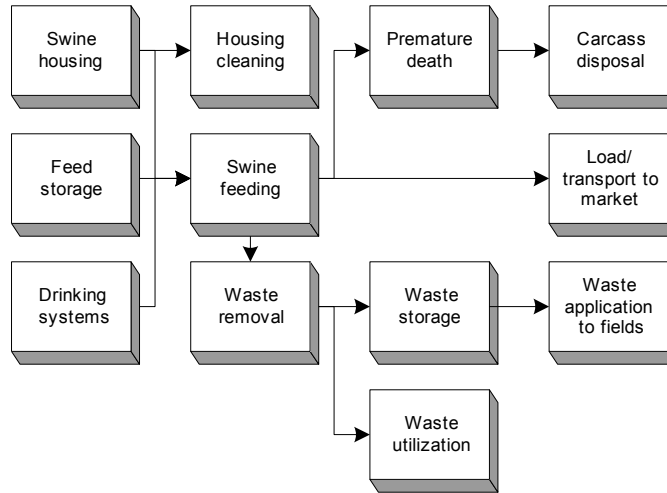
Figure 1 shows the key processes required to bring swine to the market. It does not include upstream emissions like construction, construction materials or raw feed ingredients. It also excludes downstream processes like the removal of facilities and pork processing industry. The housing is typically a large enclosed heated building. Within the housing area, the swine are kept in pens.

There are three types of swine farming operations:

1. Specialize in raising weaners
2. Specialize in raising the weaners to full market hog
3. Raising swine right from a piglet to a market hog (also referred to as a farrow-to-finish operation)

For those farms with sows, they are usually kept in a separate area with the piglets or a separate structure to allow for direct observation of the young, to determine when to wean the young, and to supervise breeding. A growing number of farms are using artificial insemination for their sows (SaskPork, 2002 7). A large amount of feed is stored onsite using drop feeder bins. Workers are not usually housed on site, however for very large operations there may be some limited housing.

The next column of processes in Figure 1 starts with the cleaning of the feedlot. Swine defecate and urinate onto the floor in their pens. The floors are slatted which allows the urine and feces to fall in to a holding area below. Cleaning is usually done by pressure washing the floors, pushing the waste and water into the underground storage. The cleaning helps to reduce the odor within the facility and reduces the likelihood of disease. Feeding is usually done using feeder troughs, which are automatically refilled as required. Water is supplied through nipples that only release water when a swine bites on the device.



**Figure 1 - Key Swine Industrial Processes**

Waste can be managed in one of two ways, solid or liquid. A liquid storage system involves shallow gutters which are washed away weekly (ACCT, 1999 35). Solid management systems involve gutters with daily washing, or bedded manure packs (ACCT, 1999 35). The third column of processes in Figure 1 includes waste storage and utilization. In Canada, the slurry of waste is usually stockpiled in the form of a lagoon, which is open to the atmosphere. Instead of being sent to a lagoon, the waste may be sent to a digester that would produce biogas. The biogas, containing mainly methane, is combusted to produce either heat or electricity or both. The use of digesters is not currently a common practice in Canada.

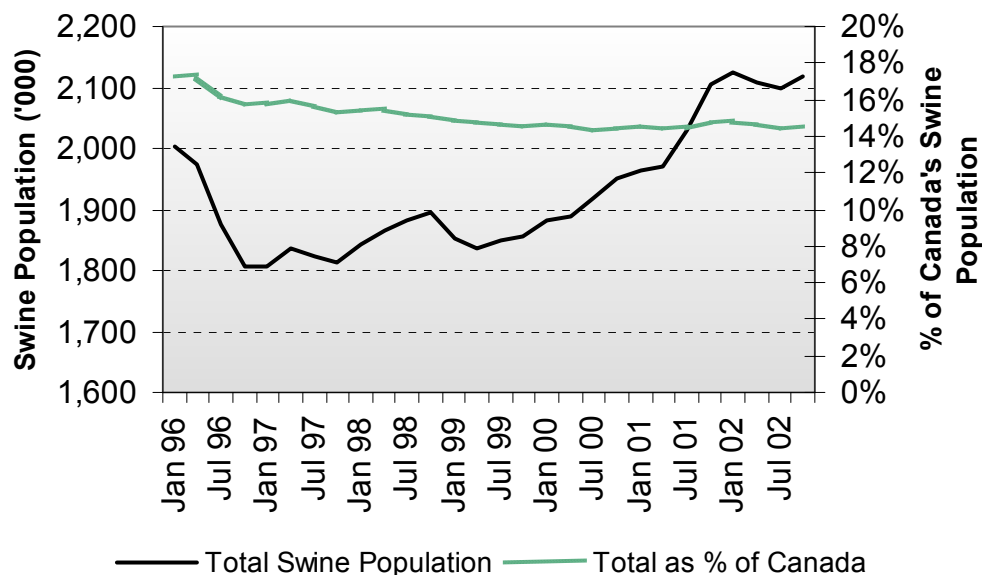
A small portion of swine waste in Canada is stored as a solid. This is usually in form of an open air above ground area, where the solid portion of the waste stream is placed. Following the waste cycle to its last phase, after being decomposed within a lagoon the liquid portion of lagoon is spread onto fields at least monthly during the summer. The mixture serves as a partial replacement for fertilizer, due to the high nitrogen content. The sludge on the bottom of the lagoon, mostly containing organic residue, is dredged from the lagoon only a few times a year and applied to the fields.

Back in the third column of Figure 1, the issue of premature death must be considered. Though premature death is a declining statistic in the industry, it still does occur, especially for younger swine (SaskPork, 2002 4). The main causes of death are disease, though the use of antibiotics and supplementation to swine has helped to reduce the incidents. Finishing with the last column of processes, carcasses resulting from the premature death of swine must be disposed of. The disposal may be performed by a separate company that collects the swine carcasses, or by onsite incineration or burial. The market hogs are loaded up regularly from the farm and transported to a pork processing facility.

The industry is under close scrutiny by certain non-governmental organizations. The criticism of the industry is typically based on concerns over animal rights or environmental impact. Animal rights activists like People for the Ethical Treatment of Animals are against the use of swine for consumption. Environmental concerns with ground water contamination and odour are the focus of groups like Environmental Defense.

## 2.1. Alberta swine population

The Alberta swine industry has been growing since 1976, when Alberta had only one million head (AB Ag, Pork Industry, 2001). Figure 2 shows an increasing population trend since late 1996, with Alberta's 2002 population at the end of 2002 being 2.117 million. This is the highest population in the last 20 years. Figure 2 also shows a continuing decline in the swine population in comparison with the rest of Canada, indicating relatively stronger growth in other provinces.



**Figure 2 - Alberta Swine Industry Population Trends**

One interesting trend to note is the movement within the industry to larger more concentrated farming operations. The number of farms in Alberta reporting raising swine in 1981 was 9,994. This is significantly higher than the 2,677 reporting in 2001 (Clowes 2003). Over the same period, the average number of swine per farm has increased from 120 to 757. The larger operations offer lower cost opportunities to control emissions, due to economies of scale.

## 2.2. Alberta swine industry economics

The production costs associated with swine production are very competitive in Alberta. A lower cost of raw materials is a key reason (AB Ag, Pork Industry, 2001 F). The removal of the Crow Rate in 1995, a grain transportation subsidy program by the federal government, has benefited the Alberta swine industry when compared with the Manitoba and Saskatchewan industries (Western Producer, 2000). The margin per swine sold has varied with no discernable trend. The average margin per hog in Alberta between 1994 and 2000 was \$70.42 and the margin in 2000 was \$88.83 (AB Ag, Pork Industry, 2001 F).

The exporting of live swine to other provinces and the United States is a key component of the industry. The revenue from exports in Alberta has grown from \$72 million in 1996 to \$119 million in 2000 with the Canadian market showing similar growth (AB Ag, Pork Industry, 2001 J).

## 2.3. Industry environmental impact

The swine industry, like most other industries, impacts the environment. Negative impacts to the land, water and air are all observed. This report focuses on the releases of greenhouse gases to the atmosphere, mainly in the form of methane and nitrous oxide. Appendix C briefly looks at

other impacts, most notably being groundwater contamination by waste run off and the odor surrounding swine facilities.

#### **2.4. Forecasted swine population**

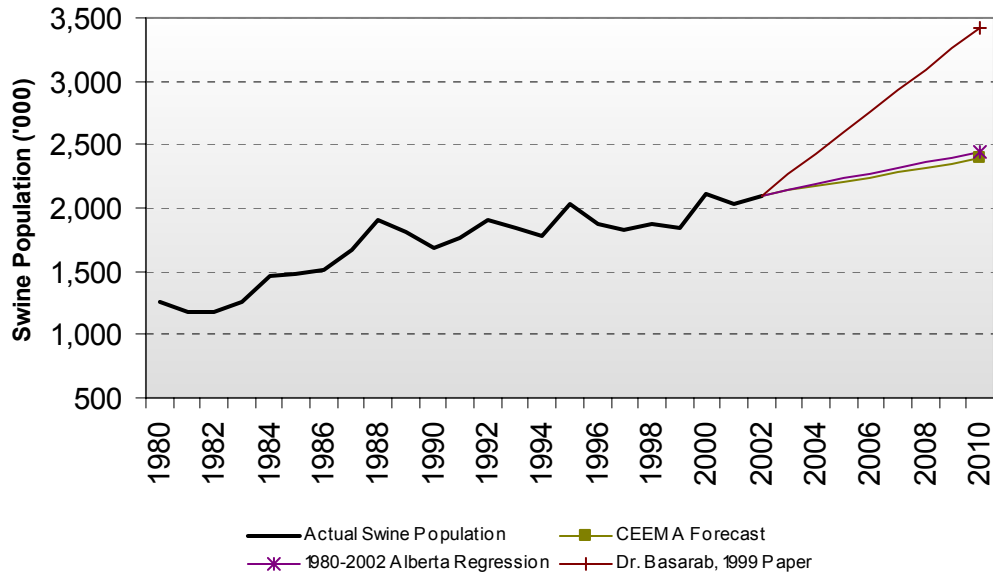
Because the swine industry operates in a competitive market, forecasts are not readily available. Furthermore, forecasting any industry as far as 10 years into the future, during the first commitment period under the Kyoto protocol, is far from an exact science. Having said this, there were two forecasts identified in published literature. The report, "Canadian Economic and Emissions Model for Agriculture (C.E.E.M.A. Version 1.0) Report 2: Preliminary Results of Selected Scenarios" published in 1999 by Agriculture and Agri-Food Canada forecasted 14,261,000 swine for all of Canada in 2010, a 2% drop from 2002<sup>4</sup>. Using a set of linear regressions as described in Appendix B, section 1, the Canadian value translates to 2.39 million swine in Alberta. This is a 13% increase when compared to the Alberta population in 2002. The discrepancy in the growth forecasts for Alberta and Canada is due to the linear regressions. The linear regression of the Alberta swine population is forecasting a stronger growth than the linear regression of Canada's swine population.

The second forecast, presented in a paper by Dr. Basarab of Alberta Agriculture, Food and Rural Development (Basarab 1999), predicts a 100% increase in sow units between 1996 and 2010. This forecast cannot be directly applied to the swine population because the sow unit includes within it, a measurement of the production efficiency of the swine. A sow efficiency value was calculated based on the total swine population excluding sows, divided by the number of sows. If more swine can be supported with the same number of sows, then the industry has become more efficient. A linear regression was applied to the efficiency factor as described in Appendix B, section 1. The forecasted swine population is then 3.4 million swine in 2010, an 83% increase in the population compared with 1996. This is a crude analysis, but given the uncertainty associated with a long term forecast such as this, and the limited availability of forecasts, it is deemed necessary and acceptable. It is noted that the basis of the sow unit forecast is not supplied within the paper.

As an alternate forecast, a simple linear regression was applied to the Alberta swine population. The regression analysis, using annual data from 1980 to 2002, is described in more detail in Appendix B, section 1. Using a linear regression to extrapolate populations out to 2010 does not include any analysis of the provincial, national or international markets. This approach bases the forecast on a period that has shown increases in productivity, which can be reasonably assumed to continue into the near future. Even with these limitations, it is useful to utilize regression, as history can sometimes be the best indication of future trends. The fit on the regression is quite good with an r-squared value of 0.814. The projected population in 2010 using the regression is 2.44 million head. Figure 3 shows the historical population within Alberta with the three different forecasts, one from regression and two from published literature.

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<sup>4</sup> This does not necessarily assume a stagnant industry. The production efficiency of swine farms has seen significant improvements in productivity between 1996 and 2001 in Alberta. The production efficiency, the number of swine sold to market divided by the average annual population, for 1971 was approximately 1.05. This increased by 84% to 1.94 in 2001 (AB Ag, Pork Industry, 2001).



**Figure 3 - Alberta Swine Population Forecasts**

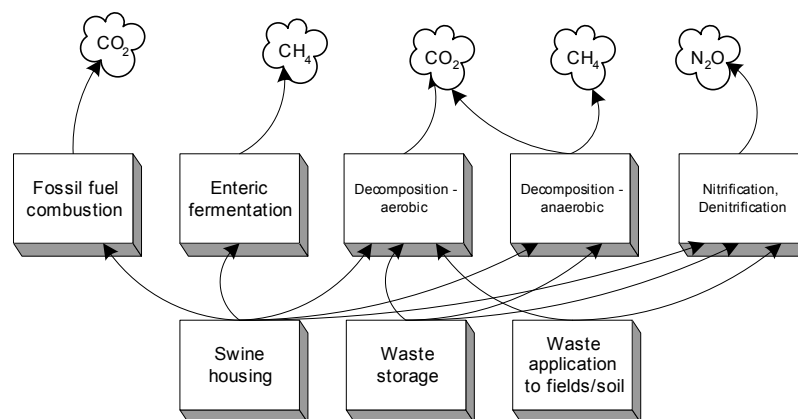
The forecast based on the linear regression for Alberta data and the CEEMA forecast are very similar. The main reason for this is that the CEEMA forecast for Canada in 2010 is only 2% below the linear regression of the Canadian swine population. For the purposes of calculating emissions, the forecast of 2.44 million head based on the linear regression of Alberta population data will be used. The forecast made using Dr. Basarab's projections, combined with the forecasted sow efficiency, does not seem reasonable given the historic trend of the industry.

### 3. GREENHOUSE GAS EMISSIONS

The swine industries release carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) mainly from swine housing, waste storage and the application of waste to fields. Current research on the emission rates is not extensive, and produces high uncertainty when estimating emissions from the industry. Different published emissions data and emission methodologies vary by which point sources on a swine farm are included or excluded. Two methodologies were used to estimate the emissions from the swine industry in Alberta. The IPCC methodology estimates releases of 664 kT while the Dr. Laguë produced an estimate of 341 kT. The IPCC methodology was deemed more accurate, due to the extent that the emission factors are peer reviewed. However, the IPCC approach excludes some releases of CO<sub>2</sub> and N<sub>2</sub>O that are included in Dr. Laguë's approach. Therefore, a combined methodology was deemed the most accurate and produced an estimate of 733 kT in 2002, rising to 858 kT in 2010. Based on these estimates, the swine industry accounts for only 0.3% of Alberta's emissions, making it a very small contributor to the province's GHG emissions.

#### 3.1. Types of greenhouse gases emitted

The swine industry emits multiple greenhouse gases directly from its operations. Figure 4 highlights the processes that contribute significant levels of greenhouse gases. Some sources have been omitted due to their small quantities of releases, such as the CH<sub>4</sub> and N<sub>2</sub>O releases from the combustion of fossil fuels. CO<sub>2</sub> is released from the combustion of fossil fuels that are used to heat facilities. Swine housing, also called a feedlot, produces emissions from all of the biological processes. CO<sub>2</sub>, CH<sub>4</sub> are released by the exhaling and flatulence of the swine. Manure and urine deposited on the floor begin to decompose and as well as nitrification. These processes produce all three GHGs. There are two fundamental types of decomposition, aerobic and anaerobic. Aerobic decomposition tends to produce higher emissions of carbon dioxide and lower emissions of methane. Anaerobic decomposition, is the opposite, producing more emissions of CH<sub>4</sub> and less of CO<sub>2</sub>. The quantity of nitrous oxide emissions is affected by additional factors; however, emissions are generally higher for aerobic decomposition. The release of methane from enteric fermentation and manure management depends mainly on the daily feed intake and digestibility rate of the swine (IPCC 1997).



**Figure 4 - Significant Sources of Emissions From The Swine Industry**

Waste storage is a significant contributor of CH<sub>4</sub>. In Canada, the typical type of storage for waste is in an anaerobic lagoon, also called an earthen manure storage (EMS), which is open to the atmosphere (Liu et al. 2001 10). In Canada, the name EMS is used because, unlike lagoons in

the United States, an EMS is not designed specifically for the treatment of waste. The EMS acts as a digester and decomposes organic matter into gases, liquids and sludge (Barker Introduction). Methane, carbon dioxide and nitrous oxide are all released from an EMS. As the EMS fills, both with waste and rainfall, liquid from the EMS is applied to fields. The EMS naturally fills up with sludge, containing material that cannot be decomposed. This sludge is also applied to fields, usually after being mechanically mixed with the liquid portion of the EMS. The application of the liquid and sludge to fields causes further releases of methane and more importantly, releases of nitrous oxide. The releases of methane from the waste applied to the soil are very small due to mainly aerobic conditions, and are estimated less than 1% of the releases from an EMS (Bates, 2001 74).

### **3.2. Current status of research**

There are a limited number of papers available focusing on greenhouse gas releases from the swine industry. A recent report released by the United States National Research Council of the National Academies stated, “Accurate estimate of air emissions from AFOs [animal feeding operations] is needed to gauge their possible adverse impacts ...” (NRC 2002 2). It later states, “...the existing emission factors for AFOs are generally inadequate because of the limited number of measurements on which they are based...” (NRC 2002 7). Dr. Ron Ball, Professor in Department of Agricultural, Food & Nutritional Sciences at the University of Alberta, indicated that very little data is publicly available for the swine industry (Ball 2002). However, he has been collecting data for three years but none of it has been published. He also indicated that it is his belief that the Canadian 1990 baseline data for swine was a “substantial underestimate of the actual emissions.” He could not at this time quantify how “substantial” the underestimation was.

Active research in the industry focuses on the three core processes that release significant levels of emissions: feedlots, waste storage, waste application onto fields. The Prairie Swine Center, located in Saskatoon, Saskatchewan, has a mandate to further scientific research of the swine industries. They have a project currently underway entitled “Greenhouse Gas and Odour Emissions from Swine Operations in Québec and Saskatchewan: Benchmark Assessments”. Alberta Agricultural Research Institute has historic and ongoing projects looking at GHG emissions. One of their current projects is “Development of Farm-level Greenhouse Gas Assessment: Identify Knowledge Gaps and Develop A Science Plan”. The Climate Change Funding Initiative In Agriculture created by Agriculture and Agri-Food Canada is a further resource for research projects<sup>5</sup>.

Although available information on the level of emissions is limited, there is work underway nationally and internationally to advance the understanding of emissions sources and methodologies to estimate GHG emissions for the swine industry.<sup>6</sup>

### **3.3. Historical and current direct emissions for Alberta swine industry**

Given the limited availability of scientific literature on emissions from the swine industry, one can expect a high degree of uncertainty in estimating historical GHG emissions. Two approaches were taken to determine the historical emissions from the swine industry in Alberta. The first summarized the currently available published data. The second calculated the emissions-based swine population and published emission factors.

#### **3.3.1. Published emissions data for Alberta swine industry**

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<sup>5</sup> The 2000-2001 activities report can be found at [http://www.carc-crac.ca/common/Activities\\_Report\\_2000-2001.PDF](http://www.carc-crac.ca/common/Activities_Report_2000-2001.PDF).

<sup>6</sup> This section is not intended to be a comprehensive list of research projects. There are other projects currently underway that have been identified, or already completed, that have not been listed here with the awareness of the space available and the scope of this document.

There are very few sources that have estimated the GHGs released from the swine industry in Alberta. The first is a paper produced by Alberta Agriculture, Food and Rural Development (Basarab et al. 1999). This paper is currently undergoing revisions to update the emissions estimate. The emission factor for methane is based on a 1997 report by Environment Canada. Environment Canada has replaced these emission factors, and therefore this paper's emission forecast is no longer accurate.

In the Foundation Paper, published by Agriculture and Agri-Food Climate Change Table, the emissions from swine manure in Alberta were estimated in 1996 at 21 kT of CH<sub>4</sub>, or 441 kT of CO<sub>2</sub>e (ACCT 1999, 59). Estimates for enteric fermentation emissions were estimated at 63 kT CO<sub>2</sub>e. These estimates were based on IPCC methodology. The emissions from nitrous oxide for the swine industry were not included.

Environment Canada regularly publishes inventories of GHGs in Canada. The majority of the report uses The Intergovernmental Panel on Climate Change (IPCC) methodology and emission factors. The latest inventory was published in June 2002 and includes data from 1990 to 2000. However, this report and the previous report published in 2001 do not provide sectoral data for swine. The industry is instead rolled up into the following categories: enteric fermentation, manure management for all farm animals. Manure management assumes that manure decomposes under anaerobic conditions, usually in lagoons, which is applicable for the Alberta swine industry. It does not include application of the manure or by-products onto the soil. The 1990-1998 inventory does provide additional details for the swine industry. It reports 383 kT CO<sub>2</sub>e in enteric emissions of methane for all of Canada and 2,554 kT CO<sub>2</sub>e of methane from manure management.

In the Environment Canada inventory, nitrous oxide emissions are only reported based on the type of manure management system and not the type animal producing the manure. Surprisingly, anaerobic lagoons are listed as releasing 0 kT CO<sub>2</sub>e of nitrous oxide. As mentioned previously, research indicates that the majority of manure produced by swine is managed in Canada in anaerobic lagoons or EMS. It is also unclear where the nitrous oxide that is produced when the liquid and sludge from the EMS are applied to fields is included in the inventory. The total emissions from the industry would be 2,937 kT CO<sub>2</sub>e in Canada not including N<sub>2</sub>O released from the EMS or the field applications. In 1998, Alberta on average had 15.3% of the swine population. Multiplying this factor by the Canadian inventory total yields 448 kT CO<sub>2</sub>e for Alberta.

The last published set of data was found in a paper that was presented in Alberta in 2001. Dr. Laguë estimated the emissions from swine feedlots, manure management systems and nitrous oxide releases from the soil for all of Canada. The values in CO<sub>2</sub>e for the three areas are 793 kT, 846 kT and 372 kT respectively for a total of 2,011 kT. In 2001, Alberta had 14.5% of Canada's swine population, or 292 kT based on this analysis. This analysis assumes all of the manure is stored in open-air anaerobic lagoons.

### 3.3.2. Calculated Alberta swine industry emissions using published emission factors

The second approach taken calculates the swine industry emissions using the population data and published emission factors.

There is significant uncertainty in published emission factors, especially for nitrous oxide. The National Research Council in the United States has released a report entitled "The Scientific Basis for Estimating Emissions from Animal Feeding Operations". It contains a comprehensive review of literature published on emission factors. The section on nitrous oxide emissions lists several studies that have found that the percentage of nitrogen emitted as nitrous oxide, due to the application of manure to solid, ranged from 0.025% to 4.9%. This included various types of animals, not just swine. By comparison, IPCC's default value is 1.25%. In the summary portion of the report, the authors conclude that for nitrous oxide emissions from animal feeding operations, there is uncertainty in the order of 300% (NRC, Interim, 2002 23). An analysis of

research literature done in Sweden by Andrew Dustan also indicates that there is great uncertainty in many of the methane and nitrous oxide emission factors currently published (Dustan 23). Some of the uncertainty is due to the “highly variable and sporadic” nature of GHG emissions from the agricultural sector, as mentioned in the Options Report by Agriculture Canada (ACCT 2000 i).

#### 3.3.2.1. Emission calculations using IPCC guidelines

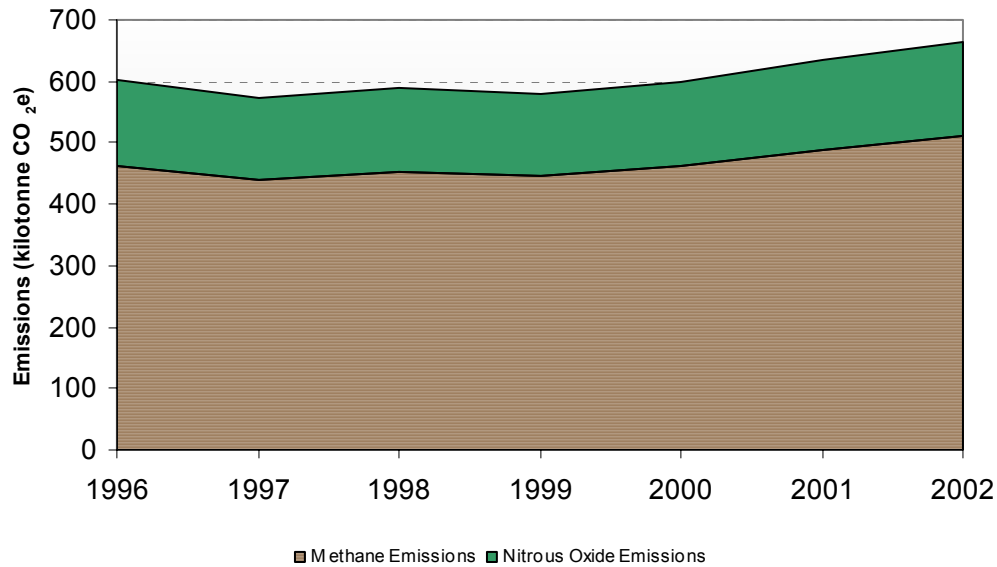
IPCC guidelines were used for calculating the majority of the Canadian GHG inventory. IPCC has the benefit of a large number of sources for their emission factors, however, they are also generalized, applying to many countries with different climates and industry best practices. IPCC has suggested emissions factors for enteric fermentation and manure management. The enteric emission factor from swine in developed countries is 1.5 kg CH<sub>4</sub> per head per year with an uncertainty of +/- 20% (IPCC 1997 4.3). “Head” is defined as the average annual population, which includes all ages of swine. The emission factor for manure management is 10 kg per head per year for swine in a cool climate in North America. No uncertainty is provided for this value (IPCC 1997 4.7). IPCC does provide a formula to estimate the N<sub>2</sub>O emissions from agricultural waste. This methodology is described in detail in Appendix B, section 2.

The IPCC methodology presents a methodology to estimate the emissions of nitrous oxide due to application of waste material onto soil. The full calculation for agriculture combines the nitrogen released from all forms of animal waste, synthetic fertilizer, crop residues and nitrogen fixing crops. However, the releases from just the swine industry can easily be calculated as the formulas are additive, and can be broken apart for each specific nitrogen source. The methodology is described in detail in Appendix B, section 3.

There is no stated methodology for calculating methane released from waste application onto soil. In the reference portion of the IPCC revised guidelines, it does state that the manure is exposed mainly to aerobic conditions when applied to the soil, which therefore produces little to no methane (IPCC Vol3, 1997 4.4). The carbon dioxide emissions produced by the swine during exhaling are not included in this calculation. Lastly, any greenhouse gas emissions produced from the onsite combustion of fossil fuels is excluded. All material indirect emissions are included in other portions of the inventory.

The emissions from the swine industry for Alberta, as calculated by the IPCC methodology are shown below in Figure 5. This calculation appears to be consistent with the Environment Canada 1998 inventory. As mentioned in section 3.3.1, the 1998 emissions from the swine industry in Canada were 448 kT CO<sub>2</sub>e, which did not include any nitrous oxide emissions. The calculated value for methane emissions using this analysis was 452 kT CO<sub>2</sub>e not including the nitrous oxide emissions in the same year.

The methane emissions from manure management are dominant, accounting for over 65% of the emissions. The methane emissions from enteric fermentation and nitrous oxide emissions from soil are much lower at 10% and 18%, respectively. The nitrous oxide emissions from manure management make up a very small portion of the emissions at 5%.



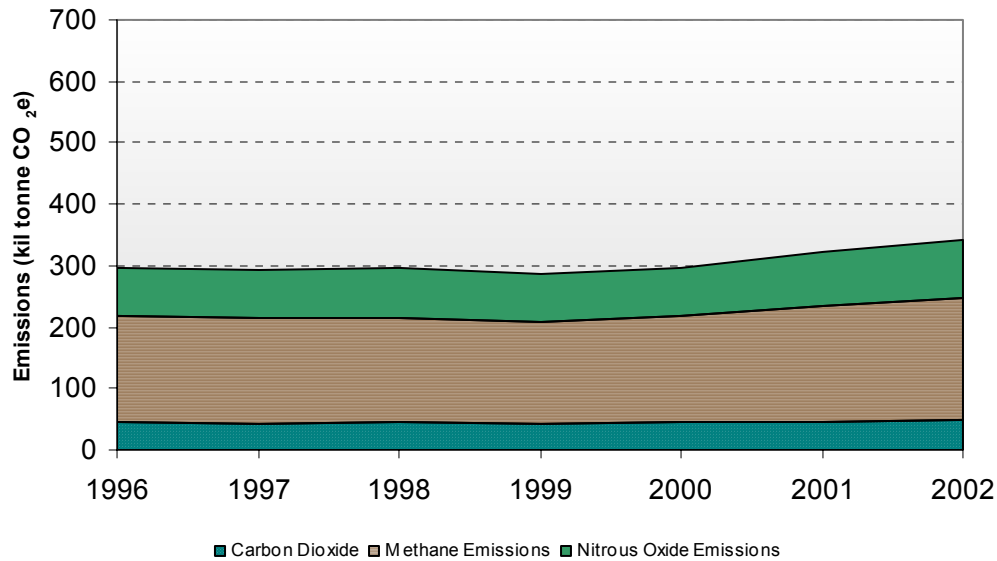
**Figure 5 – AB Swine Industry Emissions By Greenhouse Gas Type Based On IPCC Methodology**

### 3.3.2.2. Emission calculations using University of Saskatchewan paper

A paper presented in 2001 by Dr. Claude Laguë of the University of Saskatchewan, calculated emissions of CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O from the swine industry. He approached the industry in three sections, based on physical separate. Initially, he looked at the feedlot and used the emission factors 405.2 g/kg-yr CO<sub>2</sub>, 22.5 g/kg-yr CH<sub>4</sub> and 0.678 g/kg-yr N<sub>2</sub>O (Laguë 85). In order to apply these factors to the Alberta swine population data, certain assumptions are required. The assumptions and calculation are described in detail in Appendix B section 4. The calculated methane emissions are similar to the enteric fermentation calculated using the IPCC methodology. The values are within 15% of each other. It is difficult to determine how accurate the carbon dioxide values are given the limited number of published sources. Only one other source for an emission factor could be located, and that factor at 800 kg/head/yr is eight to twelve times larger than the one used by Dr. Laguë (Ahlgrimm 287). The nitrous oxide emissions seem to be reasonable, being less than the emissions produced by the manure management systems according to the IPCC calculation.

Next, Dr. Laguë looked at the manure management systems. He assumed that all of the emissions were generated from open-air anaerobic lagoons. The calculation used two emissions factors, 6.732 g CH<sub>4</sub>/T-day for methane and 0.02466 g N<sub>2</sub>O/m<sup>2</sup>-day for nitrous oxide. Both calculations require the total amount of manure produced that was estimated at 70L/day-sow by Dr. Laguë. Additional assumptions were based on the formula described in Dr. Laguë's paper.

The final estimate made was for nitrous oxide releases from waste application to soil. Dr. Laguë used an average nitrogen content of manure of 3 kg/1000L and a N<sub>2</sub>O conversion rate of 1.25%. The results of these calculations using only Alberta swine are shown in Figure 6, which are considerably less than the IPCC methodology.



**Figure 6 – AB Swine Facility Emissions By Greenhouse Gas Type Based On Dr. Laguë’s Factors**

### 3.3.3. Assessment of methodologies

The previous approaches were presented to provide estimates of the emissions from the industry in Canada. Published information on the industry for both Canada and Alberta were found and listed. Three key deficiencies exist:

- Major sources of emissions were excluded
- Data was published for Canada, requiring an extrapolation based on the annual average population of Alberta compared with Canada
- Data was usually only presented for a single year

Each of the deficiencies does not apply to each of the sources. For these reasons, the second approach, using emission factors, was deemed more accurate and applicable to the Alberta swine industry.

The emissions estimates based on the three sets of emission factors vary greatly, by approximately 200%. One difference is due to the exclusion of some emission sources by each of the methodologies. Table 1 shows a summary of which sources of greenhouse gas emissions were considered by the different methodologies. As previously stated, some of the sources, such as CO<sub>2</sub> releases from waste application to fields, are currently thought to be very small.

Source	Swine Feedlots			Swine Feedlots			Waste Storage			Waste Application To Fields		
	Enteric Fermentation			Waste Production								
	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O
<b>Published Emissions</b>												
Foundation Paper		✓			✓			✓				
Env. Canada GHG Inventory <sup>1</sup>		✓			✓			✓				
Laguë	✓	✓	✓	✓	✓	✓		✓	✓			✓
<b>Published Emission Factors</b>												
IPCC Guidelines <sup>2</sup>		✓			✓			✓	✓			✓
Laguë	✓	✓	✓	✓	✓	✓		✓	✓			✓
<b>Notes</b>												
<sup>1</sup>	Nitrous oxide emissions from waste storage and waste application to fields is included, but not detailed for the swine industry											
<sup>2</sup>	The methodology does not indicate specifically if the nitrous oxide emission factor for "manure management systems" includes feedlots											

**Table 1 - Summary of Greenhouse Gas Sources Considered In Emission Methodologies**

In 2002, calculations based on the IPCC methodology estimated that 664 kT of CO<sub>2</sub>e were released, Dr. Laguë factors estimated 341 kT while the Golder report was only 156 kT. The variance is not that surprising, given the number of sources citing the large discrepancies in emission factors and the need for further research (NRC, Interim, 2002 23, ACCT 2000 i).

Although the IPCC guidelines are generic in nature, they are thoroughly peer reviewed and are still the basis of the latest national inventory by Environment Canada. Therefore, for the basis of this analysis, they will be assumed to represent a more accurate assessment of the GHG emissions from the AB swine industry.

However, the IPCC guidelines do not include an assessment of the carbon dioxide or nitrous oxide released from swine facilities, a source that was included in the paper written by Dr. Laguë. A combined methodology is then suggested as being more representative of the industry. For the feedlots, the emission factors used by Dr. Laguë are used. For waste storage systems and waste application to fields, the IPCC methodology will be used.

Table 2 shows the summation of calculations based on the two methodologies.

Emission	Estimation Method	1996	1997	1998	1999	2000	2001	2002
Swine Production Buildings								
Carbon Dioxide	Dr. Laguë <sup>1</sup>	45	43	44	43	44	47	50
Methane	Dr. Laguë <sup>1</sup>	53	50	51	50	52	55	59
Nitrous Oxide	Dr. Laguë <sup>1</sup>	24	22	23	22	23	24	26
Manure Management Systems								
Methane	IPCC Methodology <sup>2</sup>	402	382	393	388	401	424	444
Nitrous Oxide	IPCC Methodology <sup>2</sup>	31	30	31	30	31	33	35
Waste Application to Soil								
Nitrous Oxide	IPCC Methodology <sup>2</sup>	108	103	106	104	108	114	119
Total								
Total		664	630	648	638	659	697	733
Notes								
<sup>1</sup> See "Greenhouse Gas Emissions: Is that an Issue for Canadian Pork Producers?" by Claude Laguë								
<sup>2</sup> See "Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Workbook" by IPCC								

**Table 2 - Summary of Emissions by Greenhouse Gas Type in Kilotonnes of CO<sub>2</sub> Equivalent**

To place these emissions levels in some context for an individual, in 2001 there were 2,677 farms with one or more swine in Alberta. Using the calculated emissions from Table 2, this would equate to 0.26 kT CO<sub>2</sub>e per farm, assuming each farm had the same number of swine. The largest farms in Alberta have over 4,700 head of swine. A farm with 4,700 head would emit approximately 1.62 kT of CO<sub>2</sub>e annually. By comparison, a recent mid-sized sedan releases almost 4 tonnes of CO<sub>2</sub>e per year and the average annual per capita release in Canada is 5 tonnes of CO<sub>2</sub>e (GoC 2002). So the average swine facility is equivalent to the total annual release of 50 individuals.

Another comparison can be made to air travel. Based on fuel data from Boeing and emission factors by Environment Canada, a return flight from Calgary to Toronto would emit 0.441 kT of CO<sub>2</sub>e per passenger, or 169% of the annual emissions from an average swine facility.

### 3.4. National and provincial importance of swine industry's emissions

Although not a significant contributor of greenhouse gases, the agricultural industry does emit material amounts in comparison to the national inventory. The industry accounts for 8.7% of Canada's 2001 inventory (EC, 2001 Third Report 23). The livestock industry, falling within the larger category of agriculture, accounted for 4.0% (EC, 2001 Third Report 47). The swine industry is a small contributor to the livestock industry. Based on data contained within Canada's Greenhouse Gas Inventory, 1990-1998, the Canadian swine industry contributes between 10% and 20% of the emissions to the livestock industry, or 0.4% to 0.8% of Canada's total GHG emissions (EC, 2000 Inventory 24-25).

Alberta's total emissions in 2000 were 223 megatonnes (MT) CO<sub>2</sub>e according to Canada's 1990-2000 Inventory, which represents 31% of Canada's emissions (EC, 2002 122). The agricultural industry produced 19 MT, or 8.5% of Alberta's total (EC, 2002 122). Using the calculated value of 733 kT from Table 2, the swine industry accounts for only 0.3% of Alberta's emissions, making it a very small contributor to the province's total GHG emissions.

### 3.5. Forecasted direct emissions

The baseline case assumes the swine industry continues to maintain the same greenhouse gas intensity as described in this section. No significant changes in practices are forecasted.

There were three different swine population forecasts presented in section 2.4. Forecasted emissions are calculated using the combined methodology described in section 3.3.3. Since the composition of the swine population is required for applying the methodology for CO<sub>2</sub> and N<sub>2</sub>O emissions from the facilities, the average composition from 1999-2002 was applied to all of the population forecasts in 2010. The emissions factors are all linearly applied to the swine population data so a simple multiplication is all that is required to forecast the direct emissions. The forecasted emissions are shown below in Table 3.

<b>Population Forecast Scenario</b>	<b>Forecasted Emissions In 2010 (kT CO<sub>2</sub>e)</b>
CEEMA Forecast	826
1980-2002 Alberta Regression	858
Dr. Basarab, 1999 Paper	1,225

**Table 3 - Greenhouse Gas Emission Forecasts By Population Scenario**

## 4. GREENHOUSE GAS REDUCTION TECHNOLOGIES AND METHODOLOGIES

There are several technologies that have the potential to reduce the emissions from the swine industry. Similar to the emissions from the industry, there is relatively very little research published on emission reduction technologies. This leads to significant uncertainty when estimating the reduction potential. The options with the greatest potential are: digesters, improved feeding practices, more frequent application of waste to soil, nitrification inhibitor. The potential emission reductions range from 20 kT to 330 kT per year. There are technical and financial barriers with the use of the technologies in Alberta. Lagoon digesters are only economic on larger farming operations, typically having greater than 1,350 head of swine. This would limit its application to only approximately 75% of the swine in Alberta. Nitrification inhibitors have been tested in Manitoba and netted disappointing results, though the results were subject to numerous factors.

### 4.1. Background

Although the greenhouse gas emissions estimated by the swine industry are not substantial in comparison with other industries in Alberta, they are large enough to consider options to reduce them. Given the significant gap that currently exists between the forecasted emissions in 2010 and the Canadian target of 6% below 1990, any low cost option for reducing emissions will gain interest, regardless of the industry.

Based on review of published papers conducted for this report, it appears that there is very little published data relating to greenhouse gas reduction technologies for the agricultural sector. For example, the Options Report on reducing GHGs from agriculture, prepared by the Agriculture and Agri-Food Climate Change Table in 2000, stated:

“The extensive and systematic search for GHG-reducing technologies identified only a few that with certainty could significantly reduce GHG emissions from agriculture at a low cost. In most cases little was known about the effect of alternative technologies or about the economic costs of the technologies. It became abundantly clear that more research was required to evaluate these technologies and to discover other technologies that could be even more effective in reducing GHG emissions.” (ACCT 2000 i)

With regards to the swine industry, anaerobic digesters have had the most attention due to their ability to generate revenue or reduce the costs of electricity purchases and space heating, as well as reduce GHG emissions. The abatement technologies presented in this report are arranged according to the source of the emission reduced. If the technology applies to more than one source, it has been categorized according to the largest emission source. Where possible, costs and potential reductions have been quantified. However, very little information could be located for most of the reduction options. All estimates related to greenhouse gas reductions are based on the 2002 emissions described in section 3.3.3 unless otherwise noted. The maximum amount of reductions is based on an assumed adoption rate of 100% of farms unless otherwise specified.

References will be made throughout this section to the Options Report and the Foundation Report prepared by the Agriculture and Agri-Food Climate Change Table. All emission reductions estimates are made based on the Alberta swine industry.

### 4.2. Enteric fermentation

The majority of research on emission reduction technologies in enteric fermentation is focused on ruminant animals, such as cattle, because of their significant releases of methane. For swine, there was limited published information available. Typically a co-benefit of reduction of emissions

of enteric fermentation, is the increase in productivity, either through reduced feed quantities, or increase in market hogs per number of sows.

#### 4.2.1. Improved feeding practices – Edible oils

There are different research claims, all without significant research, that indicate methane released from swine by enteric fermentation can be reduced. Edible oils may be added to the diet that inhibits the activity levels of methane-producing bacteria (ACCT 1999 29). The Foundation Paper by Agriculture and Agri-Food Climate Change Table indicates that this option may not be currently cost effective. A reference made in a Manitoba Government publication indicates that as much as 33% of the methane emissions from swine can be reduced by adding canola oil to the diet (CCC Manitoba 8). This level of reduction would equate to annual reductions of 22 kT CO<sub>2</sub>e.

#### 4.2.2. Improved genetics

Any action that reduces the number of swine required to meet the current level of demand, reduces emissions from the sector on a per unit basis. Improving the genetics of swine, either from selective breeding practices or direct genetic modifications, can improve the production efficiency of farms. Genetic selection through selective breeding has been in use for many years. When swine are naturally bred using boars, farmers select those boars and sows that have an above average history of producing swine with positive growth characteristics. These characteristics include: less prone to disease, faster growth rate, larger size and larger litters. This process is accelerated using technologies such as In Vitro Fertilization (IVF). IVF allows for a significant increase in the population that can provide the improved genetic matter, thereby increase the chances of better characteristics. The costs associated with improved genetics through selective breeding are considered within normal business operations. No quantification was found of the greenhouse gas benefits of this technology, however, it should already be incorporated into the baseline described in section 3.3.3, and this practice has been ongoing as these are “no-regrets” measures.

The literature also mentions the developing field of genetic engineering of farm animals, including swine. This involves modifying the DNA of swine to improve the production characteristics. Very little information was found due to this being an emerging technology with little chance of affecting the industry’s emissions during the next decade.

#### 4.2.3. Improved reproduction

The more rapidly a sow becomes pregnant, the greater the number of hogs that can be produced within a period of time. Although this was cited as one production method to reduce greenhouse gas emissions in the Options Paper, estimates of the potential greenhouse gas benefits could not be found (ACCT 2000 49).

#### 4.2.4. Reduce effects of disease

As with improved reproduction, reducing the number of premature deaths increases the overall production, and decreases the relative greenhouse gas emissions. No estimates regarding the potential reductions could be found.

### **4.3. Waste management**

There are several different systems that can be used in handling waste produced by swine. The waste management systems begin in the swine housing facilities and continue outdoors to the stockpiling of waste. In Alberta, most swine facilities use a slatted floor that allows the waste to fall through to a storage pit below. The waste is then carried away using water to a storage facility. Based on the expert opinion of Ray Desjardins, 90% of manure is stored in lagoons and

10% is stored in solid storage (EC, 2002 108). This opinion was confirmed as accurate for Alberta, given the lack of data, by both Michelle Follensbee and Andy Cumming, who are both with Alberta Agriculture, Food and Rural Development (Follensbee 2003, Cumming 2003).

#### 4.3.1. Adoption of solid handling systems

The oxygen availability is usually higher in solid management systems, than in liquid systems (ACCT, 1999 29), reducing the amount of methane produced while increasing the release of carbon dioxide. This is due to aerobic decomposition replacing anaerobic decomposition. However, the nitrous oxide emissions factor for solid storage is 20 times greater than liquid storage based on IPCC methodology. Since the methane emissions are approximately 10 times greater than the nitrous oxide emissions for lagoons (see section 3.3.3), a net benefit could probably be realized. The quantity of the net reduction is unknown, as the IPCC methodology does not provide separate methane emission factors for lagoons and solid storage. US EPA states that this option may reduce emissions, however, it is impractical because of the additional surface and water pollution by solid systems. As well, the degree to which handling systems are integrated into the overall management of existing facilities makes retrofitting a different technology very costly (USEPA, 1999 5-7).

#### 4.3.2. Improved feeding strategies

Swine have difficulty digesting phytate in cereal grains, and are unable to utilize the phosphorous within phytate (USDA 1998 80). Adding phytase, which is not naturally occurring in non-ruminant animals, assists in the breakdown of phytate. The Options Report indicates that potentially large reductions of nitrous oxide can be achieved because of the reduced nitrogen output (ACCT, 2000 50).

Another option is to provide swine with a more easily digestible food supply. A recent study at the University of Manitoba showed that a diet containing raw or micronized peas reduced manure production by 25-33% and reduced total nitrogen excretion by 21-32% (Nyachoti 2002 1:3).

A third option is a reduced protein diet, which decreases the nitrogen production in manure and is more cost effective than edible oils described in section 4.2.1 (ACCT 1999 34). This option requires closely matching the protein requirements of the swine with the diet, and can usually be achieved without any additives. The report lists that as much as 50% of the nitrogen can be reduced with a regimented protein diet process. Other sources cite that reasonable nitrogen reductions are achieved in the range of 10-20% (Brink et al. 2002 6) and 12-40% (Bates, 2001 16).

An Ontario report indicates that a combination of reduced protein and phytase supplements would reduce nitrogen excretion by 20-35% (SRG 2000 71). Assuming a linear relationship between nitrogen production and nitrous oxide production, as used in the IPCC methodology for emission calculations, a 20-35% reduction in nitrogen would equate to an approximate reduction of 36-63 kT of CO<sub>2</sub>e annually in Alberta.

#### 4.3.3. Covered storage lagoons

Covered storage lagoons are cited as one of the two most significant technologies to reduce greenhouse gases in the Foundation Paper (ACCT, 1999 33). However, the cover does not actually reduce emissions by itself. The cover provides more suitable conditions for anaerobic decomposition and the stabilization of the organic material in manure (Liu et al. 2001 i). The cover also increases the average temperature of the lagoon, therefore increasing the level of methane production, as the ideal temperature for anaerobic digestion is 30 - 57 °C (Liu et al. 2001 5). Brink estimates an increase of methane production of 10%, a decrease in nitrous oxide emissions from the storage lagoon by 10% and an increase of nitrous oxide emissions from soils by an average of 13% (Brink et al. 2002 6). The increase in the emissions from the soil is most

likely due to the reduced loss of nitrogen that occurs because of the cover, which is then converted in part to nitrous oxide when applied to the soil. In order to reduce GHG emissions, the methane must be captured and combusted.

A conflicting reference can be found in the agricultural best practices paper produced for the Ontario Ministry of Agriculture. This report states that methane reductions of 60% to 90% can be achieved by applying a cover (SRG 2000 23). The cover also allows for partial re-absorption of N<sub>2</sub>O. It could not be determined why there is such a significant difference between this report and others.

There are several different types of covers that can be applied to lagoons. The simplest is a straw based cover, however, this technology does not allow for the capture of methane. Costs are quoted at between \$2,000 - \$2,500 CDN for a 600 sow farrow-to-finish operation and the cover needs to be replaced annually (Filson, 2000). It is also unknown if there is a net release of greenhouse gases as the straw slowly sinks into the lagoon, and introduces additional organic material. The new organic material decomposes which releases further amounts of methane.

A floating cover is a better solution for the control and capture of methane. Costs can be as low as \$6,000 CDN for a 200 sow farrow-to-finish operation. Permanent solid structures are also an option, however they can cost as much as \$150,000 CDN for a 600 sow farrow-to-finish operation (Zhang et al. 1997). In either structure, the methane gas production can be captured using a negative pressure blower and fed into small power generation facility, heating unit, or simply flared to reduce the climate change impact. The first two options generate a revenue stream or reduce costs.

A lagoon cover also reduces the loss of nitrogen to the environment, although this does not necessarily translate to a reduction of nitrous oxide emissions. If the waste is applied to match the nitrogen uptake of crops described later in section 4.4.1, the farmer may realize production benefits. However, if the waste were applied without regard to the soil nitrogen content, then nitrous oxide emissions would still occur from the nitrogen.

Other non-greenhouse gas benefits include: reduced odour and ammonia emissions, rodents and flies are less attracted to the digested waste, rainfall entry is prevented resulting in less frequent material removal.

#### 4.3.4. Large scale waste treatment facilities

In some regions, opportunities exist to set up large-scale waste treatment and biogas production facilities. This requires economies of scale to offset the transportation costs of the waste. However, given the relatively low density of the swine population in Alberta, few if any cost effective opportunities exist in Alberta. The Red Deer region is likely the only area that large-scale waste treatment facilities may be feasible given that it has the highest swine population density in Alberta, at 30-40 swine per square kilometer (Golder, 1999 2-5). This large-scale solution may have some additional incremental reductions over an on-farm digester due to reduced fugitive emissions from the process; however, they are most likely to be minimal. This option also has the negative impact of removing from the farm a valuable nutrient source for the soil, unless the digested waste is transported back to the farm, imposing another incremental financial and environmental cost.

#### 4.3.5. Increase waste removal frequency

Increasing the frequency of waste removal from feedlots has been suggested as a strategy to reduce emissions (ACCT, 2000 59). The feedlot is usually held at a higher temperature than the waste storage facility. A decrease in the temperature reduces the production of methane during decomposition. Bates states that a drop from 20°C to 10°C can reduce CH<sub>4</sub> emissions by as much as 60-100% (62). However, the net reduction may be reduced as a result of an increase in

emissions from the waste because it is moved from partially aerobic conditions in the feedlot, to mainly anaerobic conditions during storage. This change creates additional CH<sub>4</sub> releases while reducing CO<sub>2</sub> releases. Bates estimates that an overall average of 10% reduction in methane emission within the feedlot could be achieved (Bates, 2001 62). The emissions of methane from manure within the feedlot are not estimated separately in the methodology in section 3.3.3, therefore the reductions cannot be determined.

#### 4.3.6. More frequent application of waste to soils

Because waste applied to soils decomposes in a mainly aerobic environment, there are significant reductions in methane emissions that could be achieved by decreasing the amount of time that the waste remains in the storage facilities. More frequent application of the waste to soils is hampered by climate conditions, especially in Alberta, where waste cannot be applied to frozen or very wet soil. However, a large portion of the methane emissions from manure management occurs during summer months, due to the higher ambient temperatures. A European paper indicated that daily application of waste could reduce the methane emissions by as much as 90% (Brink et al. 2002 5). The same source indicates that nitrous oxide emissions may increase by up to 80%. Using the estimates contained in the European paper, even with the increase in nitrous oxide emissions, there would be a net decrease in emissions. The net decrease would be 331 kT CO<sub>2</sub>e per year. The reason is that the majority of the emissions from swine are in the form of methane released from waste management systems.

#### 4.3.7. Anaerobic digesters

Significant research exists on the use of anaerobic digesters for managing animal wastes. The main reason is that digesters offer a revenue stream, along with reduction of methane emissions. Two basic types of digesters exist that are applicable to the swine industry in Alberta's climate, and are readily available. The simplest design is the typical waste storage lagoon, covered to capture methane. The cover may be a simple floating design or a permanent structure, as described in section 4.3.3. It is often more efficient to have a primary and secondary lagoon when intending to capture the methane. The secondary lagoon stores digested wastewater that exited the primary lagoon, and remains stored until applied to the field (USEPA, 1999 5-7). In colder climates, such as Alberta, anaerobic lagoon digesters would not produce methane in the period from late fall to early spring due to the lagoon temperature. This usually prevents it from providing a base load supply of electricity or heat for the farm, but rather a supplemental source to existing grid electricity or natural gas heaters.

The second type of digester is called a complete mix digester. The complete mix digester is a tank, or set of tanks into which the manure slurry is added. The slurry is mechanically agitated while in the digester to ensure thorough decomposition. As the waste decomposes in the anaerobic environment, methane is extracted from the top of the digester and combusted. Any waste heat released from the combustion of the methane is used to heat the digester, improving the efficiency of the anaerobic decomposition. The digested material is removed as more slurry is fed in, and stored in a waste storage system like a lagoon. Complete mix digesters have the advantage in colder climates of producing methane year-round, however they have significantly higher costs than anaerobic lagoon digesters if the site already contains a lagoon.

There is a significant amount of cost and revenue data available for digesters, though most of it is based in the United States. The United States Environmental Protection Agency's AgSTAR programs have been focused on the implementation of anaerobic digesters for several years. The AgSTAR program has the following foci (USEPA 2003):

- Federal initiatives that include funding of proven technologies
- Products which include comprehensive project development tools such as a handbook and software

- Performance Evaluations: These are comparative mass balance assessments which characterize environmental and economic performance of traditional as well as digestion technologies
- Collaboration with State programs that fund or support energy development and affect key policies

Mr. Kurt Roos, project manager for the AgSTAR program, believes that "...these aspects we find are key to facilitating the demand for these types of unconventional technologies in the livestock industry..." while referring to the above AgSTAR focus areas (USEPA 2003).

The US EPA 1990-2020 methane emission report contained the summary shown in Table 4 on digester capital costs and revenue (USEPA 1999):

	Units	Lagoon Digester	Complete-mix Digester
<b>Capital costs per sow (operations &gt; 1,000 head)<sup>1</sup></b>	USD/sow	\$162-\$310	\$162-\$350
<b>Break even herd size<sup>14</sup></b>	head	1,350	2,500
<b>Capital cost - break even herd<sup>14</sup></b>	USD	\$193,000	\$332,000
<b>Annual revenue - break even herd<sup>134</sup></b>	USD	\$39,000	\$62,000
<b>Average capital costs per sow<sup>2</sup></b>	USD/sow	\$160	\$506
<b>Average annual measured emission reduction</b>	T CO <sub>2</sub> e/sow	2.42	4.44
<b>Notes</b>			
Reference: "United States Department of Agriculture, "Agricultural Uses of Municipal Animal and Industrial Byproducts", Chapter 4 – Swine Manure Management. 1998.			
<sup>1</sup> Values are in 1996 USD			
<sup>2</sup> Agstar Website - Guide to operational systems			
<sup>3</sup> Values are in 2000 USD, farrow-to-finish, only single value available for complete-mix digester			
<sup>4</sup> Annual revenue includes an assessment of the value of the emission reductions created by the digester			
<sup>14</sup> Break even is the number of animals required to achieve an NPV of 0 with a 10% discount factor			

**Table 4 - USEPA Summary of Digester Implementation Costs**

Noted by its absence are the annual maintenance costs. Given the simplicity of the equipment, it can be expected to be low, however not zero. Bates estimates that the annual maintenance costs of a digester and heating facility are 10% of the capital costs (Bates, 2001 71). A supplemental power generation facility would have an additional maintenance cost of 2% of the capital costs. All of the facilities have a life expectancy of 15 years (Bates, 2001 71). The costs for a lagoon digester also include excavation of soil. If a digester is retrofitted on to an existing lagoon, it would have lower costs<sup>7</sup>.

In theory, 100% of the methane could be captured, however, due to the permeability of the covering material, further decomposition outside the digester, inability to achieve 100% air tight seal and other losses, less than 100% would be achieved in a real world application. Sources vary on the percent captured, though 50-70% is quoted in a European paper, and seems reasonable and conservative (Brink et al. 2002 6). Bates supports this range by suggesting that a 50% capture rate is achievable at the farm scale level in cool climates (Bates, 2001 65). It should be realized that this technology is not economical on a large percentage of farms. The break-even herd size for a lagoon digester is 1,350 according to EPA. The average herd size in Alberta

<sup>7</sup> A list of over two dozen installed systems in the United States can be found on the Agstar website at <http://www.epa.gov/agstar/operation/bytype.htm#covered>. The list includes the capital costs and an estimate of the methane reductions.

in 2001 was 757 and only 15% of farms have more than 1,127 head according to Alberta Agriculture (AB Ag, Pork Industry, 2001 A). Without government incentives, only a small number of farms could implement this technology in a cost effective manner at current gas and electrical prices. However, because of their much larger size, 15% of the farms represent approximately 75% of the swine population in Alberta (AB Ag, Pork Industry, 2001 C). The reduction of 50-70% of emissions on 75% of the swine population would then equate to 166-232 kT of CO<sub>2</sub>e.

A further greenhouse gas benefit of a digester combined with power generation is the indirect offsetting of emissions from off-site power generation facilities. There is also a reduction in line losses, as is the case with all distributed generation technologies. The majority of the power generated in Alberta is from the combustion of coal, releasing large quantities of carbon dioxide.

#### **4.4. Waste application to fields**

##### **4.4.1. Improved timing of manure applied to soils**

The excess application of nitrogen to soils leads to higher emissions of nitrous oxide. Swine waste is just one source of nitrogen, in addition to fertilizers and the nitrogen already present in the soil. Matching the application of nitrogen compounds to the requirements of crops would lower nitrous oxide emissions (ACCT, 2000 30). Specifically, avoiding the application of large amounts of manure to the soil as a means of disposal and avoiding application during fall when the crops are nearing harvest, or have already been harvested, can reduce emissions.

Determining the nitrogen content of the soil is cost effective. Although not confirmed for Alberta, in the UK and Ontario, software is available to estimate the nitrogen of manure and fertilizer application and soil samples can be tested for less than \$100 CDN (Bates, 2001 26, SRG 2000 18). One report indicates that significant reductions of nitrous oxide releases can be attained by using regular nitrogen testing (SRG 2000 65). Another report suggests a savings of \$1,521 USD per tonne of nitrous oxide reduction when using soil testing in the agricultural sector (Gale 4). Because an estimate of the percent reduction of emissions could not be located, reductions in Alberta cannot be estimated.

##### **4.4.2. Nitrification inhibitors**

As the name implies, some substances applied to soils inhibit the conversion of nitrogen to nitrous oxide. This typically is achieved using a compound called dicyandiamide, which slows the conversion of ammonia to nitrate by soil organisms. This results in an increased uptake of nitrogen by crops, thereby reducing emissions of nitrous oxide. Use of the substances in combination with waste application would reduce the production of nitrous oxide (ACCT, 2000 30). A report published by the Government of New Zealand indicated that 50% reductions of nitrous oxide could be achieved when using nitrification inhibitors with fertilizers (Clark et al. 2001 20). The Ontario Ministry of Agriculture indicates that nitrous oxide reductions of 45-71% are possible (SRG 2000 69).

There have been disappointing results recently in Manitoba using one specific nitrification inhibitor when used with swine manure. Results showed that there was little change in the nitrogen uptake of the crops however, results were subject to a number of environmental conditions including the type of application used (AAFC, 1999 19). A UK report indicates a high abatement cost of \$20,826 USD per tonne nitrous oxide (Gale 4).

Acknowledging that reducing nitrous oxide using nitrification inhibitors involves a complex soil management process that extends beyond the swine industry, if reduction rates were specifically applied to the nitrogen in swine manure, a 45-71% reduction would result in 53-84 kT of CO<sub>2</sub>e reductions in Alberta.

#### **4.5. Other activities and options**

Several other emission reductions activities were identified, however, very little information could be located on their cost or emission reduction potential within Alberta.

The Foundation Paper lists solids separation as a technology to reduce emissions (ACCT, 1999 59). Solids can be separated out of the waste stream to reduce the organic loading on the waste storage facility and reduce odour. It is noted that the separated solids could be used to generate biogas with the addition of other equipment.

Use of bedding material, such as hay, increases the amount of carbon that can be converted to methane in the storage facility (ACCT, 2000 30). Minimizing the use of bedding material would therefore reduce the net emissions.

For those facilities employing waste storage tanks between the feedlot and end storage facilities, a reduction in the temperature can reduce the methane production (ACCT, 2000 30).

Based on the Options Report, a small amount of manure is sent to landfills in Canada (ACCT, 2000 30). Since the decomposition within a landfill is mainly anaerobic, a small reduction in emissions could be achieved by storing the waste in a lagoon or solid storage facility.

Aerating manure during composting can reduce the methane produced. Unfortunately, data describing how much waste is being composted in Canada or Alberta cannot be located. It has not been mentioned as a source of greenhouse gases in any of the material identified, thus it is assumed to be a small percentage.

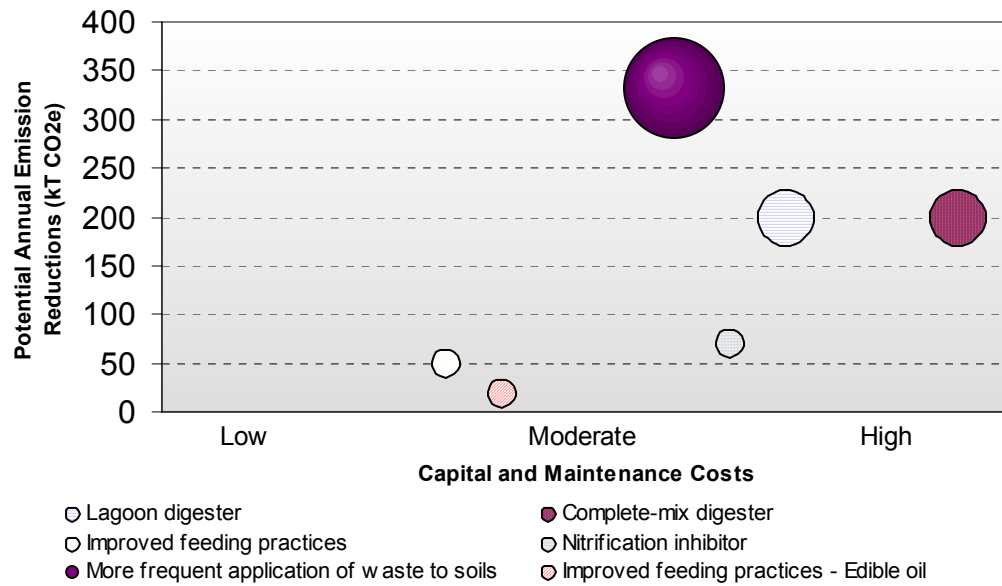
Very wet fields reduce the availability of oxygen to decomposing material, thereby increasing the methane emissions. Better management of irrigation water, and tillage practices that improve soil structure, would reduce emissions (ACCT, 2000 30).

Waste that is either applied at too shallow or too deep a depth can increase the emissions of nitrous oxide. This is due to the fact that the path of the nitrogen to the crop roots is more indirect, thereby allowing more time for nitrification to occur (ACCT, 2000 30). Ensuring the proper depth application of waste, during its application to fields, would reduce emissions.

#### **4.6. Summary**

Several technologies and management practices have been described in this section. It should be clear, given the uncertainties and lack of information, that there needs to be further research into many of the options. There are also interactions between technologies that have only been touched on briefly, such as the interaction between solids separation and a biogas digester.

Of those reviewed, there are a handful of technologies for which estimates of the emission reduction potential was quantitatively estimated. For these same technologies, a range of costs was identified in the literature or a qualitative assessment was determined. These technologies are shown below in Figure 7.



**Figure 7 – Potential Emission Reductions and Costs of Reduction Options**

Figure 7 summarizes the qualitative assessment of the capital and maintenance costs on the x-axis. As this appears to be a significant barrier to the widespread application of certain technologies like anaerobic digesters, it was determined that it was more important to indicate the cost than the net cost, or payback period. Options with a high capital cost or a high annual maintenance cost were assessed as high on the x-axis. The y-axis describes the potential emission reductions that the technologies could achieve. Three sizes were selected for the circles, representing different levels of uncertainty in the emission reduction estimates.

The two lowest cost options address the feeding practices of swine. Adding canola oil, reducing the protein and adding phytase supplementation all have low to moderate abatement costs. All of these options are attractive because of the ease of implementation, and reduced production costs from reduced feed consumption and/or reduced manure management.

Applying waste more frequently to fields has the potential to reduce a significant amount of greenhouse gases, though at a moderate cost to the farmer. Unlike feeding practice options, there are no production benefits to this option. This practice may also be limited geographically to those farms that have the capacity within the soil to accept waste on a regular basis. For most of Alberta, including central Alberta where there is the largest swine industry, this practice could not be adopted in the winter due to frozen soil. This option presents emission reduction benefits though the adoption rate is expected to be low.

Nitrification inhibitors offer another moderate cost option to reduce emissions. If managed properly, crop growth rates can be increased to generate more revenue for the farmer. The potential emission reductions are relatively low and lack of successful application has been found in Canada (AAFC, 1999 19).

The last two options, both digesters, represent a relatively high capital cost and are only economic at larger swine operations containing over 1,350 head. Generating biogas from the decomposition of manure can be a new and valuable revenue stream to farmers implementing this technology. There has not been wide spread implementation in either Canada or the United States of digesters, and several installations are not currently operating in the US (Lusk 1998 4-1). This would seem to suggest further research could be beneficial as well as training and resources for farmers wishing to set up systems on their farms. For farms with a combination of

swine, cattle and poultry, a digester may offer additional benefits, such as handling multiple waste sources.

Other key technologies not included in Figure 7 due to lack of data include:

1. Improved timing of manure applied to fields. This has the potential to offer significant reductions while reducing the use of fertilizer and production costs.
2. Increased waste removal frequency. The option would reduce air emissions within the feedlot while potentially creating a moderate amount of emission reductions.
3. Covered storage lagoons. It was difficult to determine the net benefit to the environment due to conflicting research estimates. This may have the potential to create low cost reductions with the simple purchase of an inexpensive tarp.
4. Improved production. A combination of improved genetic characteristics, reduced premature death and reduced incidence of disease would greatly benefit the industry as a whole and result in emission reductions. Farmers are currently highly motivated to continue to implement and improve on these options due to the direct increase in revenue from increased hog sales.

## 5. BARRIERS AND CHALLENGES TO IMPLEMENTATION

There are several barriers that will prevent partial or full acceptance of greenhouse gas reduction technologies. Some of these barriers are easier to overcome than others, however, many of them require some type of government involvement using policy to provide adoption incentives that remove or reduce the impact of the barrier. This would be described as the “carrot” approach by encouraging farmers to do the right thing. There may also be policies that use the “stick” approach to punish those who do not abide by the policies and laws. Given the relative contribution of the swine industry to Canada’s inventory, it would seem unlikely that strict laws will be put in place for GHG mitigation.

### 1. Cost prohibitive

Many of the technologies are currently cost prohibitive. This barrier occurs in two different ways. The first is that many of the technologies have an operating cost associated with them and either a small or non-existent future revenue stream. As with any other industry, farmers are unlikely to invest in technologies that lose money. The second financial barrier is the large capital investment that is required to implement digesters. Most available research, and actual implementation experience, shows that the revenue stream is sufficient to pay back part or all of the original investment in under 10 years, however, the average farmer may not have \$100,000 to over \$1,000,000 available to invest.

The profit margins are very tight in most agricultural industries, creating further constraints on the availability of capital. Any increase in annual costs due to implementation of abatement technologies has the potential to reduce the competitiveness of the farmer (ACCT, 2000 22). Because hogs are exported from Alberta, and the market price is set in part internationally, increases in production costs cannot be directly passed on to the consumer. The government or industry associations cannot directly address this barrier but it is important to be aware of its impact.

This barrier can be addressed by: further research (public and private sector) to verify the net financial benefits of each technology, direct financial incentives or loans to farmers who wish to implement key abatement technologies, providing farming associations with more information on the environmental benefits of the technologies.

### 2. Economies of scale

There were 2,677 farms with swine in 2001 in Alberta, with the number of swine per farm ranging from 1 to over 4,000. The large number and variability of swine production facilities make it difficult to recommend some technologies for the entire industry. It has already been mentioned that only 15% of farms in Alberta would find a digester economically viable.

There is a significant historical trend to a decreasing number of farms with swine in conjunction with an increasing average number of swine per farm (AB Ag, Pork Industry, 2001 A). If this trend continues, it will help to make the industry in Alberta more homogenous, which will help to simplify research, policy development and incentives. Due to economies of scale, digesters will become more economical for a larger number of farms.

### 3. Lack of knowledge

There is a general lack of knowledge of the costs, benefits and impact of most abatement technologies within the research community (ACCT, 2000 22). Although there is a better understanding of the GHG emissions, there still exists as much as 500% variation in estimates of

the releases of GHG from the swine industry. Further research on GHG emissions and abatement technologies needs to be done within Canada.

#### 4. Difficult to realize value from CO<sub>2</sub> reductions

For several years companies have been trading greenhouse gas emission reductions. However, with the exception of certain regulatory systems such as in the United Kingdom, an emission reduction is not a commodity, and varies based on different quality assessments. The majority of the emission reduction opportunities should meet the minimum quality requirements for an offset project. However, given the limited amount of research available, having the emission reductions verified by an independent third party may be difficult. This would affect the value of the emission reductions, and therefore the investment potential. The second issue is the size of the reduction projects. Most emission reduction transactions completed by the larger GHG emitters require a minimum 20 kT to 200 kT of reductions per year. Except for the largest Alberta swine operations, the annual volume of reductions may not be large enough to attract attention of the current emission reductions buyers.

## 6. CONCLUSION

The goal of this report was to provide an estimate of the greenhouse gas emissions and reduction opportunities for the swine industry, while also providing a background on the industry so a better understanding can be gained of the information presented.

The swine industry raises piglets to hogs, ready to be sent to market. Relative to other regions in North America, the population density of swine is low in Alberta. There are three greenhouse gases that are released in significant amounts by the swine industry: carbon dioxide, methane, and nitrous oxide. Feedlots, waste storage, and waste application to fields are the key processes that emit GHGs from swine operations. Waste is typically managed in anaerobic lagoons in Canada. The swine population within Alberta has been growing steadily since 1980. In 2002, there were 2.1 million swine in Alberta and this number is expected to increase steadily to 2.44 million head by 2010.

For the swine industry there is a significant variance in the published greenhouse gas emissions and emission factors. For the purposes of simplification, and because the guidelines are internationally reviewed, the IPCC methodology was the main source for the emission estimates. Further research is required to refine the estimates, preferably research specific to the Canadian climate and swine industry. Estimated GHG emissions associated with the Alberta swine industry in 2002 were 733 kT of CO<sub>2</sub>e, which is approximately 0.3% of Alberta's total GHG emissions. As a result of the relatively small impact of the swine industry on GHG emissions, there may be little incentive for governments to focus on this industry. Based on the projected growth of the swine population in Alberta, GHG emissions are forecasted to be 858 kT of CO<sub>2</sub>e in 2010.

A key finding was that there are number of options to reduce the GHG emissions from the industry, some of which are more promising than others. The various abatement options have the potential to reduce annual greenhouse gas emissions from as little as 20 kT to over 300 kT of CO<sub>2</sub>e. Anaerobic digesters have received the most research focus to date because of the potential to generate revenue from the capture and combustion of methane. Significant capital costs are associated with digesters, making them uneconomical for smaller farms, and represents a financial barrier for larger farms. A lower cost option, with possible significant reduction potential, is increasing the frequency that waste is removed from the feedlot and applied to fields. There are restrictions to this option given the low winter temperatures in Alberta. If this practice is combined with nitrogen testing, and more appropriate timing of waste application to fields, significant amounts of methane and nitrous oxide emissions can be avoided.

Through a variety of biological processes, the swine industry emits gases such as carbon dioxide, methane and nitrous oxide, all of which contribute to the acceleration of GHG concentration in our atmosphere. However, through additional research of abatement technologies and incentive programs for farmers, significant reductions in GHG emissions from the Alberta swine industry can be achieved.

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## APPENDIX A GLOSSARY

**Aerobic:** occurring in the presence of oxygen.

**Anaerobic:** occurring in the absence of oxygen.

**Animal feeding operation (AFO):** a term used in the United States to represent facilities where swine, poultry and cattle are raised.

**Barrow:** a castrated male swine.

**Boar:** an uncastrated male swine.

**Carbon dioxide equivalent (CO<sub>2</sub>e):** see GWP.

**Commitment Period:** refers to the period defined as the first commitment period under the Kyoto Protocol, which begins in 2008 and ends in 2012.

**Direct emission:** a release of a substance that is caused by a user action, in the same geographic area, and that the user has some control over. For example, the release of carbon dioxide from a power plant after the combustion of coal is a direct emission for the power plant facility. Direct and indirect emissions are mutually exclusive.

**Earthen manure storage (EMS):** a term used within Canada to describe a large area that has been excavated for the purposes of storing animal wastes (also referred to as a lagoon).

**Enteric fermentation:** A digestive process occurring in animals. Carbohydrates are broken down into simpler molecules for absorption into the bloodstream.

**Farrow:** a new born litter of piglets.

**Farrowed:** to give birth (swine).

**Farrow-to-finish:** a swine facility raising swine from newborn to market weight.

**Gilt:** a young unbred female swine.

**Global warming potential (GWP):** An index, describing the radioactive characteristics of well-mixed greenhouse gases, that represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in absorbing outgoing infrared radiation. The index uses carbon dioxide as a base, with an assigned value of 1. (IPCC Glossary 2001 374). Multiplying the mass of emissions by their corresponding GWP calculates the value of carbon dioxide equivalent (CO<sub>2</sub>e).

**Greenhouse gas (GHG):** Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds. Under the Kyoto Protocol to the United Nations Framework Convention on Climate Change there are six classes of greenhouse gases (GHG) specified: CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, hydrofluorocarbons, perfluorocarbons and SF<sub>6</sub>. (IPCC Glossary 2001 374).

**Head:** a single swine of any age. Usually used within a factor to represent a release of emissions per swine.

**Hog:** an adult swine, usually possessing a weight greater than 54 kg. Hog, swine and pig are often interchanged when referring to the swine industry.

**Indirect emissions:** a release of a substance that is caused by an action and occurs in a different geographic area, usually by a separate industry than the facility, and the user has no direct control over. For example, the purchase of electricity from the Alberta electricity grid is an action that causes the release of carbon dioxide from fossil fuel plants. However the plants are not owned or located within the same area as the purchaser. The purchaser also has no control over the type of fuel or operation of power plants that supply the grid with electricity. Direct and indirect emissions are mutually exclusive.

**Kilotonne(kT):** one thousand metric tonnes.

**Megatonne(MT):** one million metric tonnes.

**Pig:** used either as a synonym for swine or as an abbreviated version of piglet.

**Piglet:** a young swine.

**Phytate:** A phosphorus-containing compound in the outer husks of cereal grains that binds with minerals and inhibits their absorption (ADA 2002)

**Pork:** the flesh and muscle of a swine, processed for human consumption.

**Ruminant methane:** methane emissions released by ruminant animals. Ruminant animals, such as cattle and sheep, have a multiple chamber stomach. Ruminant animals produce more methane than non-ruminant animals, due to increased fermentation of the food in the rumen, or fore stomach, because of the anaerobic conditions within the stomach.

**Sow:** an adult female swine who has given birth.

**Sow unit:** Represents a sow and her annual production (also called a sow marketable unit).

**Swine:** any of a family of stout short-legged hoofed mammals with bristly skin and a long flexible snout (The New Merriam-Webster Dictionary). Hog, swine and pig are often interchanged when referring to the swine industry.

**Weaner:** A piglet who has recently been weaned (removed from its sow and placed on solid food). May also be called weanling.

Please note that the Intergovernmental Panel on Climate Change manages an excellent and comprehensive glossary of terms that are relevant to climate change. The glossary can currently be found at <http://www.ipcc.ch/pub/syrgloss.pdf>.

## APPENDIX B METHODOLOGY

### 1. Linear Regression of Swine Population

Linear regressions were applied to two different population data sets in this study. A regression was applied to the annual Canadian swine population from 1980 to 2002. A second regression was applied to the annual Alberta swine population data from 1980 to 2002. Both regressions were then used to extrapolate the population in 2010 for Alberta and Canada. In each of the regressions, the year was independent variable, and the population was the dependant variable.

Because the CEEMA forecast was for Canada, some method must be used to calculate what Alberta's share of the market will be. The Alberta forecasted value in 2010 was divided by the Canadian forecast, in order to estimate Alberta's percent share of the market.

The Alberta forecast strictly based on the regression was used as a third scenario, in addition to Dr. Basarab and the CEEMA scenarios. All of the population data was supplied by Emma Clowes, Pork Systems Specialist with Alberta Agriculture, Food and Rural Development. Table 5 shows a summary of the two regressions and their forecasted population values.

A third regression was done to be able use the forecast of 100% increase in sow units by Dr. Basarab. A sow efficiency value was calculated based on the total swine population excluding sows, divided by the number of sows. If more swine can be supported with the same number of sows, the industry has become more efficient. The linear regression formula and fit are also shown in Table 5. The fit is quite poor with an r-squared value of 0.331, however, there is a visible slow upward trend to the data.

	Alberta	Canada
	Formula	Formula
	2010 Population (000s)	2010 Population (000s)
<b>Population 1980 thru 2002</b>	$y = 38,541x + 1,250,141$ $R^2 = 0.814$	$y = 180,858x + 8,992,066$ $R^2 = 0.781$
<b>Sow Productivity</b>	$y = 0.0395x + 8.367$ $R^2 = 0.331$	959%
<b>Alberta's Market Share</b>	16.7%	

**Table 5 - Summary of Swine Population Regression Equations and Results**

### 2. Estimation of Nitrous Oxide Releases From Manure Management Systems

This calculation is done using the guidelines published by IPCC in the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Workbook Volume 2 and the update document IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. The calculation begins with the equation 4.18 on page 4.42 of the Good Practices guide:

$$(N_2O-N)_{(mm)} = \sum_{(S)} \{ [\sum_{(T)} (N_{(T)} \times Nex_{(T)} \times MS_{(T,S)}) ] \times EF3_{(S)} \}$$

where :

$$(N_2O-N)_{(mm)} = N_2O-N \text{ emissions from manure management in the country (kg N}_2\text{O-N/yr)}$$

$N_{(T)}$  = Number of head of livestock species/category T in the country  
 $Nex_{(T)}$  = Annual average N excretion per head of species/category T in the country (kg N/animal/yr)  
 $MS_{(T,S)}$  = Fraction of total annual excretion for each livestock species/category T that is managed in manure management system S in the country  
 $EF3_{(S)}$  = N<sub>2</sub>O emission factor for manure management system S in the country (kg N<sub>2</sub>O-N/kg N in manure management system S)  
S = Manure management system  
T = Species/category of livestock

The default factor for  $Nex_{(T)}$  is listed in the Revised 1996 Guidelines however in the Environment Canada 2000 inventory, a revised value of 11.6 is used (EC, 2002 108). Table 4-7 on page 4.11 of the Revised 1996 Guidelines provides the values for  $MS_{(T,S)}$  which states for North America: 25% anaerobic lagoon, 50% liquid system, 18% solid storage, 6% other. In the 2000 Inventory, Environment Canada provides a supplemental assessment to this data. Based on an expert opinion by Ray Desjardins with Agriculture and Agri-Food Canada, 90% of manure from swine in managed in anaerobic lagoons and 10% is managed in solid storage (EC, 2002 108). This opinion was confirmed as accurate for Alberta, given the lack of data, by both Michelle Follensbee and Andy Cumming, who are both with Alberta Agriculture, Food and Rural Development (Follensbee 2003, Cumming 2003). As this opinion is more specific to the Canadian agricultural industry, it is assumed more accurate and will be used in this assessment.  $EF3_{(S)}$  is found in table 4.12 on page 4.43. The table lists the factors 0.001 for anaerobic lagoons and 0.02 for solid storage with an uncertainty of -50%/+100%. Since only the swine industry is being examined, T is swine only. Finally, in order to convert from N<sub>2</sub>O-N to N<sub>2</sub>O, the result must be multiplied by 44/28 = 1.57.

For each separate animal waste system, a separate calculation of the equation is required. Below is a sample calculation for the Alberta swine population in 2002 for anaerobic lagoon manure management systems.

$$\begin{aligned}
 (N_2O-N)_{(mm)} &= 2,112,730 \text{ swine} \times 11.6 \text{ kg/animal/yr} \times 90\% \times 0.001 \text{ kg N}_2\text{O-N/kg N} = 22,056 \text{ kg N}_2\text{O-N/yr} \\
 22,056 \text{ kg N}_2\text{O-N/yr} \times 44/28 &= 34,659 \text{ kg N}_2\text{O/yr} \times 310 \text{ N}_2\text{O GWP} = 10,744 \text{ T CO}_2\text{e/yr}
 \end{aligned}$$

### 3. Estimating Nitrous Oxide Releases from Waste Application On To Soil

This calculation is done using the guidelines published by IPCC in the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Workbook Volume 2 and the update document IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. The calculation begins with the equation 4.23 on page 4.54 of the Good Practices guide:

$$F_{AM} = \sum_T (N_{(T)} \times Nex_{(T)}) \times (1 - \text{Frac}_{GASM}) \times [1 - (\text{Frac}_{FUEL-AM} + \text{Frac}_{PRP})]$$

where:

$F_{AM}$  = manure nitrogen used as fertiliser in country, corrected for NH<sub>3</sub> and NO<sub>x</sub> emissions and excluding manure produced during grazing (kg N/yr);  
 $\text{Frac}_{FUEL-AM}$  = fraction of livestock nitrogen excretion contained in excrements burned for fuel (kg N/kg N totally excreted);  
 $\text{Frac}_{PRP}$  = fraction of livestock nitrogen excreted and deposited onto soil during grazing (kg N/kg N excreted);  
 $\text{Frac}_{GASM}$  = fraction of total nitrogen excretion that is emitted as NO<sub>x</sub> or NH<sub>3</sub> (kg N/kg N);  
 $N_{(T)}$  = number of animals per Type of animal in country;  
 $Nex_{(T)}$  = nitrogen excretion per Type of animal in country (kg N/yr);

T = Species/category of livestock

$N_{ex(T)}$  = was calculated for swine using the methodology describe in section two of this appendix. Based on the expert opinion of Ray Desjardins with Agriculture and Agri- Food Canada, no manure is used as fuel, which makes  $Frac_{FUEL-AM} = 0$  (EC, 2002 108). Ray Desjardins also estimated that no swine are raised in a paddock and pasture system, causing  $Frac_{PRP} = 0$ . Based on table 4-17 in the Revised 1996 Guidelines, the default value for  $Frac_{GASM}$  is 0.2 kg  $NH_3-N + NO_x-N$ /kg of nitrogen excreted by livestock. The equation can then be simplified to:

$$F_{AM} = (N_{(T)} \times Nex_{(T)} \times (1-0.2)) = 0.8 \times N_{(T)} \times Nex_{(T)}$$

The next equation required is:

$$N_2O_{Direct-N} = \Sigma[(F_{SN} + F_{AM} + F_{BN} + F_{CR}) \times EF_1] + (F_{OS} \times EF_2)$$

where:

$N_2O_{Direct-N}$  = the direct releases of nitrous oxide from agricultural fields (kg N/yr);

$F_{SN}$  = nitrogen input from total synthetic fertilizer (kg N/yr);

$F_{AM}$  = manure nitrogen used as fertiliser in country, corrected for  $NH_3$  and  $NO_x$  emissions and excluding manure produced during grazing (kg N/yr);

$F_{CR}$  = nitrogen input from crop residues (kg N/yr);

$F_{BN}$  = nitrogen input from N-fixing crops (kg N/yr);

$EF_1, EF_2$  = emission factors;

$F_{OS}$  = area of cultivated organic soils (Histosols) in country.

The scope of this paper does not include the calculation of other types of nitrous oxide releases from the agricultural industry. The above equation is structured in a way that each source of nitrogen is added to the other sources. Therefore, each individual source may be analyzed separately. This then simplifies the equation for this analysis to:

$$N_2O_{Direct-N} = F_{AM} \times EF_1$$

The default value for the emission factor  $EF_1$  is found in table 4-18 in the Revised 1996 Guidelines and is equal to 0.0125 kg  $N_2O-N$ /kg nitrogen input. 2002 is used as the example year. The conversion factor from  $N_2O-N$  to  $N_2O$  is  $44/28 = 1.57$ . The calculations are then straightforward for the  $N_2O$  released.

$F_{AM} = 0.8 \times N_{(T)} \times Nex_{(T)} = 0.8 \times 2,112,730 \text{ swine} \times 11.6 \text{ kg/animal/yr} = 19,606,134 \text{ kg N/yr}$   
 $N_2O_{Direct-N} = F_{AM} \times EF_1 = 19,606,134 \text{ kg N/yr} \times 0.0125 \text{ kg } N_2O-N/\text{kg} = 245,077 \text{ kg } N_2O-N/\text{yr}$   
 $245,077 \text{ kg } N_2O-N/\text{yr} \times 44/28 = 385,120 \text{ kg } N_2O/\text{yr}$   
 $385,120 \text{ kg } N_2O/\text{yr} \times 310 \text{ } N_2O \text{ GWP} = 119,387 \text{ t } CO_2e/\text{yr}$

#### 4. Estimating GHG emissions from swine facilities

In order to apply the emission factors specified in the paper by Dr. Laguë, the average weight of the swine must be known. The population data used in section 2.1 is broken down into 5 categories: sows & bred gilts, boards 6 months plus, under 20 kg, 20-60 kg and over 60 kg. The average weight of 150 kg/animal for sows will be used from Dr. Laguë's paper. An average weight for the boars of 205 kg from the PEI Department of Agriculture will be used (PEI 2002). For under 20 kg category, an average weight of 10 kg is used. For the 20-60 kg category, an average weight of 40 kg is used. Finally, many documented sources indicate that the finishing weight of swine are usually 120 kg, therefore an average weight of 90 kg will be used for the over 60 kg category.

The average weights are then multiplied by the average population for that category in each year, to determine the kg-yr rate. As the last step, the emission factors shown in Dr. Laguë's report are multiplied by this data.

## APPENDIX C ENVIRONMENTAL CO-BENEFITS AND IMPACTS

The release of greenhouse gases is not the only environmental impact by the swine industry. For many stakeholders, GHG mitigation is a much lower priority than odor emissions, hydrogen sulphide releases or ground water contamination. This section will briefly review some of the other environmental impacts associated with the industry.

### 1. Air emissions

#### 1.1. Odor

Historically, the most significant public complaint related to the swine industry has been the odor associated with operations. Odor is produced by dozens of compounds that are released from anaerobic decomposition of waste. Odor can be dramatically reduced by some of the same technologies used to reduce GHG. Digesters can reduce as much as 97% of the odor released when compared with the undigested waste stream (Lusk 1998 2-22). Lagoon covers are often installed not to capture methane, but to reduce odor. Various chemicals and enzyme treatments can also be added to waste storage facilities to decrease the odor.

#### 1.2. Ammonia

Ammonia has a strong odor that can be released at all stages during swine production. Ammonia is emitted from manure and then released as the manure is removed from the feedlot, stored in a lagoon and then finally applied to soil. Ammonia emissions from swine operations are considered a significant environmental issue and have been linked to acidification of soils and lakes (Golder, 1999 3-2,3-6). Many of the technologies that reduce nitrogen excretion also reduce ammonia emissions, however, each individual technology has different impacts.

#### 1.3. Hydrogen sulphide

Hydrogen sulphide (HS) produces an odor similar to rotten eggs. It is produced during anaerobic decomposition of waste. It is a growing safety concern because at high concentrations, it poses a direct health threat to animals and workers within feedlots. Increasing the frequency of manure application to soil reduces greenhouse gas emissions as well as HS emissions within the feedlot.

#### 1.4. Particulate matter

Particulate matter (PM) poses a health risk when inhaled by humans. PM can be emitted directly by animals (dander, hair, bacteria pollens) and from animal wastes (Golder, 1999 3-5,3-8). PM within feedlots can be significant, with PM<sub>10</sub> (particulate matter 10 micron and smaller) emission levels ranging from 100 to 300 µg/m<sup>3</sup> (Golder, 1999 3-9). Any of the technologies that reduce the amount of waste produced would also reduce the PM emissions.

## 2. Groundwater and surface water emissions

### 2.1. Nitrogen and Ammonia

Excess nitrogen in the form of nitrates and ammonia within groundwater can be a health risk to humans, especially infants (Golder, 1999 3-24). Nitrogen in the form of nitrates is contained within swine manure, and has been shown to cause liver damage and various types of cancer within humans. Nitrate from manure can enter groundwater by leaching through the soil (i.e. from a poorly lined lagoon), or directly by surface water runoff. Some studies have shown that contamination of aquifers can be linked to the application of animal manure (Golder, 1999 3-27). Matching the nitrogen contained within the manure, with the requirements of the soil, can mitigate both greenhouse gases as well as some of the issues related to water quality.

## 2.2. Pathogens

Pathogens can enter groundwater in similar ways to nitrogen, leaching through the soil or by surface water runoff. Studies have shown contamination of fecal streptococcus bacteria in groundwater caused by two swine manure lagoons (Golder, 1999 3-28). Any technology that reduces the production of manure, including improved feeding strategies, would decrease the amount of pathogens deposited in waste storage facilities.

## 3. Land effects

### 3.1. Nitrogen

The management of swine waste can result in negative impacts to land. For example, in larger swine operations, the amount of waste produced can exceed the optimal nutrient requirements of the surrounding soil, leading to excess nitrogen being applied. Excess nitrogen can have negative impacts to crop performance (Golder, 1999 3-19).

### 3.2. Salinity

Salinity refers to the amount of salt contained within the soil. Excess salt reduces a crop's ability to take up water, and therefore can affect production. Swine manure can contain high salt levels that may create problems with salinity of the crops.