Gap and Opportunity Analysis for Advancing Meaningful Biological Greenhouse Gas Reductions

March 13, 2012

The prasino Group

Submitted by: The Prasino Group & Associates

Garth Boyd, Ph.D.
Keith Driver, M.Sc., P.Eng., MBA
Gillian Godfrey, M.Sc.
Karen Haugen-Kozyra, M.Sc., P.Ag.
Kevin Kemball, Ph.D, P.Biol.
Alison Lennie, M.Sc.
Xiaomei Li, Ph.D.
Milo Mihajlovich, B.Sc., RPF
Candace Vinke, M.A.

Executive Summary

This report built on previous work completed for Climate Change and Emissions Management Corporation (CCEMC) on biological greenhouse gas (GHG) mitigation. Specifically: 1. Enhancing Biological GHG Mitigation in Canada: Potentials, Priorities and Options and; 2. Biological Opportunities for Alberta. These reports concluded that in order to meet the GHG reduction targets being contemplated in North America by 2020, Alberta requires a "next wave" of GHG reduction and mitigation. Biological capture and fuel replacement strategies were seen as the most efficient mitigation options readily available for Alberta.

This report directs the potential possibilities for development of an investment road map on how to efficiently engage the biological sector in achieving meaningful GHG reductions. Areas covered included: *Nitrogen Management, Livestock Management, Transportation, Waste Management, Forestry, and Peatland*.

The area that showed the largest emission offset potential was Waste Management, with a potential of 19.95-21.24 Mt CO_2e. The lowest total emission reduction potential would be achieved with changes in Transportation. In total these practice changes were estimated to provide only 1.65 Mt CO_2e in potential emission offsets. The report was unable to quantify the potential offset of peatland reclamation and avoidance, due to a lack of available scientific data. However, the offset potential is assumed to be of significant value.

In order to achieve these emission reductions, technology development opportunities for each of sector were evaluated. In particular, emphasis is placed on technology development opportunities that may offer breakthrough solutions for biological GHG reductions. Further, recommendations on how to effectively engage Alberta's biological GHG sectors through communication activities, strategic partnerships and effective information sharing were also examined.

From this analysis, a number of opportunity areas across the biological sector were discussed and opportunities/constraints identified. Each of these opportunity areas is evaluated based on its reduction potential, verifiability and whether the tools (i.e. protocols) are in place for validating and verifying the project type. Based on these three factors each opportunity area was given one of three project classes:

Enabler – Opportunity areas that are ready for demonstration and have a total reduction potential of greater than 1 Mt CO_2e/yr across the biological reduction sector.

Accelerator – Opportunity areas that either have a small total reduction potential (less than 1 Mt CO2e/yr) or do not have all the necessary measurement tools in place for project validation and verification (i.e. protocols)

Technology Opportunity – Opportunity areas lacking the science and/or data to calculate a theoretical reduction potential and the necessary tools for project validation and verification. A significant amount of work is still needed in these areas before they will be ready for further development.

Priority actions for each biological reduction sector are presented in the Opportunities and Constraints tables and the Key Messages sections at end of each portion of the report. The Opportunities and Constraints tables were broken down into inputs, activity and outputs; and into science, technology, markets and policy. Each cell was then color coded based on the items readiness for investment. Red indicated an area where there were no issues or no opportunity for investment. Yellow represented an area with some potential; however, at present this potential is not a priority. Finally, areas shaded in green highlighted the best opportunities for investment and as such are presented in the following tables. Tables E1 and E2 summarize the priority action items identified (green areas) for Enabler and Accelerator projects respectively. These areas are the most ripe for investment.

Table E1 – Priority Actions for the Enablers

	Items for Action
Nitrogen Management – 4R Variable Rate Technology	• Research is needed on the impacts of reduced N fertilizer use on yields. • Demonstration of variable rate technologies on-farm; precision application of fertilizers/ pesticides, tools for measuring emissions and nutrient recovery technology are needed.
Livestock Management - Beef & Dairy Cattle	**Beef Cattle:** • Illustrating the quality and synergistic co-benefits of the output. • Data collection and data gaps need to be identified to support GHG calculations and promote practice change. • Supporting infrastructure and platforms for aggregating multiple operations are needed. • Due to the lack of blood tests for RFI there is a need for an integrated trait index (RFI). Further, more affordable methods of testing bulls for RFI are needed. • Market acceptance of the practicality of data management requirements needs to be demonstrated and costs-benefits assessed. • Research on the potential impacts on the quality of the beef – positive or negative. • Enforcement of tracking dates of birth. **Dairy Cattle:** • Upgrade existing dairy protocol with new synthesized science. • Support expansion and continuation of the ADFI Dairy Pilot in Alberta; this will provide valuable insight for GHG data platforms and aggregation mechanisms. • Move to a full programmatic approach in implementing dairy GHG reductions in Alberta; building on recommendations from the pilot. • Integration of Energy Efficiency Protocol with Dairy Protocol for greater emissions reductions. • Systematic assessment of potential GHG reductions for dairies (both energy

	and biologically based). • Development of integrated data management and aggregation platforms; methods approved by ARD/AEW. • Streamlined implementation resulting in reduced transaction costs.
Waste Management	**Methane Avoidance, Capture and Destruction:** • A monitoring procedure needed to document CH_4 and odor reduction. • Need to provide education on avoidance strategies and develop a method for marketing reduction attributes. • Marketing strategies to promote environmental stewardship. • Develop GHG mitigation protocol and waste management policy. • Need methods for quantifying carbon credits and measuring environmental impacts. **Pyrolysis and Biochar:** • Science of biochar composition and properties needs to be better understood. • Pyrolysis technology needs to be piloted at various scales, particularly systems that process approximately 10,000 tonnes feedstock/year; standardize the operation procedure. • Standards for measuring biochar and bio-oil quality are needed. Post-processing technologies to be tested for application. • Markets need to be developed and acceptance of biochar promoted. Need commercial volumes. Carbon sequestration potential needs to be measured/verified to sell offsets. • Land application rules to be tested. • Develop GHG mitigation and offset protocols for biochar/bio-oil. • Need to regulate landfills for organic material collection/diversion. • Competing and seasonal markets to be defined. Agricultural residues need to be secured. **Anaerobic Digestion and Nutrient Recovery** • Refine solid/liquid separation-drying process; develop nutrient recovery technologies. • Bio-fertilizer packaging to meet fertilizer standards. • Make system more cost effective/economically viable. Need to establish market value for product. • Promote market acceptance of bio-fertilizer. Measurement standards needed to determine quality of bio-fertilizer. • Develop GHG mitigation and offset protocol for using bio-fertilizers. • Land application rules to be tested for bio-fertilizer.

Table E2 – Priority Actions for the Accelerators

	Priority Actions
Nitrogen Management – Bio-fertilizers	• Distribution of bio-fertilizers is limited to the immediate area around its source. • A protocol is needed for bio-fertilizers.
Livestock Management - Farm Energy Efficiency	• Better information to support cost-benefit information and base energy data; identify and target companion funding programs. • Build decision support tools for farmers that will use existing programming for farm energy audits. • Small tonnage from each farm requires the development of a platform to implement the Energy Efficiency Protocol across a large number of farms; can adapt similar programs being built for Oil and Gas Installations. • Can connect energy efficiency projects with available On-Farm Energy Management Programs under Growing Forward. • Link to ARD's On-Farm Energy Footprint Calculator developed by Don O'Connor to broaden the Energy Efficiency quantification protocol in Alberta.
Livestock Management - Swine	• A pork pilot to identify data gaps, find solutions and develop recommendations to build the needed infrastructure and platforms to aggregate GHG reductions across Alberta pork operations. • Opportunities to streamline implementation of practice changes to reduce GHGs; increase capacity of pork producers to respond. • Pilots to identify opportunities to streamline implementation of the aggregation platform; identify synergies with Energy Efficiency Protocol. • Reduced transaction costs result in greater returns to pork producers; opportunity to co-implement energy efficiency actions for greater returns. • Development of integrated data management and aggregation platforms for Energy Efficiency and Pork protocols; methods approved by ARD/AEW. • Streamlined implementation resulting in reduced transaction costs.

Livestock Management - Improved Manure Management (Excluding Bedding Type)	• Research on GHG emissions from applying varying forms of manure to land and CH_4 emissions from manure storages under varying conditions. • Develop BMPs to further reduce GHG emissions from land application of manure and CH_4 emissions from storage. • Refined estimates incorporated into Pork and Dairy protocols; upstream emission reduction opportunities incorporated into Anaerobic Digestion protocol. • Demonstrate the data management and aggregation platforms as part of the Pork and Dairy pilots. • Streamlined implementation of mitigation strategies to reduce emissions. • Incentive programs to increase adoption of improved manure management practices; regional anaerobic digesters. • Build synergistic programming with the Alberta Bioenergy Program.
Transportation	• Protocols are needed. • Theoretical or on-highway estimates require calibration for off-highway use. Intermodal quantification is difficult. • Require adjustment and fitment to off-highway application or development and parameterization. Local sources and technological conversion of fleet is limiting adoption. Data to support intermodal shift is not available. • Agriculture sector lags due to slower turnover of fleet. Rail support on intermodal-data and willingness to develop infrastructure is lacking. • Development of a model - data management system to plan and document implementation is needed. • Active support of intermodal by railways is absent. Linkages between reduction in fuel consumption and GHG emission reduction need to be made routine. Extension and aggregation tools are required. • Minimal market pull from users – limited by economic constraints and relatively high capital value/dispersed nature of “fleets” resulting in slow turnover. • Refinement of quantification of aggregated and integrated activities is needed. • Calibration/adaptation of SmartWay technologies to off-highway use
Forestry	• Accurate estimates exist, but potential is essentially unrealized. • Numerous bio-mass and cellulosic feed stock processes require supply (e.g. cellulosic ethanol, pyrolysis, high value fuels, rayon). • Clarification on stumpage is needed, particularly across multiple users of a single tree. Brokering of value of “commercial wood” between existing fibre-based industry and emergent bio-industries. • Some protocols are in place. Need to clarify the potential and role of more

	novel processes (e.g. pyrolysis, cellulosic ethanol, etc.) • Need to clarify how harvested wood that is being directed to multiple industrial processes will have stumpage and ownership assigned. • Need to integrate improvements in forestry into broader initiatives, improve integration between forest entities and integrate forestry tree use efficiency with transportation efficiency through load densification and modal freight switching.

Table of Contents

List of Tables

List of Figures

List of Acronyms

AD	Anaerobic Digestion
ADFI	Atlantic Dairy Forage Institute
AEW	Alberta Environment and Water
AFPA	Alberta Forest Products Association
Ag EMP	Agricultural Energy Management Plan
AIA	Alberta Institute of Agrologists
ALMA	Alberta Livestock and Meat Agency
AMTA	Alberta Motor and Transport Association
ARD	Alberta Agriculture and Rural Development
ASRD	Alberta Sustainable Resource Development
BMP	Best Management Practice
BSE	Bovine Spongiform Encephalitis
CANAMEX	Canada, America and Mexico Corridor
CCEMC	Climate change and Emissions Management Corporation
CCIA	Canadian Cattle Identification Agency
CCS	Carbon Capture and Storage
CFL	Compact Fluorescent Lamp
CH_4	Methane
CLA	Conjugated Linoleic Acid
CHP	Combined Heat and Power
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
DFC	Dairy Farmers of Canada
DDGS	Dried Distillers Corn and Solubles
DMI	Daishowa-Marubeni International Ltd.
EMOLITE	Evaluation Model for the Optimal Location of Intermodal Terminals in Europe
EPA	Environmental Protection Agency
FERIC	Forest Engineering Research Institute of Canada
GHG	Greenhouse Gas
GIFT	Geospatial Intermodal Freight Transportation
GIS	Geographic Information System
Gj	Giga joule
GPS	Global Positioning System
Ha	Hectare
Hd	Head (cattle)
IBI	International Biochar Initiative
IEA	International Energy Agent
ITS	Intelligent Transport Systems
IPCC	Intergovernmental Panel on Climate Change
K	Potassium
LCA	Life Cycle Analysis
LEED	Leadership in Energy and Environmental Design
LiDAR	Light Detection and Ranging
LNG	Liquefied Natural Gas

MJ	Mega Joule
MMV	Monitoring Measurement and Verification
MOU	Memorandum of Understanding
MPB	Mountain Pine Beetle
Mt	Mega tonne
MW	Megawatt
MWh	Megawatt hour
MSW	Municipal Solid Waste
NRC	Natural Resources Canada
NERP	Nitrous Oxide Emissions Reductions Protocol
NGO	Non-Governmental Organization
NIR	National Inventory Report
N	Nitrogen
NH_3	Ammonia
N_2O	Nitrous Oxide
NO_3^-	Nitrate
NRC	Natural Resources Canada
OSB	Oriented Strand Board
P	Phosphorus
PM	Particulate Matter
PSNT	Pre-side dress Soil Nitrate Test
R&D	Research and Development
RFI	Residual Feed Intake
SRM	Specified Risk Materials
TRANS	Alberta Transportation
TW	Terawatt
TWh	Terawatt hour
UNFCCC	United Nations Framework Convention on Climate Change
UPS	United Parcel Service
VSD	Variable Speed Drives

1. Background/Introduction

Alberta is rich in natural resources including, but not limited to, fossil fuel deposits, agricultural lands, forests and other natural areas. The province has used and continues to use these resources to build its economy. However, increasing concern over the impacts of climate change has resulted in significant international pressure on the province to “green” its energy sector. In response, the province has developed a Climate Change Strategy that lays out its plan for creating a more sustainable and less carbon intensive energy sector by 2050. Although this plan focuses primarily on the energy sector, Alberta’s vast forest, agricultural and natural lands make the biological sector particularly well suited to contribute to greenhouse gas (GHG) emission reductions. Moreover, many of these reductions can be achieved while still providing food, feed, fibre and renewable fuel for a growing global population.

The following report is an extension of previous work completed for Climate Change and Emissions Management Corporation (CCEMC) on biological GHG mitigation. Specifically, the report builds upon the following two previous reports: 1. *Enhancing Biological GHG Mitigation in Canada: Potentials, Priorities and Options* and; 2. *Biological Opportunities for Alberta.*

Enhancing Biological GHG Mitigation in Canada: Potentials, Priorities and Options explored the opportunity for agriculture, forestry, waste to energy and landscape level/large scale integrated management for emission reductions in Canada up to 2020. This study employed common carbon accounting principles and identified constrained and theoretical reduction potentials from biological management. The analysis covered a range of biological reduction activities, most of which are also covered in the present report. The overall objective of the paper was to provide further information on biological GHG mitigation opportunities for Canada.

The report analyzed each opportunity in full, including the mechanism and methodology for mitigation, constraints to realizing the theoretical potential and requirements for operationalizing the opportunity (or sub-wedge). Each opportunity (sub-wedge) was then rated based on the speed of development, the magnitude of the potential emission reduction, the scalability of the emission reduction and the research and development stage.

The Canadian theoretical biological GHG mitigation potential was estimated to be over 200 Mt CO_2e/yr. Once constrained, this potential was reduced to a range of 52.91 to 65.65 Mt CO_2e/yr. Under both scenarios over half of this potential was associated with changes to waste management practices.

Short and long-term strategic plans were suggested to achieve the mitigation potentials identified. Key components of the short-term plan were to address gaps in the quantification tools and enable policy for large-scale opportunities. The long-term strategy identified the need to enable large-scale opportunities through policy and/or infrastructure changes.

The second report*, Biological Opportunities for Alberta*, examined the technical potential for emissions management and emissions capture in Alberta’s core biological industries – agriculture and forestry. The paper explored the technical potential of biological mitigation options in order to determine the most promising areas for strategic investment and further investigation. The reduction assessments included in this report were quantified using accepted Alberta government offset protocols, where such protocols existed.

Alberta's potential to capture and manage carbon stocks through agriculture and forestry related activities were found to be between 23.9 and 33 Mt CO_2e per year. These estimates did not include changes in forest soil storage, mountain pine beetle (MPB) management impacts, bio-products or natural materials.

The report concluded that in order to meet the GHG reduction targets being contemplated in North America by 2020, Alberta requires a "next wave" of GHG reduction and mitigation. Biological capture and fuel replacement strategies were seen as the most efficient mitigation options readily available for Alberta.

2. Objectives and Structure of the Report

2.1 Objective

The objective of this report is to support Alberta Innovates Bio Solutions (AI Bio) and the Climate Change and Emissions Management Corporation (CCEMC) in advancing meaningful and direct GHG reductions from the biological sector. Throughout the report care is taken to ensure alignment with the United Nations Framework Convention on Climate Change (UNFCCC) principles of additionality, uncertainty, verifiability and permanence. The main outcome is a set of recommendations for the development of an investment road map on how to efficiently engage the biological sector in achieving meaningful GHG reductions.

2.2 Report Structure

The following report covers six areas of biological mitigation. These areas are:

1. *Nitrogen Management* – includes reductions related to soil nitrogen management (integrated BMPs variable rate technology), irrigation management and switching to bio-fertilizers;
2. *Livestock Management* – includes beef and dairy cattle emission reductions, farm energy efficiency improvements, swine reductions and improved manure management;
3. *Transportation* – includes intermodal freight shift, improved fuel efficiency, fleet management, transportation efficiency and fuel switching;
4. *Waste Management* – includes avoided methane emissions, methane capture and destruction, pyrolysis/biochar and anaerobic digestion/nutrient recovery;
5. *Forestry* – includes changes in harvesting practice, improvements in product recovery and reductions in waste streams and;
6. *Peatlands* – includes avoided peatland disturbance and improved peatland management.

Although biological energy production (biofuels and biogas) is out of the scope of this project, some forms of biomass/waste to energy are examined as they relate to and contribute to the waste management sector.

For each area of biological mitigation (with the exception of Peatlands[1] and parts of the Forestry sections of the report – these opportunity areas were included as additional or other opportunities) the report follows the following structure:

- Introduction to the Opportunity
- Literature Review
    - Science
    - Technology (Applications/ Demonstrations)
    - Markets
    - Policy
- Greenhouse Gas Emission Reduction Potential
    - Magnitude and Verifiability
    - Justification
- Gaps and Constraints
    - Science, Data and Information Gaps
    - Policy Gaps
    - Technology Gaps
    - Demonstration Gaps
    - Metric Gaps
    - Other gaps
- Opportunities to Address the Gaps/Constraints Identified

At the end of each section a summary is provided for the entire biological reduction sector. This summary is broken down into four components: summary of findings (highlighting opportunities and constraints), total theoretical provincial impact (reduction) potential, impacts of any gaps/constraints on this reduction potential and key messages (a point form summary across all opportunity areas under the biological reduction area).

The opportunities and constraints presented in the summary of findings section are organized in a table. This table is broken down into inputs, activity and outputs. It is also color coded. Red indicates an area where there are no issues or there is no opportunity for investment. Yellow represents an area with some potential; however, at this point this potential is not a priority and areas shaded in green highlight the best opportunities for investment.

The summary of finding tables for nitrogen management, transportation, and forestry are presented using an integrated approach that incorporates all reduction areas under an area of biological reduction

[1] The majority of information available on peatland carbon relates to sequestration. Since this report is interested in emissions reductions rather than sequestration, the best options for peatland management relate to avoided disturbance/alteration and peatland restoration. Data is inconsistent and often contradictory on whether drainage or flooding has positive or negative effects on peatlands. Further, some studies identify extrinsic influences as the primary drivers of change, rather than direct human impacts. Due to these nuances, it is difficult to qualify the carbon emission reduction potential of peatlands. As such, the peatlands section of this report is significantly shorter than the other areas of biological mitigation discussed.

into a single table. In contrast, a separate table is used for each opportunity area under waste management and livestock management. This approach was used in order to effectively capture the diversity in science, technology, markets and policy found within the waste management and livestock management biological reduction areas.

The report concludes with a summary of the technology development opportunities for each biological reduction area offering breakthrough solutions, a section on how to efficiently engage the biological sector through communication activities, strategic partnerships and effective information sharing and a set of final recommendations for Climate Change and Emissions Management Corporation (CCEMC).

3. Biological Reduction Potentials and Analysis

3.1 Nitrogen Management

3.1.1 Soil Nitrogen Management – Integrated Best Management Practices (BMPs) Variable Rate Technology and Irrigation Management

In the environment, fertilizer-derived nitrogen (N), like any form of mineral N[2] (or 'free' or 'soluble' N), is subject to: 1) emission as nitrous oxide (N_2O) from nitrification or denitrification; 2) indirect losses through leaching of nitrate (NO_3^-) and/or volatilization of ammonia from the system; and 3) re-deposition on soils where it can further be converted to N_2O. For these reasons, simply decreasing the rate of N fertilizer may not result in a corresponding decrease in emissions of GHGs.

Instead, a multifaceted approach that employs a set of four management practices to increase nitrogen use efficiency of cropping systems is needed. These practices include decreasing the amount of nitrogen fertilizer applied (right rate), placing the fertilizer deeper into the soil (right place), applying nitrogen fertilizer in the spring rather than the fall (right timing) and using nitrification inhibitors and slow-release fertilizers (right source). Collectively these practices are commonly known as the "4Rs" (right rate, right place, right timing and right source). The 4Rs minimize the opportunity for nitrate N to accumulate in the soil and help optimize nitrogen use efficiency gains (Roberts, 2007 as cited in Denef, Archebeque, & Paustian, 2011). Several studies have found application of the 4R's to be an effective method of decreasing N_2O emissions from cropland (Akiyama et al., 2010; Robertson & Vitousek, 2009; Snyder et al., 2007).

Additional reductions in GHG emissions can be achieved by changing irrigation practices. Irrigation management reduces GHG emissions by decreasing upstream energy use (and associated emissions) and reducing soil water content (which contributes to anaerobic conditions that are conducive to N_2O emission through denitrification). Although irrigation management is not typically included in the 4R approach, it offers an added opportunity for producers to reduce their emissions and hence is briefly mentioned here.

[2] Mineral N refers to NH_4^+ (ammonium) or NO_3^- (nitrate)

3.1.1.1 Literature Review

Science

Integrated BMPs Variable Rate Technology: Nitrous oxide (N_2O) emission rates are positively correlated with the concentration of mineral nitrogen (ammonium and nitrate) in the soil; however, carbon substrate suitability and soil water content also play a role (Eagle & Sifleet, 2011). Nitrogen in fertilizer is subject to direct emission loss as N_2O from denitrification or nitrification; processes performed by microorganisms in the soil. Nitrous oxide is a by-product of nitrification and an intermediate product in denitrification. Since denitrification requires anaerobic conditions, practices that reduce soil aeration or drainage such as irrigation typically produce higher N_2O emissions (TAGG, 2010 as cited in Denef, Archebeque, & Paustian, 2011). Additional indirect losses of N occur through the leaching of NO_3^- and/or the volatilization and re-deposition of NH_4. Fortunately, although these emissions can be significant, activities that reduce direct N_2O emissions frequently reduce indirect emissions as well (Olander et al., 2012a).

Nitrous oxide emissions from soils are variable, occurring in fluxes from locations where moisture and dissolved carbon/nutrients collect. For example, Liu et al. (2010), found that close to one-third of annual N_2O emissions occurred in the month following N fertilization. In contrast, Mosier et al. (2006), found significantly different N_2O flux rates between years, with the same cropping system and nitrogen fertilizer rates. In general, fluxes seem to be influenced by climatic factors (rainfall, freeze/thaw cycles, depth of frost), cropping variables (type, fertilizer rate), soil texture, and irrigation status (Eagle & Sifleet, 2011). Although it is difficult to obtain precise data for N_2O gas fluxes, emissions can be reduced by managing the amount of nitrogen applied and minimizing the frequency at which nitrogen accumulates in the soil (Haugen-Kozyra et al., 2010). A brief summary of the science behind each of the 4R practices is given below.

Right Rate: Several field studies have found a positive correlation between N fertilizer rates and N_2O emissions in cropland (Halvorson et al., 2008; McSwiney & Robertson, 2005; Mosier et al., 2006; Ogle et al., 2010). Specifically, N_2O emissions have been found to increase at a higher rate after crop N needs have been met (Snyder et al., 2007; Snyder et al., 2009). Given this, IPCC Tier I methods employ a direct linear multiplier of 1.0% of total applied fertilizer nitrogen lost as N_2O-N (IPCC, 2006).

McSwiney & Robertson (2005) found that once crop nitrogen needs have been met, additional application of fertilizer does not lead to an increase in crop yield. Hence, it may be possible to decrease N_2O emissions by tailoring the amount of N fertilizer applied to the crops uptake capacity, without compromising yields. This latter point is of particular importance since a decrease in yields could cause production to shift elsewhere, ultimately leading to an increase in GHG emissions (Eagle et al., 2011).

Since a number of producers currently over fertilize their soil, there is significant potential to reduce N_2O emissions in this way. However, excess nitrogen application may be seen as an important risk reduction strategy by farmers and therefore may be a difficult practice to change (Olander et al., 2012a).

Right Place: Right place involves applying fertilizer where plant demand for it is the greatest. Rather than broadcast N fertilizer in equal amounts across a field it should be placed in bands or placed under the surface closer to the zone of active root uptake. Banded placement can reduce mobilization of N, thereby causing delayed leaching or denitrification (Snyder et al., 2009). A study conducted in Saskatchewan by Hultgreen & Leduc (2003) found that in comparison to broadcast placement, banding reduced emissions. However, similar studies have found no significant relationship (Sehy et al., 2003).

Research on GHG impacts of shallow versus deep injection has also been conflicting. For example, in Ontario, reduced N_2O emissions were found when using shallow placement of ammonium nitrate (Drury et al., 2006). In contrast, in Colorado increased emissions were found with shallow placement of liquid UAN_{35} (Liu et al., 2006).

An alternative option is to use site specific technologies to add nitrogen at variable rates across the field according to crop production potentials (Follett et al., 2011; Olander et al., 2012a). Since plant nitrogen needs vary by yield, even application can result in over-application in areas with low yield (Eagle & Sifleet, 2011).

Right Timing: Several studies have found that improving the timing of fertilizer application (from spring to fall) can reduce N_2O emissions (Hao et al., 2001; Hultgreen & Leduc, 2003). Further, shifting from single to split application may reduce emissions from leaching and denitrification (Burton et al., 2008; Snyder et al., 2007; Snyder et al., 2009).

Split application involves applying a starter rate of fertilizer at planting and then subsequently applying the remaining amount once the crop has germinated and entered its rapid growth phase. The science on the benefits of this practice over one time application has been conflicting (Snyder et al, 2007). Further, applying nitrogen in small doses as a crop matures is often impractical and has an average GHG mitigation potential of only 0.1 t CO_2e/ha/yr (range from 0 to 0.3) (Olander et al., 2012a). As a result, right timing more frequently involves applying nitrogen in the spring or closer to the time of maximum up-take (Follett et al., 2011). Hao et al. (2001), found potential emission reductions from spring application instead of fall of 0.48t CO_2e/ha/yr in Southern Alberta.

Right Source: Enhanced efficiency fertilizers, including nitrification or urease inhibitors and slow or controlled release fertilizers, can increase crop fertilizer use efficiency by improving the synchronization of fertilizer N availability with plant N uptake needs (Akiyama et al., 2010; Olander et al., 2012a; Snyder et al., 2007; Snyder et al., 2009). In doing so, these fertilizers decrease soil N_2O emissions. Current research has found emission reduction potentials of approximately 0.7 t CO_2e/ha/yr (range from 0 to 1.6) associated with the use of nitrification inhibitors (Bhatia et al., 2010; McTaggart et al., 1997; Snyder et al., 2009). Enhanced nitrogen efficiency may also lower the need to nitrogen application, creating further emission reductions (Olander et al., 2012a).

In 2011, the Technical Working Group on Agricultural Greenhouse Gases (T-AGG) conducted a survey of experts on the scientific certainty associated with the GHG mitigation potential of a range of agricultural land management practices. It is important to note that all of the N_2O reduction activities covered in the survey generated results of low confidence and low evidence (Eagle & Sifleet, 2011). Therefore, further research into these practices in order to improve the level of certainty associated with them is warranted.

Irrigation Management: In general, irrigation reduces soil aeration and stimulates microbial activity, thereby increasing the potential for N_2O emissions. Reducing irrigation intensity by changing irrigation practices can therefore decrease emissions (Denef, Archebeque, & Paustian, 2011). Irrigation improvements include converting from furrow irrigation to central-pivot or even more efficient drip irrigation systems. According to Kallenbach et al. (2010), buried drip irrigation systems leave the soil surface dry, reducing N_2O emission significantly. Drip irrigation systems have also been reported to require 25% to 72% less water than furrow irrigation in agronomic and horticultural crops with no negative yield impact (Eagle & Sifleet, 2011).

The GHG mitigation potential of irrigation practices must take into consideration the fact that N_2O emissions can increase under wet and anaerobic conditions (Denef et al., 2011). A recent study conducted by T-AGG (2010) as cited in Denef et al. (2011), found N_2O and CH_4 emissions to increase on average 0.42 t CO_2e/ha/yr when dryland is converted to irrigated land. However, at the same time, decreased N_2O emissions of 0.14 to 0.94 t CO_2e/ha/yr have been associated with a reduction of irrigation intensity and from switching from furrow irrigation to drip irrigation (T-AGG, 2010 as cited in Denef et al., 2011).

Technology (Applications/Demonstrations)

In order to predict crop nitrogen requirements and avoid over fertilization, producers need appropriate decision support tools. Although GPS based precision application technology is available, to date its adoption has been low (Haugen-Kozyra et al., 2010). Other technologies include on-the-go fertilization equipment using crop canopy spectral reflectance to determine real-time N needs (Scharf & Lory, 2009). Schmidt et al. (2009), showed that such sensors can successfully identify crop N needs, making it possible to adjust N fertilizer application rates. More specifically, in comparison to uniform N fertilizer application, on-board sensors have been found to result in a 15 to 20 percent increase in N use efficiency (Liu et al., 2009; Raun et al., 2002 as cited in Eagle et al., 2011). As a result, significant reductions in N_2O emissions may be possible when sensors are employed to reduce the amount of excess fertilizer applied.

Greenhouse gas fluxes can be measured using chamber methods. Although inexpensive, the chambers are small. As a result, a number of them must be employed to account for high spatial variability at the field or landscape level (Olander et al., 2012a). Further, they are labour intensive and require ongoing sampling (Olander et al., 2012a). Alternatives include flux towers and aircraft measurements. These methods have the added advantage of being able to capture and quantify indirect N_2O and other emissions; however, they are significantly more expensive.

Soil nitrogen tests such as the pre-side dress soil nitrate test (PSNT), which is performed at planting, may help farmers adjust their nitrogen application rates according to yield goals. This would decrease the frequency of over fertilization and corresponding N_2O emissions (Robertson & Vitousek, 2009; Snyder et al., 2007; Snyder et al., 2009). However, research has found that this test is not always effective in predicting future N needs (Denef, Archebeque, & Paustian, 2011). As a result, approaches that use site-specific N rates based on the economic value of increased yields and cost of added nitrogen are now being adopted in the U.S. Corn Belt (Robertson & Vitousek, 2009) and in Alberta (Agricultural Research Extension Council of Alberta, 2010).

Markets

Nitrogen management mitigation activities will compete with other mitigation strategies, as well as demands for food and/or bioenergy (Olander et al., 2012a). Further, producers often need greater incentives than opportunity costs alone to adopt a new practice (Kurkalova et al., 2006). Co-benefits such as improved environmental sustainability may provide this added incentive if valued in other ecosystem service markets (Kurkalova et al., 2004). However, non-market factors may also shift producer and land manager practices (Olander et al., 2012a). Consequently, it is difficult to predict potential adoption rates.

Policy

A protocol referred to as the *Nitrous Oxide Emissions Reductions Protocol (NERP)* that uses the 4R approach, has been approved and is available for use in the Alberta Offset System. This protocol was developed based on comprehensive scientific and technical review, by both the federal and provincial government. Canada's leading experts in soils, cropping and agronomic science as well as scientists from abroad were consulted in its development. As such, the science and quantification is robust and highly confident. Currently, there is no protocol for changes in irrigation management practices.

3.1.1.2 Greenhouse Gas Emission Reduction Potential

Magnitude and Verifiability

Table 1 – Emission Reduction Magnitude and Verifiability for Soil Nitrogen Management – Integrated BMPs Variable Rate Technology and Irrigation Management

Opportunity Area	Theoretical Provincial Impact (Mt CO_2e/yr)	Verifiability
4R's Variable Rate Technology	Basic – 0.58 Advanced – 0.97	Modelled
Irrigation Management	Unquantified	Unquantified

Justification

The quantification approaches used in the estimates in Table 1 above are based on the Alberta GHG quantification protocol for N_2O management. The protocol calculates GHG emissions using IPCC best practice guidance (Climate Change Central, 2009; IPCC, 2006) and Canadian-based Tier II emission factors as set out in the National Emissions Inventory methodology. Crop 2009 reporting statistics from Statistics Canada were used in the analysis. Further, to streamline the calculations, the five major annual crops, capturing 61% of production across Alberta were also used (Spring Wheat, Barley, Canola, and Corn (grain and silage)) (Statistics Canada, 2010b). Data from 2009 was used because it was deemed more representative of a typical cropping year (less catastrophic events such as flooding or drought in Western Canada).

To estimate the amount of N_2O that could be reduced from the adoption of precision-management practices, the reduction modifiers established in the *Nitrous Oxide Emissions Reduction (NERP) Protocol* in Alberta were used (Table 2). The reduction modifiers were scientifically developed (based on the last 40 years of research on soil N balance and soil N_2O studies across Canada for individual practices) and vetted with experts from the US and Canada to determine the potential reductions conservatively achievable as a result of implementing the suite of practices across the four performance areas (right source, right rate, right time, right place).

Table 2 - Management Practices and Reduction Coefficients for the Three Performance Levels of the NERP Drier Soils of Canada.

Performance Level	Right Source	Right Rate	Right Time	Right Place	Reduction Modifier
4R plans must **Basic**	• Ammonium-based formulation	• Apply N according to recommendation of 4R N stewardship plan*, using annual soil testing and/or N balance to determine application rate.	• Apply in spring; or • Split apply; or • Apply after soil cools in fall.	Apply in bands / Injection	0.85
account **Intermediate** for all	• Ammonium-based formulation; and • Use slow / controlled release fertilizers; or • Inhibitors; or • Stabilized N.	• Apply N according to qualitative estimates of field variability (landscape position, soil variability).	• Apply fertilizer in spring; or • Split apply; or • Apply after soil cools in fall if using slow / controlled release fertilizer or inhibitors / stabilized N	Apply in bands / Injection	0.75
s* 4R plans **Advanced** must *	• Ammonium-based formulation; and • Use slow / controlled release fertilizers; or • Inhibitors; or • Stabilized N.	• Apply N according to quantified field variability (e.g. digitized soil maps, grid sampling, satellite imagery, real time crop sensors) and complemented by in season crop monitoring.	• Apply fertilizer in spring; or • Split apply; or • Apply after soil cools in fall if using slow / controlled release fertilizer or inhibitors / stabilized N	Apply in bands / Injection	0.75

*4R plans must account for all sources of N, including previous crop residues, fertilizer, manure or biosolids applications.
** Where appropriate for the crop, and calibration data is available
*** Rochette et al. 2008

The accounting methods applied in the NERP protocol identify two emission reduction pathways:

1. Possible reductions in fertilizer rate as a result of implementing the 'Basic', 'Intermediate' or 'Advanced' 4R Management Plan; and/or,
2. Applying the reduction modifier coefficient to emissions intensity of the crops produced.

For ease of calculation, the estimates for reducing N_2O from agricultural soils (see Table 2) only applied the reduction modifier, since assumptions about the rate reductions of N application as a result of implementing the performance levels would be prone to error. However, the reduction potential could be even higher if rates of fertilizer reduction decreased per hectare due to more variable application.

3.1.1.3 Gaps and Constraints

Science, Data and Information Gaps: Further research is needed on 1) the impacts of integrated BMPs on GHGs across a range of soils – cropping systems; 2) the performance of enhanced efficiency fertilizers and their long-term effect on emissions of N_2O across regions/cropping systems; 3) the optimal timing for fertilizer application in order to maximize crop uptake and minimize N_2O emissions; 4) the impacts of reduced fertilizer application on nitrogen yields; 5) N_2O flux timing and location across agricultural lands; 6) nitrification inhibitor interactions with different fertilizers, timing, placement, depth, soil temperature and pH; 7) the fate of eroded carbon and nitrogen losses from NO_3 leaching/runoff or volatilizations; and 8) the N_2O impacts of irrigation management (reductions in direct N_2O emissions can lead to increased leaching of NO_3 and off-site N_2O emissions).

Policy Gaps: A protocol for the 4R approach already exists; however, it should be updated once more scientific data is available (see science, data and information gaps above). In addition, research on irrigation management is needed before effective policy and a protocol can be developed.

Technology Gaps: Technological tools for predicting crop nitrogen requirements and avoiding over fertilization are available; however, adoption has been low. Similarly, tools for measuring GHG fluxes exit, but are either labour or cost intensive. In order to improve adoption of these tools, the benefits of their use must be demonstrated to growers (see demonstration gaps below). Further, once the scientific gaps identified above are filled and additional information is available, this information must be incorporated into current technology.

Demonstration Gaps: The GHG impacts of variable rate technologies and precision application systems still need to be demonstrated on farm across a range of soils-cropping systems. Further, the cost benefits of in-field GPS application of fertilizer need to be demonstrated to growers.

Metric Gaps: Integrated measuring, monitoring and verification systems are needed that use remote sensing, optical satellite sensors, geographic information system (GIS) databases and biogeochemical process models for direct farm measurement of GHG emissions.

Other Gaps: None identified.

3.1.1.4 Opportunities to Address the Gaps/Constraints Identified

The difficulty for agricultural protocols and projects in relation to non-agricultural or point-source activities can be illustrated by comparing N_2O reductions from a nitric acid production facility with those from the management of nutrients on agricultural land. In the case of a nitric acid facility, existing facility personnel, who already work in a highly regulated situation, will have training in engineering and instrumentation though longstanding infrastructure to support operation of industrial facilities. Consequently, achieving the protocol-prescribed activity (installing the catalyst and calibrating/monitoring the emissions monitoring system) is a relatively straight-forward extension of their existing duties and expertise.

In contrast, to achieve N_2O mitigation on cropland, farmers and their advisors need to adopt the innovative nutrient management strategy described above. In order to accomplish this, proper infrastructure is needed not only to support farmers and their advisors in correctly implementing the best management practices (BMPs), but also to provide guidance on incorporating these practices into a farm-specific plan. This type of infrastructure is only beginning to emerge and at present few growers are accessing it. The lack of or limited access to such infrastructure constitutes a barrier to adoption. Hence, agricultural protocols and the projects which implement them will need demonstrated infrastructure to overcome this barrier and to effect practice change.

Another opportunity to address the gaps/constraints identified is to develop an outreach program through an educational institute or conduct a series of workshops to help accelerate market uptake of the *Nitrous Oxide Emissions Reductions Protocol (NERP)*.

3.1.2 Bio-fertilizers

Agricultural GHG emissions will likely continue to rise for the foreseeable future as production expands to keep pace with growing food, feed, fiber and bioenergy demands. Increased efficiency in energy and fertilizer inputs is needed to keep overall emissions as low as possible and to reduce the level of emissions per unit of agricultural output. Efficient and responsible production, distribution and use of fertilizers are central to achieving these goals. Many good agricultural practices, that increase productivity, can also moderate agricultural GHG emissions and have other sustainable development benefits, including greater food security, poverty alleviation, and conservation of soil and water resources. Proper management and application of bio-fertilizer, which is a product from reusing biomaterials and bio-wastes, can be one of the strategies for keeping agricultural GHG emissions low.

3.1.2.1 Literature Review

Science

In 1997, global fertilizer production was responsible for 1.2% of total GHG emissions (Kongshaug & Agri, 1998). By 2008, global GHG emissions from this sector had fallen to 0.93% (IFA, 2009). Canadian agricultural synthetic fertilizer emissions from 2009 to 2010 are summarized in Table 3 below.

Table 3 - Synthetic Fertilizer Market and GHG Emissions from Production in Canada (2009-2010)

Fertilizer	Market (t/yr)	Emission Factor[1] (t CO_2e/t nutrient)	GHG (t CO_2e)
N	1,900,000	2.67	5,073,000
P	625,000	0.15	94,000
K	260,000	0.33	86,000
Total	**2,785,000**		**5,253,000**

[1]GHG emission factors are based on estimates from the International Fertilizer Industry Association (2009).

Reductions in agricultural fertilizer emissions can be achieved by switching from synthetic N fertilizer to bio-fertilizers. Bio-fertilizers are plant nutrients, particularly nitrogen (N), phosphorus (P) and potassium (K), with biological origin. The main sources for these nutrients are livestock manure and N fixing plants such as alfalfa. Bio-fertilizers contain the appropriate balance of micronutrients (beyond N, P and K) needed for plant growth and as such can improve soil fertility and quality (Haugen-Kozyra et al., 2010).

Bio-based fertilizer has long been recognized as a valuable product for improving soil fertility (nutrient value) and quality. Research has indicated that soil quality in the prairie regions has been declining due to intense production and heavy dependence on chemical fertilizers in conventional agricultural practices. Organic carbon content, one of the important indicators of soil quality, is also decreasing in Alberta's cropping land. Therefore, there is a need for bio-fertilizer to improve the quality of prairie soils.

The benefits of using bio-fertilizers include increased soil organic matter, improved soil structure, improved soil quality, increased soil buffering capacity (which improves capacity to resist chemical contamination), increased soil water infiltration and retention, improved productivity (reduced nutrient loss) and a reduction in the intensity of energy needed for tillage and other soil management practices (Haugen-Kozyra et al., 2010). Further, since conventional agriculture uses synthetic fertilizers, greater adoption of bio-fertilizers would result in reduced need for chemical fertilizers. However, it is important to note that switching to bio-fertilizers may require added energy input to produce and process the raw materials (manure and legumes).

Technology (Applications/Demonstrations)

Biogas technology can be used to process input materials while producing energy and concentrating nutrients in bio-fertilizer products. On farm anaerobic digesters typically use manure for primary feedstock; however, other organic feedstock such as post-consumer food waste, food processing waste or even grass crops such as hay make excellent digester feedstock. Digesters do not alter the nutrient profile of the feedstock. However, they do improve the plant availability of nutrients by changing the form of nutrients from organic to inorganic (mineralization), essentially performing the same step that occurs in the soil after nutrient application as a result of soil microbial activity.

Nutrients in the inorganic form are readily absorbed by the plant and will not burn plant foliage when applied during the growing season. This is important because it allows irrigation of the digestate without burning the plants. It is common for as many as eight applications of up to 30 pounds of N per application of digestate to be applied to corn for example. Prior to storage and irrigation, the digestate is put through a solids separator and the solids are typically land applied. Since they are in a solid form, they can be transported further distances and used for organic fertilizer. Nutrient levels are typically low but the carbon content of the solids improves the soil structure and moisture retention capacity.

Markets

In general, conventional agricultural practices use synthetic nitrogen fertilizer for crop production. The value of animal manure as a source of plant nutrients and in improving soil quality is generally recognized; however, the high moisture content, low nutrient concentration, low density and large volume of manure needed per unit of plant increases costs and limits direct land application to approximately 10 to 80 km from the source (depending on cropping systems, land productivity and the properties of manure) (Araji & Stodick, 1990). This can create large scale imbalances in nutrient distribution and environmental problems if more manure nutrients are applied than are needed for agronomic plant uptake. In areas where crop products are exported, depletion in soil nutrient reserves must be compensated with fertilizer.

Relatively little has been done to rebalance this nutrient distribution by creating nutrient flows in the other direction. The long-term implications of this imbalance will be felt more for nutrients that rely on finite, non-renewable natural resources, such as P. The re-balancing of nutrient distribution requires developing conditions and products, and enabling policies (e.g. bio-fertilizers) which can be transported and distributed economically over long distances.

One obvious market for bio-fertilizers is organic farm operations; however, conventional crop producers also use bio-fertilizers under some situations depending on the nutrient profile of their soil. In 2009, approximately 1.7% of Canadian farmland was organic (Canada's Organic Industry at a Glance, 2009). This market could be expanded if municipal organic waste was processed through compost technology or anaerobic digestion (Haugen-Kozyra et al., 2010).

Policy

Government policy is needed to educate farmers and/or create incentives for farmers to replace commercial fertilizer with manure derived nutrients. Further, a protocol for quantifying bio-fertilizers potential to replace inorganic fertilizer and reduce GHG emissions is needed. In order for this to be accomplished, policy makers need to recognize the full benefits and economic value of bio-fertilizer for soil quality and fertility.

3.1.2.2 Greenhouse Gas Emission Reduction Potential

Magnitude and Verifiability

Table 4 – Emission Reduction Magnitude and Verifiability for Bio-fertilizers

Opportunity Area	Theoretical Provincial Impact (Mt CO_2e/yr)	Verifiability
Bio-fertilizers	0.97 Mt[1]	Modelled

[1]Based on Alberta's potential available N and P supply.

Justification

The above estimation is based on the following assumptions:

- Alberta's current cropping land is equal to 10 million hectares.
- Average N and P application rates are 60 kg N/ha and 13 kg P/ha respectively.
- Total estimated N and P usage rates for cropping production in Alberta are 600,000 t N/yr and 132,000 t P/yr respectively.
- The total estimated bio-fertilizer production from available bio-waste in Alberta (section 3.4.4) is equal to 298,887 t N/yr and 199,258 t P/yr.
- Therefore, the potential GHG offset for using bio-fertilizer (based in Alberta) will be 298,887 t N/yr and 132,000 t P/yr.
- Emission factors for producing N and P fertilizer are: 2.67 kg CO_2e/kg N and 1.28 kg CO_2e/ kg P.
- This will result in a total reduction potential of 0.97 Mt CO_2e/yr.

This estimate is based solely on replacing inorganic fertilizer with the potentially available supply of bio-fertilizer in Alberta. If the remaining of 300,000 t N used yearly were also replaced by bio-fertilizer the GHG offset potential could be doubled.

This demand could potentially be fulfilled using Canadian vast marginal lands. Canada has over 37 million hectares of marginal land (Milbrandt & Overend, 2009) with a potential biomass yield of 3 t/ha. If one assumes that 10% of these lands could be used to grow legumes (represented by alfalfa) in Alberta, this could produce 9.8 Mt of biomass annually. With an average N content of 2.9% (in alfalfa), this would result in a total of 286,000 t N/yr. However, growing, harvesting, and processing this biomass is energy intensive. One plausible scenario is to use this biomass for livestock production.

The above calculation does not include N_2O emissions from fertilizer application to agricultural land and does not account for the fact that the stable organic matter in bio-fertilizers could contribute to soil carbon sequestration. Gregorich et al. (2005), reported that N_2O emissions from solid manure application are only 35% of that from the land associated with synthetic N fertilizer application. Thus, if these potentials were considered in this calculation, the offset potential would be significantly higher.

3.1.2.3 Gaps and Constraints

Science, Data and Information Gaps: Nutrient balance information is needed to determine the correct sending and receiving zones for nutrients/bio-fertilizers. Further, the value of bio-fertilizers in increasing N use efficiency, improving water holding capacity and reducing N_2O emissions still needs to be qualified.

Policy Gaps: Currently, there is no approved protocol under the Alberta Offset System for quantifying GHG reductions associated with the switch to bio-fertilizers. Consequently, there is a clear need for a quantification protocol.

Technology Gaps: Nutrient recovery technology is currently in the early development stage and needs to be further developed.

Demonstration Gaps: There is a need for demonstration sites for growing legumes on marginal lands for proven carbon benefits.

Metric Gaps: There is no comprehensive approach for quantifying bio-fertilizer's potential for replacing inorganic fertilizer and enhancing soil carbon sequestration. In particular, an approach is needed for assessing the costs/benefits of bio-fertilizers in addressing the imbalance in the distribution of nutrients.

Other Gaps: The feasibility of transporting bio-fertilizers over long distances needs to be addressed.

3.1.2.4 Opportunities to Address the Gaps/Constraints Identified

In order to address the gaps/constraints identified, systematic, well designed and long-term (at least 5 years) field experiments should be conducted to provide scientifically defendable data and to verify the benefits of bio-fertilizer. Further, development of an Alberta Offset System GHG protocol for bio-fertilizers would help accelerate market uptake. Finally, there is an opportunity for Alberta based researchers and biotech companies to develop/deploy nutrient recovery technologies and become leaders in this field (see section 3.4.4 for additional information).

3.1.3 Nitrogen Management Summary

The nitrogen management section of this report included reductions from 1) integrated BMPs variable rate technology (the 4R's) 2) irrigation management and 3) bio-fertilizers. The following summary covers opportunities and constraints, total theoretical reduction potential, impact of gaps/constraints on the reduction potential and key messages across these three opportunity areas.

3.1.3.1 Summary of Findings

Nitrous oxide emissions from soils are variable, occurring in fluxes from locations where moisture and dissolved carbon/nutrients collect. In order to predict crop nitrogen requirements and avoid over fertilization, producers need appropriate decision support tools. Practices to increase nitrogen use efficiency include decreasing the amount of N fertilizer applied (right rate), placing the fertilizer deeper into the soil (right place), applying N fertilizer in the spring rather than the fall (right timing) and using nitrification inhibitors and slow-release fertilizers (right source).

Many good agricultural practices, such as fertilizer, that increase productivity can also moderate agricultural GHG emissions and have other sustainable development benefits, including greater food security, poverty alleviation, and conservation of soil and water resources. Proper management and application of bio-fertilizer, is one strategy for keeping agricultural GHG emissions low. Bio-based fertilizer has long been recognized as a valuable product for improving soil fertility (nutrient value) and quality. Research has indicated that soil quality in the prairie regions has been declining due to intense production and heavy dependence on chemical fertilizers in conventional agricultural practices.

In general, irrigation reduces soil aeration and stimulates microbial activity, thereby increasing the potential for N_2O emissions. Reducing irrigation intensity by changing irrigation practices can therefore decrease emissions. The GHG mitigation potential of irrigation practices must take into consideration the fact that N_2O emissions can increase under the wet and anaerobic conditions.

The following table summarizes the opportunities and constraints across all three nitrogen management reduction opportunities. The table is broken down into three categories: inputs, activity and outputs; and covers science, technology, markets and policy. The inputs column refers to the inputs needed to accomplish the activity (i.e. fertilizers). The activity column refers to the change in practice itself - in this case adopting the 4R approach, switching to bio-fertilizers or improving irrigation management. The outputs column refers to the product, which in this case is the crop.

The table is also color coded. Red indicates an area where there are no issues or there is no opportunity for investment. Yellow represents an area with some potential; however, at present this area is not a priority and areas shaded in green highlight the best opportunities for investment.

Table 5 – Opportunities and Constraints for the Nitrogen Management Sector

	Inputs	Activity	Outputs
Science	No issues.	Research is needed on the impacts of integrated BMPs on net GHGs across a range of soils/cropping systems.	Research is needed on the impacts of reduced N fertilizer use on yields.
Technology	Research on the next generation of fertilizers (i.e. time-release coated fertilizers) is needed.	Demonstration of variable rate technologies on-farm; precision application of fertilizers/ pesticides, tools for measuring emissions and nutrient recovery technology are needed.	No issues.
Markets	No issues.	Competition with other mitigation strategies and demands for food and/or bioenergy.	Distribution of bio-fertilizers is limited to the immediate area around its source.
Policy	No issues.	A protocol is needed for bio-fertilizers.	No issues.

3.1.3.2 Total Theoretical Reduction Potential

Table 6 – Total Theoretical Reduction Potential for Nitrogen Management

Opportunity Area	Theoretical Provincial Impact ($Mt\ CO_2e/yr$)	Verifiability
4R's Variable Rate Technology	Basic – 0.58 Advanced – 0.97	Modelled
Irrigation Management	Unquantified	Unquantified
Bio-fertilizers	0.97[1]	Metered or Measured
Total	**1.55 to 1.94**	

[1] Based on Alberta's potential N and P supply.

3.1.3.3 Impact of the Gaps/Constraints on the Reduction Potential

In the case of Soil Nitrogen Management practices, adoption of variable rate technologies (GPS based precision application) is currently not mainstream. While most growers have monitors on their equipment for real-time yield detection during harvesting and other productivity indices, the adoption of in-field GPS application of fertilizer is lagging. The cost-benefit productivity ratio of in-field GPS fertilizer application will need to be demonstrated to growers in order to achieve the reduction potentials reported. This may be accomplished through a mixture of: 1) service-driven, on the ground consultancy; 2) private sector technical assistance to those growers who want to tackle this themselves; and 3) traditional extension agencies (who are dwindling in capacity and their ability to keep up to evolving technology) support.

The measuring, monitoring and verification (MMV) procedures for applying the integrated 4R practices are clearly laid out in the NERP protocol. In order to support mitigation that is real, measurable and verifiable, this protocol requires project-level baselines that are based on the average of three years of data. While this can be done, it requires significantly more data to be collected. As a result, data platforms will need to be developed in order to support viable and verifiable reductions. Until these systems are in place it may be difficult to achieve the emissions reductions reported.

In the case of bio-fertilizers, the main limitations in achieving the GHG mitigation potential reported are the lack of a protocol and the lack of methods to quantify and verify GHG offsets.

3.1.3.4 Key Messages

The main messages for this opportunity are:

- Increased nitrogen use efficiency through fertilizer switch or better management practices can reduce GHG emissions while also sustaining soil productivity.
- Any product or process development takes time; a major practice change requires commitment from producers, the business community and government (i.e. policy).
- Given the current high commodity prices, liberal application of nitrogen fertilizer is viewed by producers as cheap insurance for maximum yields. Field trials need to be conducted to prove that practicing the 4R's and thereby decreasing nitrogen application rate, will not hurt yields.
- Yield monitors are common; however, adoption of in-field GPS fertilizer application is lagging behind. In general, there is a need for further technology demonstration.
- There is a need for designer bio-fertilizers that supply nutrients in response to plant growth.
- AB's bio-waste industry generates more than enough potassium (K) for the cropping industry.
- A protocol is still needed to quantify emission reductions associated with the switch to bio-fertilizers.
- Cost-benefit productivity ratios of the practices need to be demonstrated to growers.
- An integrated approach involving service-driven on the ground consultancy, private sector technical assistance for growers who want to initiate practice changes themselves and non-governmental organization (NGO) support for public extension agencies who are dwindling in capacity to assist producers in their ability to keep up with evolving technology is recommended.
- The level of agricultural GHG emissions will likely continue to rise for the foreseeable future as agricultural production expands to keep pace with growing food, feed, fiber and bioenergy demands.

3.2 Livestock Management

3.2.1 Beef and Dairy Cattle Emission Reductions

Canada's National Emissions Inventory estimates the 2009 enteric CH_4 emissions from beef cattle as 19 Mt CO_2e annually, and 30 Mt CO_2e if manure emissions are included. This is the most comprehensive accounting for emissions in Canada. Alberta feeds over 65% of Canada's beef cattle, creating a large opportunity to reduce CH_4 and N_2O emissions from this sector. The beef herd in Canada and in Alberta has contracted over the last few years due to high feed grain costs, a competitive Canadian dollar and rising commodity prices for grains/oilseeds.

Dairy cattle emissions in 2009 were approximately 3 Mt CO_2e from enteric fermentation and an additional 1.5 Mt CO_2e from manure-based emissions (Environment Canada, 2010). The average dairy cow produces more milk today than in 1990, consumes more feed and also emits more GHGs. However, Dyer et al. (2008), found that from the period of 1981 to 2001, the GHG emissions per kilogram of milk produced decreased by 35%, from 1.22 kg CO_2e kg-1 milk to 0.91 kg CO_2e kg-1 milk.

Enteric CH_4 reductions in cattle can be achieved through the use of various nutritional and genetic/cattle management strategies. Many of these strategies also reduce manure production, leading to further GHG emission reductions. Between 1981 and 2006, GHG emissions/kg head decreased from 16.4 to 10.4 kg CO_2e in the Canadian beef sector (Verge et al., 2008). This figure shows that beef management production practices in Canada are becoming increasingly efficient. However, greater efficiencies can be achieved in both the dairy and beef sectors. Alberta feeds over 65% of Canada's beef cattle; thus, the opportunity to reduce emissions can be significant.

Emission reduction opportunities for beef and dairy cattle covered in this section include: 1) reducing the days on feed (beef); 2) reducing the age to harvest (beef); 3) adding feed supplements (e.g. edible oils) to the diet; 4) selecting beef for low residual feed intake (RFI); 5) ration manipulation (ionophores); and 6) reducing replacement heifers. Methane emissions from cattle are produced as a result of enteric fermentation of feedstuffs (due to the action of methanogenic bacteria in the rumen) and manure storage. Nitrous oxide is also produced as a result of nitrification and denitrification of manure (Olander et al., 2012b).

3.2.1.1 Literature Review

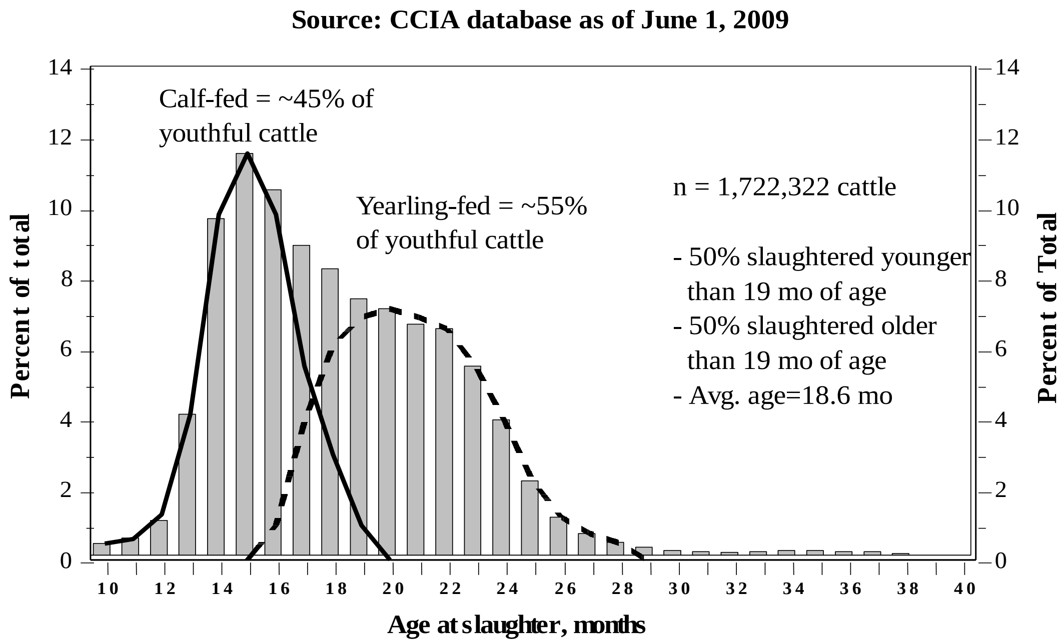
Science

Ruminant animals such as cattle have the highest CH_4 emissions of all animal types due to their unique digestive systems (Denef et al., 2011) which allow them to derive energy from the decomposition of cellulosic plant materials. Enteric CH_4 production is dependent on level of intake, environmental conditions, diet chemical composition and genetic factors of the animal itself (Johnson & Johnson, 1995). Consequently, emission reductions can be achieved by reducing the days on feed (increasing feed efficiency), reducing the age to harvest, selecting for RFI, adding edible oils to the diet, ration manipulation and/or by reducing replacement heifers. Further background information on each of these six reduction opportunities is included below.

Reduced Days on Feed: Through the use of 1) electron acceptors that compete for hydrogen; 2) compounds that inhibit uptake of electrons and hydrogen by ruminal methanogens; 3) growth promotants and beta-agonists that improve the efficiency of lean tissue growth; and 4) genetic marker panels, it is possible to improve feed efficiency and reduce the number of days beef cattle are in the feedlot (Basarab et al., 2009). Further, better husbandry practices such as improved cattle sorting procedures (by gender, weight class, grid programs) and the move towards individual cattle performance monitoring can move cattle more quickly through the feedlot stages.

Probiotics, acetogens, bacteriocins, archael viruses, hydrogen acceptors, nitrate, sulphate, plant extracts and immunization have all been studied; however, toxicity concerns and costs associated with many of these options limit their use (Mathison et al., 1998; Ungerfield et al., 2003; McGinn et al., 2004; Benchaar et al., 2006 as cited in Basarab et al., 2009). Hormonal growth promotants (i.e. estradiol benzoate and trenbolone acetate) are more common in the industry (Mathison et al., 1998; Ungerfield et al., 2003; McGinn et al., 2004; Benchaar et al., 2006 as cited in Basarab et al., 2009). Beta-agonists, fed during the last 28 days of the finishing period can help redirect nutrients away from fat deposition to protein synthesis, resulting in increased muscle fibre size, lean meat yield, increased growth rate and increased feed conversion (Schroeder et al., 2005; Winterholler et al., 2007; Gonzalez et al., 2009 as cited in Basarab et al.,2009).

Reduced Age to Harvest: This opportunity involves managing the production chain in order to shorten cattle lifespans and reduce the time they spend idle on roughage based diets, producing unnecessary CH_4 and manure (and associated CH_4 and N_2O emissions). According to Basarab et al. (2009), "optimizing the gain during each feeding period, decreasing the length of the backgrounding period, increasing the proportion of grain in backgrounding diets and reducing the numbers of days cattle spend on unproductive and poor quality pastures" can all result in a reduced age at harvest of youthful beef cattle. In Canada, the average age of harvest for beef cattle as of May 1, 2008 and June 1, 2009 was 19.1 and 18.6 months respectively (see Figure 1 below) (Canadian Cattle Identification Agency (CCIA) as cited in Basarab et al., 2009).



Age at slaughter may be over-estimated by 0.5-1 months as some producers register birth date for a group of calves as the date of first born. This only affect the average birth date slightly as most (75-79%) calves are born in the first 42 days of the calving season (Alberta Cow-Calf Audit 2001).

Source: J. Basarab, personal communication, 2011

Figure 1 – Average Age at Slaughter of Alberta Beef Cattle

Beef and Dairy Feed Supplements: Enteric CH_4 is produced primarily as a result of microbial fermentation of hydrolyzed dietary carbohydrates such as cellulose, hemicelluloses, pectin and starch (Denef et al., 2011). Methane emissions represent a loss of energy for the animal. Specifically, Kebreab et al. (2006), found feed energy losses due to CH_4 can amount to between 8.9 and 21.4 MJ d-1 animal-1 for dairy and beef cattle in North America.

Feed additives such as ionophores or edible oils can help reduce CH_4 emissions and associated energy losses by suppressing methanogenic microbes in the rumen. Adding 3-6% edible oils to the diet of ruminants has been found to decrease CH_4 emissions by 15 to 25% and has been well studied in Alberta (Beauchemin & McGinn, 2006; Beauchemin et al. 2007; Jordan et al., 2006 a,b; McGinn et al., 2004 as cited in Basarab et al., 2009). However, the addition of edible oils may also reduce fiber digestion (McGinn et al., 2004). In general, there is large variability in the observed effects of dietary changes on enteric CH_4 emissions in cattle (Denef et al., 2011). Some of this variability may be due to differences in measuring techniques, livestock production systems, animal types and climatic regions across studies (Denef et al., 2011).

Enteric CH_4 emissions depend on the availability of hydrogen and the proportion of volatile fatty acids, especially acetate: propionate produced in the rumen as a result of microbial fermentation (Denef et al., 2011). Hydrogen availability can be reduced by adding fatty acids to the animal's diet (Kebreab et al., 2008). The ratio of acetate: propionate is determined by the amount of time feed spends in the rumen, the type of carbohydrates consumed and diet digestibility (Ominski & Wittenberg, 2004).

Several different dietary additives have been shown to lower enteric CH_4 emissions; however, decreases have been inconsistent. Further, some studies have found decreases in CH_4 production to be temporary since eventually the rumen microbes adapt to the agent (Follett et al., 2011). This is particularly the case with the use of ionophores, in which case the ionophores need to be cycled.

Residual Feed Intake: Residual feed intake (RFI) is a measure of the difference between energy intake and energy required for maintenance and weight gain (or feed efficiency). It is a moderately heritable trait that increases the proportion of feed energy intake that is used for meat/milk production (Follett et al., 2011). Feed intake is positively correlated to animal size, growth rate and production (e.g. milk); and differs across animal types and management practices (Denef et al., 2011). Since the amount of feed an animal consumes affects CH_4 emissions (Seijan et al., 2010 as cited in Denef et al., 2011), increasing the productivity of an animal through genetic selection can reduce the proportion of CH_4 produced per unit of product (Beauchemin et al., 2008; Boadi et al., 2004; Moss et al., 2000).

The phenotypic and genotypic correlation between RFI and feed efficiency/growth is supported by several studies (Basarab et al., 2003; Basarab et al., 2005; Crews 2005; Crews et al., 2006; Nkrumah et al., 2006; Nkrumah et al., 2007a,b as cited in Follett et al., 2011). For example, Nkrumah et al. (2006) and Hagerty et al. (2007) as cited in Follett et al. (2011), found that low RFI steers emitted 28% less CH_4 from enteric fermentation ($P=0.04$), produced 14% less fecal dry matter/kg dry matter intake ($P=0.24$) and 19% less urine/kg of metabolic weight ($P=0.25$) than high RFI steers. Hegarty et al. (2007), also found a decrease in CH_4 emissions when animals are selected for RFI.

Although these studies are promising and demonstrate that low RFI cattle may emit less CH_4 and manure, selecting for feed efficiency alone may not be the complete solution. For example, although Jones et al. (2011) found that feed efficient cows produce lower CH_4 emissions when grazing on high quality pasture; no relationship was observed on poor quality pasture. Based on these findings Jones et al. (2011) conclude that the effects of RFI selection may be dependent on stage of production and type of diet being fed.

Reducing Replacement Heifers/Increasing Reproductive Efficiencies and More Lactation Cycles/Dairy Cow: There are a number of livestock husbandry practices that can cause reductions in GHGs, particularly in dairy operations. Many of these strategies are met with reticence by dairy operators; nevertheless, if they were demonstrated to be effective without increasing risk to the operation, increased acceptance could lead to greater success. Keeping a replacement heifer herd (sometimes up to 30% of non-lactating animals) is a dairy operator's risk management strategy for keeping milk production on track, while reducing the number of replacement heifers will reduce GHGs. Further, improving the general health of lactating animals will promote increased lactation cycles per dairy cow. Last, increasing reproductive efficiencies means that there will be less 'open' cows in the operation, and a greater calf:heifer crop.

Technology (Applications/Demonstrations)

Basarab et al. (2007a) as cited in Basarab et al. (2009), conducted a study on enteric CH_4 emissions from common finishing programs using data for 10,245 youthful cattle, from three commercial feedlots. Specifically, data on the number of cattle, gender, days on feed, average cattle weight in, average weight out, average daily feed intake, average daily gain, diet ingredients and diet composition for each feeding period were obtained.

Diets containing no edible oils were used as the baseline. Baseline CH_4 emissions for each feeding period were calculated using IPCC Tier 2 equations (IPCC 2006). Diets containing 4% edible oil were then developed using CowBytes for each feeding period. All three of the feedlots in the study used a high concentrate finishing diet over 21 to 28 days. The cattle were then switched to a 91.5%, 90.8% and 81.0% concentrate diet for feedlots 1, 2 and 3 respectively. In the end the study found that the inclusion of edible oils reduced GHG emissions by 699 (SD = 38), 690 (SD=50) and 940 (SD=24) g CO_2e/hd/day for feedlots 1, 2 and 3 respectively (Basarab et al.,2007a as cited in Basarab et al., 2009). The GHG benefit in feedlot 3 was higher since the acetate:propionate ratio decreased with decreasing forage:concentrate ration. Therefore, the oil had a larger impact on CH_4 production in the higher forage diet.

The Atlantic Dairy Forage Institute (ADFI), in conjunction with The Dairy Farmers of Canada (DFC) and Alberta Milk, are conducting a two –year dairy pilot in the province of Alberta and New Brunswick based on the Alberta Dairy GHG Quantification Protocol. In the first 12 months of effort, a number of significant data management challenges were identified, but the pilot is developing solutions to these. The pilot has been instrumental in constructing tools and a data management system that will streamline data collection in the future for participating dairy operators.

The ultimate goal of the project is to develop a streamlined data management system that will allow for effective GHG assessment into the future, allowing dairy producers across Canada an opportunity to evaluate carbon offset opportunities, and possibly engage in a carbon trading system. The building of the platform and infrastructure, as well as the capacity for dairy operators and the milk reporting companies (CanWest DHI and Valacta) to meet the information needs of the protocol is instrumental in moving forward.

Markets

Feedlot/backgrounder operations can save up to $23 CAD/head in production costs by shortening the age to harvest of beef cattle (Haugen-Kozyra et al., 2010). Similarly, Basarab et al. (2009) found reducing age at harvest by four months would decrease GHG emissions by 1135 kg CO_2e/hd and have a value of $11.35 CAD/hd assuming a carbon credit value of $10/t CO_2e. Additional benefits from decreased yardage, interest costs and a higher selling price of finished cattle had an added benefit of $111/hd (Basarab et al., 2009).

Adding edible oils to the diet of beef cattle increases conjugated and linoleic fatty acids in meat (omega 3 and 6 essential oils in human diets), resulting in a product called high CLA (Conjugated Linoleic Acid) beef (Haugen-Kozyra et al., 2010). This co-benefit may provide added market value. However, due to the high demand for oils and oilseeds for other purposes, edible oils are expensive. Dried Distillers Corn and Solubles (DDGS) could also potentially be substituted as a fat source in cattle diets, but unfortunately, the higher crude protein contents in rations with corn DDGS causes more N excretion and increased N_2O emissions from manure – negating the enteric CH_4 suppression effects of the corn fat. Basarab et al. (2009) found that including 4% edible oils in feedlot finishing diets increased feeding costs by $25 to $25 CAD/hd. As such, feeding edible oils as a GHG mitigation strategy is not viable until oil costs drop, a premium is paid for high CLA beef (Basarab et al., 2009) or carbon offset prices increase.

Current tests for selecting more genetically efficient cattle are based on phenotypic selection of more efficient seedstock bulls. Testing bulls for lower RFI costs $100 to $150 CAD (Haugen-Kozyra et al., 2010). This may discourage cow-calf operators from using such tests. Nevertheless, in the case of a 100 head cow-calf herd, selecting for low RFI cattle can save up to $2200 in production costs (Basarab et al., 2009). Researchers are actively seeking a blood test that will provide a genetic indication of low RFI cattle. This will enable more rapid testing of a greater number of animals.

Policy

Protocols for reduced days on feed, reduced age to harvest, feed supplement – edible oils and dairy operations have been developed and are currently approved under the Alberta Offset System (AOS). A protocol for selecting for RFI is pending final approval by Alberta Environment and Water.

3.2.1.2 Greenhouse Gas Emission Reduction Potential

Magnitude and Verifiability

Table 7 – Emission Reduction Magnitude and Verifiability for Beef and Dairy Cattle

Opportunity Area	**Reduction Potential – Enteric Methane and Manure Combined (tonnes CO_2e/head/yr)**	**Theoretical Provincial Impact (Mt CO_2e/yr)**	**Verifiability**
Reduced Days on Feed	Up to 0.04	0.13	Modelled
Reduced Age to Harvest	Up to 1	3.34	Modelled
Feed Supplement – Edible Oils	Up to 0.29	0.43	Programmatic Estimation
Residual Feed Intake	24 t CO_2e 4 Bull – 100 cow-calf herd	0.056[1]	Programmatic Estimation
Ration Manipulation (ionophores)	0.36	0.064	Modelled
Reducing Replacement Heifers (30%)	0.41	0.072	Modelled
	Total	**4.092**	

[1]Assumes 40% of bulls in Alberta are certified low RFI.

Justification

The reduction potentials listed in Table 7 above are based on the quantification methods used in the Alberta beef and dairy protocols and Statistics Canada information on beef cattle populations in Alberta. Table 8 below lists the actual reduction mechanisms applied to the calculations and underlying assumptions.

Table 8 – Mitigation Activities and Assumptions for Calculating the Reduction Potential for Alberta's Cattle Population

Mitigation Potential of Beef and Dairy Strategies[1]	Enteric Fermentation Mitigation Potential	Nitrous Oxide/Manure Methane Potential
Reduced Days on Feed (adding a beta-agonist to the feed).	0.02 tonnes of CO_2e/head based on 7.7 days less time in the feedlot.	0.02 tonnes of CO_2e/head.
Adding Edible Oils in the range of 4% to 6% of DM in the feedlot diet.[2]	Up to a 20% decrease in CH_4 per head.	N/A
Reducing Age at Harvest.[3]	Reducing lifecycle by 3 months results in up to 0.75 tonnes CO_2e/head.	Less manure excretion results in up to 0.25 tonnes CO_2e /head.
Selecting for Improved Feed Utilization Efficiency (RFI markers)[4]	Less CH_4 and manure excreted by Low RFI bred cattle; up to 0.035 Mt reduced annually with 10% of Canada's bulls selected for low RFI.	
Milk productivity - Higher quality feed/additives Manure management - Heifer replacement rate	Up to 1.5 tonnes of CO_2e/head; up to 1.49 Mt annually.	

[1] Quantification based on methodologies within Alberta-based protocols.
[2] Based on feeding edible oils in confined operations; number of head is based on July 1, 2010 slaughter heifers and steers one year and over in Table 9.
[3] Based on number of head on July 1, 2010, Table 9 – slaughter steers (over 1 year); slaughter heifers and 50% of the calves under one year could be harvested three months earlier.
[4] Based on a case study where four low RFI bulls in a 100 cow-calf herd reduced 24 tonnes CO_2e annually; to extrapolate to Canada, the assumption that 10% of the Canadian seed stock (bulls) is selected for low RFI; a cow to bull breeding ratio of 25:1, resulting in a progeny of 50% steers, 33% heifers, and 17% replacement heifers that are genetically more efficient.

The following Statistics Canada information (July 2010) on Beef Cattle Populations was also used to calculate the reduction potentials above.

Table 9 - Cattle on Farms in Alberta

	Bulls, 1 year and over	Beef cows	Dairy cows	Heifers			Steers, 1 year and over	Calves, under 1 year	Total
				Heifers, dairy replacement	Heifers, beef replacement	Heifers, slaughter			
	thousands of head								
At January 1									
2004	110.0	1,960.0	86.5	35.0	270.5	558.0	635.0	2,020.0	5,675.0
2005	110.0	2,090.0	83.0	36.0	255.0	630.0	595.0	2,131.0	5,930.0
2006	105.0	2,052.0	85.5	36.5	245.0	647.0	625.0	2,104.0	5,900.0
2007	101.5	2,000.0	79.5	35.0	253.0	657.0	637.0	1,917.0	5,680.0
2008	101.5	1,990.0	83.5	36.0	245.0	690.0	575.0	1,839.0	5,560.0
2009	98.0	1,850.0	87.0	37.0	210.0	575.0	580.0	1,943.0	5,380.0
2010	91.0	1,730.0	89.0	37.0	200.0	624.0	620.0	1,759.0	5,150.0
At July 1									
2004	113.0	2,150.0	82.0	39.0	320.0	765.0	780.0	2,151.0	6,400.0
2005	119.0	2,200.0	85.0	38.0	352.0	825.0	830.0	2,251.0	6,700.0
2006	105.0	2,025.0	82.0	38.0	278.0	812.0	888.0	2,072.0	6,300.0
2007	108.0	2,076.0	83.0	38.0	284.0	835.0	1,000.0	1,986.0	6,410.0
2008	105.0	1,955.0	86.0	40.0	267.0	750.0	805.0	2,002.0	6,010.0
2009	96.0	1,790.0	88.5	40.5	250.0	785.0	845.0	1,935.0	5,830.0
2010	95.5	1,704.0	88.5	40.0	249.0	725.0	749.0	1,855.0	5,506.0

Source: Statistics Canada, 2010c

Cattle populations are expected to continue to decrease due to the short supply of grain stockpiles; exacerbating events like world drought, fire and floods; and ongoing biofuel policies in the United States which drive feed prices up in North America. The reduction potentials listed in this report are based on a stable cattle population. This assumption is likely conservative given the reduced beef cow herd in Alberta, and the cattle cycle (taking about 9 to 10 years to re-build a herd). Further, dairy operations are supply side managed, so the dairy cattle populations are unlikely to change significantly. Therefore, the absolute reductions quoted in this report are likely appropriate over time.

3.2.1.3 Gaps and Constraints

Science, Data and Information Gaps: Additional research is needed on the combined effects of dietary changes on enteric and stored manure emissions. Hindrichsen et al. (2006) as cited in Denef et al. (2011), found that diet manipulations that reduce enteric CH_4 emissions, increase manure slurry methanogenesis, which may be a substrate for fecal microbes. Consequently, enteric and slurry CH_4 emissions must be combined to quantify the impact of dietary based CH_4 mitigation strategies. Quantitative estimates of the mitigation potential of individual practices are also needed. In addition, the following refinements to the science are needed through more studies and scientific synthesis (i.e. meta-analysis of existing research):

- Improved enteric CH_4 emission factors for medium and high quality forage as well as grain to determine variation in enteric CH_4 emissions;
- Meta-analysis of cattle response to ionophores, leading to a standardized use protocol for consistent reduction of enteric CH_4;
- Validation of IPCC indirect emission factors for N_2O emissions – for leaching, volatilization and re-deposition; and
- Research on the impacts of ration manipulation on forage quality.

Further, a number of information and data gaps exist that if addressed could lead to greater uptake of mitigation strategies. These gaps include:

- A lack of rapid blood tests to identify low RFI animals;
- The absence of a coordinated database of RFI values for Canada's beef cattle seedstock to improve selection and breeding of more efficient cattle; and
- A need for improved record tracking of animal birth dates on-farm and through the Canadian Cattle Identification Agency (CCIA) (note: the Beef Improvement Centre is currently working on a more publicly accountable information system for tracking beef cattle in Canada).

Policy Gaps: A protocol for beef RFI is nearing approval by Alberta Environment and Water. However, better coordination between the Alberta Livestock and Meat Agency (ALMA), Alberta

Agriculture and Rural Development's (ARD) Traceability initiative, the University of Alberta and the RFI testing stations across Alberta is needed to develop a 'certification system' to support the protocol. The inventors of the GrowSafe system (used to phenotypically identify low RFI cattle) are in the process of becoming a USDA Process Verified Program. This system will also need to be recognized in Alberta. In order for this to occur, a coordinated effort from the agencies listed above will be needed. Further, synergies between the Traceability Initiative and tools like the Low RFI protocol could re-enforce each other and provide a value-added proposition to boost positive perceptions within the industry. Tracking registries for cattle movement between types of operations and auction marts would greatly enhance the ability to identify ownership of the cattle – a key carbon offset criterion. However, industry confidence would need to be improved regarding the use of the CCIA database and other traceability initiatives to track and verify more than just the age of cattle.

Protocols are in place for dairy cattle ration manipulation and reducing replacement heifers. However, pilots in Alberta have revealed gaps in records.

Technology Gaps: A blood test is needed to test for RFI. Currently, testing of bulls is based on the breeder's guess as to whether a bull is more efficient than its neighbors. The test costs approximately $120 to $150/animal, with no guarantee of a desirable low RFI value. Further, in beef academic circles, there is still skepticism that a single trait like RFI is robust enough to stand alone as a single indicator of more efficient animals. Hence, there is a call for a more integrated trait index by some circles, particularly in the U.S. An increasing number of studies are now being published that support RFI as a valid approach.

Demonstration Gaps: To date, there has not been any carbon offsets created under the Alberta Offset System using the beef protocols. This is presumably due to the complexity of the protocols, the fact that the Days on Feed protocol was only recently approved and the effort required to retrieve and process all the data. However, we are aware that at least a couple of aggregators are working on submitting Offset Project Plans. Beef cattle producers need to be educated on the unique opportunity afforded by these protocols and actual projects need to be implemented to use as case studies on the "how to" aspects of creating offsets from the methodologies.

The ADFI-DFC-AB Milk Dairy Pilot, mentioned in the technology section above, has discovered that there are essentially 4-key components to the dataset that need to be developed for each participating farm:

- Milk Production – Average daily milk production per lactation cow;
- Herd Size – Lactation, dry cow and heifer herds;
- Feeding System – Dry matter intake details for lactation, dry cow and heifer herds; and

- Manure Management – Manure production (liquid/solid) and cropland application timing.

In order to be verifiable by a third party, a high quality data set must include all of the data required by and outlined in the Dairy Protocol. The verifiability piece is especially important. GHG project verifiers are less likely to accept data that has been generated by the farm management team. Instead, they prefer to see data that has been developed by off-farm sources. Key data components that have been identified to date through the pilot are:

- Milk Production – Dairy Farmers of New Brunswick and Alberta Milk shipment records and Canwest DHI and Valacta milk test reports.
- Herd Size – Dairy Comp records and Valacta milk test reports.
- Feeding System – Nutritionist feed sheets, automatic TMR feed tracking software
- Manure Management – Custom manure hauler invoices

The pilot has identified two data gaps that need to be filled: 1) mature animal weights; and 2) daily dry matter intake for each ration component. Effort is being made to set up ways to collect this data – with cooperating dairy producers and the milk reporting companies (Canwest DHI and Valacta). This has been an invaluable exercise in moving the industry forward and realizing GHG reductions from dairy cattle operations.

Metric Gaps: An algorithm is needed to process the voluminous amount of feedlot data required to take a project through the Alberta Offset System. This algorithm should also have the capacity to assess costs and determine if a project is feasible/will be able to create a profit for the producer/aggregator. Similarly, pilots such as those for the Dairy Protocol will go a long way to identifying these opportunities.

Other Gaps: The high cost of oils and lipids poses a challenge for edible oils. There is also a lack of eco-labeling programs to market or communicate the value of low carbon meat and milk products. Further, milk quality and price are given greater priority by producers than cycling of ionophores. In addition, replacement heifers are seen as insurance by dairy producers and as such most producers are reluctant to reduce their numbers. Finally, another significant concern is that transaction costs for Offset Projects are expected to increase significantly starting in 2012, due to the requirement to meet a higher level of assurance (from limited to reasonable level of assurance). This will make the data tracking and management, as well as evidence gathering requirements more onerous and verification costs more expensive (expected to double or triple). Verifying aggregated beef or dairy projects will be a complex and expensive undertaking.

3.2.1.4 Opportunities to Address the Gaps/Constraints Identified

There are multiple and synergistic co-benefits arising from implementing these strategies, including higher efficiencies of production for ranchers and dairy operators. Additional co-benefits, as noted by Basarab et al. (2009) include: 1) identifying management practices that improve the efficiency of feed and energy utilization without adversely affecting production and profitability; 2) reducing the environmental impacts of beef/dairy production; 3) taking advantage of the carbon credit market; and 4) differentiating 'green' products (on the basis of an improved carbon footprint) and healthier products.

In order to address the opportunities/constraints identified and achieve meaningful GHG mitigation in the cattle sector, the means of implementing these changes in practice will need to be further specified. In addition, feedlot operators and their advisors will need 1) appropriate support infrastructure to help them correctly implement the mitigation strategies laid out in the protocols and 2) guidance on incorporating these mitigation strategies into a farm-specific offset project plan. New types of infrastructure that incorporate data management and collection for verifiable GHG reductions into a single platform would be helpful in addressing these needs. Such infrastructure is beginning to emerge; however, access is not yet commonplace for feedlot operators (as was found in the Dairy Pilots currently underway in New Brunswick and Alberta). This lack of access poses a barrier to adoption. Undertaking beef pilots in Alberta, similar to those being conducted for dairy, would help identify the data and farm record gaps in implementing the beef protocols. Once identified, new solutions may emerge.

3.2.2 Farm Energy Efficiency

This opportunity involves improving farm energy efficiency and energy conservation in poultry, swine and dairy operations in order to save costs, improve profitability and reduce GHG emissions. Inefficient practices, inefficient equipment and opportunities for energy generation can be identified through a farm energy audit. An energy audit provides a plan for how a farmer can prioritize energy efficiency investments. General recommendations on how to save energy abound, but it is only through an analysis of a farmer's unique energy usage and production patterns that a farmer can truly learn what opportunities are best for his or her operation. Due to the large number of facilities in Alberta and evidence of increasing operating costs, energy efficiency projects are an attractive means of decreasing operating costs associated with energy use, and significantly reducing Alberta's GHG emissions. According to Alberta Agriculture, apart from Alberta Agriculture's energy audit manual there is currently very little information targeted to energy efficiency on farms, despite energy use being a large operational expense for many types of farm operations.

3.2.2.1 Literature Review

Science

In the U.S, energy costs typically make up four to five percent of total dairy farm operational costs (Innovation Center for U.S. Dairy, 2012). The main sources of these costs are milk cooling, ventilation, milking lighting and electric water heating (Innovation Center for U.S. Dairy, 2012). Opportunities for increasing energy efficiency on dairy cattle operations include shifting to higher efficiency fluorescent light fixtures (i.e. CFL's), using a milk pump variable speed drive, employing electronic ballasts in fluorescent lamps (instead of the older magnetic ballasts) and improving ventilation. Proper ventilation also helps with herd health and profitability, since heat stress can cause cows to decrease their food intake, which lowers milk production (Innovation Center for U.S. Dairy, 2012).

Employing variable speed drives (VSD) on milking machines can decrease vacuum system energy costs by half (Innovation Center for U.S. Dairy, 2012). VSD units only use the amount of suction pressure that is needed, while still preventing bacteria from entering the cow's teat (Innovation Center for U.S. Dairy, 2012). Water-cooled plate coolers can also be used to save energy by reducing the number of hours that the compressor must operate. Plate coolers use well water to cool the milk while it is being transferred from the milking system to the tank. This speeds the cooling process so that once the milk reaches the storage tank its temperature has already decreased. As a result, less energy is needed to chill the milk once it's in the storage tank.

Other opportunities for saving energy include switching from a reciprocating compressor to a scroll compressor system and installing a heat recovery system that uses heat from the compressor to pre-heat water (Innovation Center for U.S. Dairy, 2012). Co-benefits of energy savings activities include increased comfort for the animals and staff, reduced maintenance costs and/or improved farm productivity (Gulkis & Clarke, 2010).

Technology (Applications/Demonstrations)

Agricultural Energy Management Plans (Ag EMP) serve as a decision support tool for farmers. In particular, their purpose is to help farmers choose the energy saving activities/ technologies that make the most sense for them. Key components of an Ag EMP are (Gulkis & Clarke, 2010):

- A summary of the facility's location, production level, any unusual factors that affect energy use, and any energy efficiency measures already in use.
- A summary of the site's energy use over one year, broken down by type of usage and month.

- A summary of how much money the farmer would save if the recommended measures were employed and how much money the farmer would continue to lose if no action were taken.
- A list of recommended measures to reduce energy use, including annual energy (electricity, natural gas, propane, diesel, oil, etc.) savings and an estimated payback in years.
- A narrative summary of the recommendations made through the audit, including a description of the technology, how the technology would affect the site, and how much energy would be saved annually by installing the equipment.

Ag EMP's also help farmers apply for any federal of provincial grants or cost share programs aimed at energy conservation.

Markets

On farm energy savings save costs and therefore improve operation profitability. Ag EMP's typically cost a few thousand dollars per farm. The audit will determine if the energy savings potential will offset the cost of having the audit done. Most farm energy efficiency carbon offset projects do not produce a large number of credits. As a result, quantification and verification costs are too high without aggregation.

Policy

Under the Growing Forward Initiative, Alberta Agriculture and Rural Development is currently running an On-Farm Energy Management program. This program was designed to help improve energy efficiency on agricultural operations, resulting in cost savings, energy conservation and reduced GHG emissions (Alberta Agriculture and Rural Development, 2010). Additional goals include 1) contributing to rural economic development by enabling the establishment of a regional energy network and by lowering the cost of energy use; 2) using demonstration projects to showcase opportunities; and 3) ground proofing the applicability of technologies/practices on Alberta farms.

The program has three components: On-Farm Energy Assessments, Energy Efficiency Retrofits and Energy Efficiency Construction. Through the On-Farm Energy Assessment component farmers can obtain an assessment of their farm's energy use by trained assessors free of charge. The Energy Efficiency Retrofits program is a financial incentive to retrofit high-efficiency equipment into existing operations and the Energy Efficiency Construction program is a financial incentive for using high-efficiency equipment and methods in new building construction.

The On-Farm Energy Management program runs until 2013. One long-term goal of the program is to create a database of energy efficiency on agricultural operations in Alberta. Hence, energy usage data and farm production data are being collected from each participant. Further, ARD recently released an on-farm energy calculator. This calculator still needs to be thoroughly tested; however, could serve as a basis for a future energy efficiency protocol.

Finally, ARD is also currently piloting a solar PV equipment program. This program provides modest financial support for farmers who are installing grid-connected (minimum 2.2 kW size) solar photovoltaic (PV) systems. In order to enter the program applicants must first apply for and have a solar site assessment conducted. If successful, they can then apply for the Solar PV Equipment Pilot grant.

3.2.2.2 Greenhouse Gas Emission Reduction Potential

Magnitude and Verifiability

Table 10 – Emission Reduction Magnitude and Verifiability for Farm Energy Efficiency

Opportunity Area	Theoretical Provincial Impact (Mt CO_2e/yr)	Verifiability
Poultry (fans, lighting)	0.064	Modelled
Swine (fans, lighting, creep heating)[1]	0.072	Modelled
Dairy Cattle (fans, pre-coolers, VS vacuum pump, scroll compressor)	0.005	Modelled
Total	**0.141**	

[1]Note: farrow to finish facilities were taken to be representative of swine facilities

Justification

Due to the lack of availability of Alberta specific farm audit data, Ontario data was used as the basis of this analysis. Audit information collected in Ontario indicates varying degrees of efficiency gains from the implementation of energy conserving technologies; however, the greatest gains came from changes to lighting, ventilation, vacuum pumps, and creep-heating.
The following method was applied in estimating the emission reduction potential for energy efficiency in Alberta:

1. The average annual electricity cost per farm by farm type in Ontario was obtained;
2. The equipment with the greatest potential for energy efficiency savings was determined based on each equipment's relative proportion of energy consumption and by facility type;
3. Data on the average total opportunity for annual savings on all audited farms by equipment type was applied for the equipment identified for each farm type as having the greatest potential for energy efficiency improvements to determine the overall potential energy savings in dollars per farm and by farm type. The monetary

energy savings were then converted to kWh using the average cost of electricity in Alberta for 2006;

4. Ontario data for potential energy savings per farm was extrapolated for Alberta by adjusting savings by a size factor representing the average farm size by facility type in Ontario versus Alberta and by applying the Ontario based energy savings to the number of farms of each type operating in Alberta; and
5. The electricity Grid Intensity Factor for Alberta was applied to the potential energy savings to determine the potential CO_2E savings for energy efficiency projects.

3.2.2.3 Gaps and Constraints

Science, Data and Information Gaps: Presently, there is a lack of Alberta specific farm audit data.

Policy Gaps: The current Energy Efficiency protocol was drafted to allow for a wide range of energy efficiency projects to participate. While in some ways this is advantageous, it can also be disadvantageous since there are no farm specific guidelines included. Therefore, supporting guidance documents are needed for farm project types and operations.

Furthermore, in terms of government programs/services, there is disconnect between what farmers believe is available to them and what is actually available. In particular, many farmers are unaware of the fact that assessments are available free of change and that there are financial incentives available for implementing energy efficiency activities. In addition, many farmers are unaware of the value stream carbon offsets can provide. Therefore, improved communication and dissemination of information on energy efficiency programs is needed.

Technology Gaps: Energy conservation technology exists. What is needed is a decision tool to help farmers estimate the energy savings that can be generated by making changes to their farm.

Demonstration Gaps: Alberta farm audit data showing before and after energy efficiency implementation measures data is needed to demonstrate to other farmers the effectiveness of making changes.

Metric Gaps: A standardized Ag EMP is needed to provide a basis for decision making. In the US, on-farm energy audits need to comply with the American Society of Agricultural and Biological Engineers (ASABE 2009) standard S612: Performing On-farm Energy Audits. This standard is provided to guide the reporting of data and the preparation of specific recommendations for energy reduction and conservation with estimates of energy saving. This means that auditors registered to provide Ag EMPs are highly qualified to provide these services.

Energy efficiency carbon offset projects are dependent on metering. Facility wide metering degrades emission reduction precision (causing energy savings from more efficient equipment to be lost) making sub-metering more desirable. However, many producers do not have sub-metering. This presents a barrier to quantifying energy savings and emissions reductions.
In the absence of sub-metering, a program that that supports benchmarking would allow producers to evaluate their efficiency levels and create an industry benchmark based baseline. Such a program could also be linked to funding to ensure that producers have knowledge of how they compare.

Other Gaps: There is a lack of information on the potential cost savings of energy efficiency improvements amongst farmers. There is also no decision support tool available to help farmers make decisions on farm energy efficiency. Furthermore, while many farmers have some idea of the energy efficiency upgrades and retrofits they need, few have the capital to implement them. Although energy efficiency projects may result in savings over the long-term, farmers bear the costs of paying for the project in the beginning. This delay poses a financial barrier that should be addressed.

Moreover, many farmers perceive the application process for grants and rebates as being time consuming, creating an administrative burden. Given this, effort is needed to make grants and rebates more accessible.

3.2.2.4 Opportunities to Address the Gaps/Constraints Identified

ARD recently released an On-Farm Energy Footprint Calculator. Although this calculator still needs to be tested and evaluated, it could serve as a useful tool for identifying other GHG mitigation opportunities on-farm, leading to expanded opportunities for farmers. ARD is also revising and upgrading the Energy Efficiency protocol for expanded opportunities related to on-farm energy efficiency improvements. This will broaden the scope of the protocol and allow for more carbon offset pathways. Once approved by Alberta Environment and Water (AEW), a demonstration pilot could be coordinated with ARD in conjunction with current Energy Efficiency and Renewable Energy programming that provides federal and provincial incentives to adopt these practices.

Agricultural opportunities to increase off-farm transport of hay and other agricultural commodities are being developed as part of the Transportation Efficiency protocol. This opportunity crosses over with the Transportation section of this report, specifically those sections that relate to increased fuel efficiency and greater containerization of agricultural commodities (with increased opportunity for truck to rail intermodal transport).

There is also an opportunity to improve communication surrounding current energy efficiency programs. In order to accomplish this, a well-developed marketing strategy will be needed. This strategy should involve pilot projects, appropriate marketing materials for the target audience and working with industry associations to disseminate information.

3.2.3 Swine Reductions

Between 1981 and 2001, growth of the Canadian swine population led to an increase of 54% in GHG emissions from pork (Verge et al., 2009). The main GHG was CH_4, representing approximately 40% of the total in 2001 (Verge et al., 2009). Nitrous oxide and fossil CO_2 both accounted for approximately 30% (Verge et al., 2009). However, during the same time frame, improvements in management practices caused the GHG emission intensity of the Canadian swine industry to decrease from 2.99 to 2.31 kg of CO_2e per kg of live market animal (Verge et al., 2009).

Since that time, the Canadian Pork Industry has experienced a significant decline in swine populations and production systems. In mid-2010, Alberta Pork reported that there were only 381 pork producers left in Alberta, 935 less than the 1315 pork producers reported in 2001. Furthermore, the total sow base decreased from 200,000 (less than five years prior) to 137,000 (Alberta Pork, 2010). Overall, GHG emissions would have declined by a concomitant 30 to 35% in Alberta's pork sector, due to the reduction in the production of pigs.

That being stated, there are still opportunities for decreasing emissions from swine. The mitigation activities covered in this report include: 1) increasing feed conversion efficiency (10%); and 2) decreasing crude protein in feed (15%). Increasing feed conversion efficiency decreases the amount of manure and N excreted by swine (Haugen-Kozyra et al., 2010; NRCS, 2012). Likewise, decreasing crude protein in feed decreases the volatile solid content of excreted manure (NRCS, 2012).

3.2.3.1 Literature Review

Science

Opportunities for reducing GHG emissions from swine operations arise from feed management strategies and manure management. Feed manipulation can be used to increase feed conversion efficiency, reduce nutrient excretion and shift nutrient excretions from urine to feces (NRCS, 2012; Olander et al., 2012b). Specifically, matching dietary nutrients with swine requirements can reduce the excretion of nutrients such as N and carbon, which in turn reduces GHG emissions from manure (Olander et al., 2012b).

Reducing the amount of crude protein in the ration, and using balanced amino acids to meet N requirements has been demonstrated to reduce N excretion in pigs and can therefore lower N_20 emissions from land application of manure. For example, Ball et al. (2003) as cited in Olander et al. (2012b), found that low protein diets decreased GHG emissions from growing pigs by 25 to 30% and from sows by 10 to 15%. Consequently, diet modification has been proposed as a strategy for reducing GHG emissions from the biodegradation of nutrients in pig manure (Lague 2003 as cited in Olander et al., 2012b).

In addition, Moehn et al. (2004) stated that efforts to increase animal nutrient utilization efficiency would certainly decrease the release of CO_2. Further, CH_4 emissions from manure depend on the amount of excreted volatile solid (VS), the maximum CH_4 producing capacity for the manure produced (BO) and CH_4 conversion factors (MCF) (Olander et al., 2012b). If diets can be manipulated to decrease the amount of volatile solids excreted by the pigs, then CH_4 emissions from manure storage will be reduced.

A final strategy to reduce CH_4 emissions from liquid swine manure storage is to empty the storage more frequently. This is covered in the Improved Manure Management section of this report.

Technology (Applications/Demonstrations)

In the early 2000's, an aggregator known as AgCert Inc. contracted over 150 hog producers in Alberta to empty their manure storages in the spring and fall to avoid CH_4 emissions. Unfortunately, the project faltered due to the inability of AgCert to apply the quantification they developed under the Clean Development Mechanism of the UNFCCC. Since then, no other GHG reduction projects have occurred in Alberta, despite the fact there is an approved government GHG quantification protocol in the Alberta's Offset System.

Markets

The economic benefits of hog production are threatened by volatility in oil seed and grain prices. As a result, producers following a least cost ration formulation may be limited in their ability to follow a ration formula that reduces GHG emissions. Balancing protein content with supplemental amino acids will likely not be economical for most operations. In general, high feed costs combined with a strong Canadian dollar and increasing market demand for animal welfare, food safety and environmental standards, has led to increasingly tight margins in the beef and pork sectors. However, market performance for Alberta's remaining pork producers is increasing as world demand for protein increases. Many are finding that raising weaner pigs and exporting them to the US to be finished where feed is cheaper, while still retaining ownership (contract feeding), is turning out to be a lucrative undertaking. This may curtail ability to implement the Alberta Pork Protocol to the degree originally thought.

Policy

A Pork GHG Quantification Protocol, along with Interpretive Guides on how to implement the protocol and Project Builder™ software are available and have been in place for the past few years.

3.2.3.2 Greenhouse Gas Emission Reduction Potential

Magnitude and Verifiability

Table 11 – Emission Reduction Magnitude and Verifiability for Swine

Opportunity Area	Reduction Potential (tonnes CO_2e/ hog/yr)	Theoretical Provincial Impact (Mt CO_2e/yr)	Verifiability
Increased Feed Conversion Efficiency (10%)	Up to 0.013	0.02	Modelled
Decreased Crude Protein in Feed (15%)	Up to 0.059[1]	0.09	Modelled
Total		**0.11**[2]	

[1] Taken from Gill & MacGregor, 2010
[2] Avoided CH_4 emissions potential from manure storage emptying is in Table 13

Justification

Most of the mitigation strategies listed in Table 11 above are efficiency gains in pork production, expressed on an emissions level per product output basis (with the exception of emissions from manure management, which are reported on in the Improved Manure Management section). This means that between the baseline and mitigation activities, the compared functional unit for estimating mitigation potential is measured in tonnes of CO_2e per kg of pork produced. The Alberta protocol calculates the tonnes of CO_2e per kg of pork per pig class; however, for the purposes of this calculation a tonne per head amount has been rolled up from a 600-sow farrow-to-finish base case in Central Alberta (Blue Source Canada, 2008). The increased feed conversion efficiency is assumed to be from: improved pig genetics; ration balancing and manipulation; and improved feeder designs.

To roll up the estimates for Alberta, Statistics Canada information on Alberta swine populations were applied (Statistics Canada, 2010a). To calculate the total, the total hog numbers were applied (Table 12).

Table 12 – Hogs on farms in Alberta

	Total hogs	Breeding stock	Boars, 6 months and over	Sows and bred gilts	All other hogs	Under 20 kg	20 to 60 kg	Over 60 kg
	thousands of head							
At January 1								
2003	2,139.8	215.5	7.5	208.0	1,924.3	619.5	644.3	660.5
2004	2,050.0	212.3	7.4	204.9	1,837.7	637.3	589.1	611.3
2005	2,045.0	206.1	7.3	198.8	1,838.9	603.0	605.0	630.9
2006	2,036.0	199.2	7.1	192.1	1,836.8	576.6	629.9	630.3
2007	2,045.0	193.4	7.0	186.4	1,851.6	607.5	641.0	603.1
2008	1,800.0	178.4	6.4	172.0	1,621.6	529.8	559.2	532.6
2009	1,590.0	167.3	5.3	162.0	1,422.7	437.8	512.8	472.1
2010	1,505.0	156.3	4.9	151.4	1,348.7	435.4	472.5	440.8
At April 1								
2003	2,100.0	213.5	7.5	206.0	1,886.5	614.4	636.3	635.8
2004	2,030.0	208.4	7.4	201.0	1,821.6	600.9	627.9	592.8
2005	2,025.0	202.7	7.3	195.4	1,822.3	597.7	615.7	608.9
2006	2,050.0	197.1	7.1	190.0	1,852.9	625.2	617.5	610.2
2007	2,020.0	191.9	6.9	185.0	1,828.1	611.3	607.2	609.6
2008	1,700.0	175.0	6.2	168.8	1,525.0	520.0	504.1	500.9
2009	1,540.0	165.2	5.2	160.0	1,374.8	454.6	454.9	465.3
2010	1,490.0	154.3	4.6	149.7	1,335.7	463.3	454.5	417.9
At July 1								
2003	2,030.0	211.0	7.5	203.5	1,819.0	636.5	585.6	596.9
2004	2,030.0	205.3	7.3	198.0	1,824.7	622.7	623.3	578.7
2005	2,000.0	204.0	7.2	196.8	1,796.0	615.1	621.9	559.0
2006	2,056.0	195.1	7.1	188.0	1,860.9	614.4	676.4	570.1
2007	1,970.0	189.5	6.9	182.6	1,780.5	582.2	615.2	583.1
2008	1,670.0	171.0	6.0	165.0	1,499.0	504.8	488.8	505.4
2009	1,530.0	161.5	5.0	156.5	1,368.5	441.9	476.5	450.1
2010	1,495.0	153.1	4.6	148.5	1,341.9	426.4	476.5	439.0
At October 1								
2003	2,020.0	212.4	7.4	205.0	1,807.6	653.4	592.8	561.4
2004	2,010.0	206.4	7.3	199.1	1,803.6	581.5	620.3	601.8
2005	2,020.0	202.5	7.2	195.3	1,817.5	598.9	620.0	598.6
2006	2,035.0	195.5	7.0	188.5	1,839.5	602.9	629.5	607.1
2007	1,890.0	186.6	6.8	179.8	1,703.4	557.2	588.0	558.2
2008	1,650.0	169.6	5.6	164.0	1,480.4	438.5	528.7	513.2
2009	1,515.0	157.4	4.9	152.5	1,357.6	436.3	455.2	466.1
2010	1,500.0	151.3	4.4	146.9	1,348.7	433.9	424.9	489.9

3.2.3.3 Gaps and Constraints

Science, Data and Information Gaps: Gathering ration data by pig class is intensive and complex. Integration of PiGCHAMP and other systems is available, but farmers have to be incentivized to spend the necessary time to ferret out the data for use in quantifying reductions and seeking carbon qualification. Also, because the Pork Protocol has not yet been implemented in Alberta, an assessment of the availability of the needed data from individual swine operations, and feed nutrition companies needs to be conducted.

Policy Gaps: Some of the mitigation strategies outlined in the Alberta Pork Protocol as well as some mitigation strategies not mentioned in the Protocol may not be cost-effective for pork producers to implement. Accompanying incentives may need to be incorporated into a programmatic approach to enhance practice change.

Technology Gaps: It's likely that not all of the information needed to calculate GHG reductions is available from pork operations. For example, the ability to assess the daily dry matter intake of animal groupings in the hog barn, electronically record the information and synthesize the information in accordance with ration balancing programs like PIGCHAMP or PIGWIN to increase animal performance is lacking. Better integration of these tools, in a data collection and management platform will enhance protocol uptake and practice change.

Demonstration Gaps: Since the amount of reductions from each hog operation is likely to be small, aggregation of data across numerous farms will be required to assemble the numbers needed to meet an economy of scale to cover the many fixed costs associated with aggregation and carbon qualification. Presently, there is no template for an aggregator to use to embark on this process. The risk seemingly outweighs the perceived reward and has been a barrier to adoption.

Metric Gaps: Please refer to the technology gaps above.

Other Gaps: The reduction potential of increased feed conversion efficiency on a per operation basis is small. As a result, projects need to be aggregated. Further, tight margins are a barrier to anything innovative that may have a cash outlay (i.e. high costs of balancing amino acids). Fertility insurance is also an issue.

3.2.3.4 Opportunities to Address the Gaps/Constraints Identified

Incentive programs that assist producers in contracting the expertise they need to get set up for tracking carbon reduction opportunities over time and help offset the costs of adopting some of these practices would help address some of the above gaps. In particular, those associated with tight margins and the complexity of gathering ration data. In addition, pilot demonstrations would help pork producers identify data gaps and determine ways to overcome these gaps. Further, through actual implementation of the protocol, opportunities to streamline data collection and set up practical data management platforms will emerge – thereby reducing transaction costs of originating carbon offsets from pork.

3.2.4 Improved Manure Management

Improved manure management mitigation strategies include: 1) changing the timing/frequency of emptying (switching from fall to spring); 2) changing the timing of manure application (switching to spring and summer); and 3) changing bedding type (Olander et al., 2012, NRCS 2012; Alberta Pork and Dairy Protocols).

3.2.4.1 Literature Review

Science

Emptying and Manure Application: Livestock manure produces N_2O and CH_4 emissions during storage, treatment and application (Denef et al., 2011; Follett et al., 2011). Improved manure management practices aim to reduce these emissions by decreasing the amount of time the manure is stored and by maximizing plant uptake of manure derived N (CAST, 2004 as cited in Denef, Archebeque, & Paustian, 2011; Follett, et al., 2011). Specific strategies include 1) emptying manure storage in the spring rather than in the fall and 2) spreading manure in the spring/summer closer to the time of active plant growth. Ideally, these two strategies should be used together in order to prevent additional emissions at the time of application (i.e. due to over-fertilization and corresponding indirect NH_3 emissions) (Olander et al., 2012b). Avoiding losses of gaseous N and leaching/runoff from stored manure also helps reduce indirect off-site N_2O emissions (Follett et al., 2011). In addition, applying manure to farmland can reduce the need for mineral N fertilizers, which in turn may further lower N_2O emissions.

A significant amount of the N in manure can be lost as ammonia (NH_3), nitrate (NO_3) or nitrous oxide (N_2O) once applied to the land. Ammonia causes air quality problems, NO_3 reduces water quality and as already discussed N_2O is a GHG. Since all three N loss pathways are connected, efforts to reduce N_2O emissions from manure application have additional environmental co-benefits associated with lower NH_3 and NO_3 losses (Eagle et al., 2011).

Storage conditions (i.e. aeration, temperature, pH) and manure composition impact emission rates as well as the type of gas emitted (Follett et al., 2011). Methane production following manure application depends on manure type (solid, slurry, effluent), origin (type of animal), composition, time since last application, climatic conditions, amount of water available and soil conditions (Chadwick et al., 2000; Saggar et al., 2004 as cited in Denef et al., 2011 & Follett, et al., 2011). For example, Saggar et al. (2004) as cited in Denef et al. (2011), found greater denitrification losses following cattle slurry injection in comparison to surface application on grassland soil. The increased denitrification rates associated with slurry injection were attributed to large quantities of inorganic N, high organic carbon levels and increased soil water content (Saggar et al., 2004 as cited in Denef et al., 2011).

Gregorich et al. (2005) found that N_2O emissions were lower for solid manure application in comparison to liquid manure. Nitrification inhibitors can also reduce N_2O losses after applying manure to the land; however, consistent results have yet to be shown due to the large number of variables influencing N_2O emissions from soils (Saggar et al., 2004 as cited in Denef et al., 2011).

Bedding Type: According to Cabaraux et al. (2009) and Dourmad et al. (2009) as cited in Olander et al. (2012b), CH_4 and N_2O emissions are lower for sawdust bedding systems than for fully slatted floor/pit systems. Likewise, Nicks et al. (2003, 2004) as cited in Olander et al. (2012b), found that pig houses with saw dust based litter emitted 33% less CH_4 than straw-based systems. Straw bedding systems have also been reported to produce more NH_3 and N_2O emissions than slatted floors (Philippe et al., 2007b as cited in Olander et al., (2012b). The same study found CH_4 emissions from straw bedding systems and slatted floors to be the same.

Technology (Applications/Demonstrations)

The AgCert projects undertaken in Alberta from 2003 to 2005 proved that carbon reductions could be achieved by more frequent and appropriate time of emptying of manure storages. Fortunately, improved manure management does not require large capital investments and therefore may be a feasible approach to reducing emissions and obtaining carbon credits. Indeed, AgCert succeeded in contracting over 150 hog operators during the above time period. Nevertheless, multiple annual applications of manure takes time, labour and scheduling. This may be a barrier to adoption without proper rewards. Further, farms would need to be aggregated in order to increase viability and implementation.

Markets

The beef and pork sectors are both facing increasingly tight margins with high feed costs, a strong Canadian dollar, and market demand for animal welfare, food safety and environmental standards. Fortunately, improved manure management does not require large capital investments and where applicable can give rise to carbon offsets that would provide a small incentive for undertaking this practice change.

Policy

The Alberta Pork Protocol includes mitigation strategies for more frequent and proper timing of emptying as well as timing of application of liquid swine manure.

3.2.4.2 Greenhouse Gas Emission Reduction Potential

Magnitude and Verifiability

Table 13 – Emission Reduction Magnitude and Verifiability for Improved Manure Management

Opportunity Area	Reduction Potential (tonnes CO_2e/head/yr)	Theoretical Provincial Impact (Mt CO_2e/yr)	Verifiability
Time/Frequency of Emptying – Switching from Fall to Spring	Dairy - Up to 0.70 Swine - Up to 0.036	Dairy - 0.062 Swine - 0.054	Modelled
Timing of Manure Application – Switch to Spring and Summer	Dairy - Up to 1 Swine - Up to 0.04	Dairy - 0.089 Swine - 0.060	Modelled
Bedding Type	Unquantified	Unquantified	N/A
	Total	**0.265**	

Justification

Most of the mitigation strategies listed in Table 13 above are expressed on emissions level per head. The Alberta protocols calculate the tonnes of CO_2e per kg of pork per pig class and per litre of fat corrected milk for dairies. For the purposes of this calculation, a tonne per head amount has been rolled up from a 600-sow farrow-to-finish base case in Central Alberta (as per the swine section above) and on a per head dairy basis in the case of dairy cattle. To roll up the estimates for Alberta, Statistics Canada information on Alberta swine and dairy cow populations were applied as per the population data shown in Tables 9 and 12 in the swine and beef/dairy management sections of this report.

3.2.4.3 Gaps and Constraints

Science, Data and Information Gaps: Additional research on: 1) manure storage emissions and emissions from applying different forms of manure to land; 2) livestock-pasture systems (to enable more opportunities for the pastured dairy animal to realize real and verifiable GHG reductions); 3) impacts of manure application rates on carbon sequestration; 4) the distance manure and transformed types of manure can be transported before GHG emissions associated with transportation exceed GHG reductions; 5) GHG reductions due to the decreased need for fertilizer N application (reduced upstream fertilizer production emissions); and 6) the reduction potential of changing bedding type is needed.

Policy Gaps: There is a lack of programmatic approaches to enhance adoption of improved manure management practices for liquid manure. Alberta has an Anaerobic Digestion (AD) Quantification Protocol, but to date it has not been implemented due to the high cost of digester construction and operation on individual farms. The Bioenergy Program in Alberta has received an increase in funding of $441 million over the next three years (on top of the original base funding of $239 million). However, unfortunately the program - which was implemented in 2008 - has not yet resulted in the completion of any new anaerobic digestion projects.

Technology Gaps: Monitoring and reporting systems for tracking animals and their production system practices over time are needed. These systems should have electronic data transfer capability in order to increase the reliability and quality of data collection. Further, programs that help confined feeding animal operations build regional digesters in areas where the high costs and the sophistication of the technology prevent application are needed. This is particularly important in areas where digesters would provide additional opportunities to better manage and transport manure from Alberta farms.

Demonstration Gaps: The manure reduction potential of dairy operations is being tested in the Dairy Pilot in Alberta. However, there is no such pilot for pork. Pilots are useful in identifying data gaps, building data management platforms, finding data solutions and streamlining the application of protocols. Further, they help producers to better understand the pathways to emissions reductions and the mechanics of engaging in emission reduction projects.

Metric Gaps: Manure practice and record keeping, including details on date of emptying, extent of emptying and application practices needs to improve.

Other Gaps: None identified.

3.2.4.4 Opportunities to Address the Gaps/Constraints Identified

More pilots that identify data management and implementation challenges to emission reduction strategies are needed. The Dairy Pilot has been instrumental in constructing tools and a data management system that will streamline data collection in the future for participating dairy operators.

Streamlined data management systems and associated data aggregation platforms will allow for effective GHG assessment into the future. In particular, these systems will give dairy, beef and pork producers across Alberta an opportunity to evaluate carbon offset opportunities and possibly engage in a carbon trading system. The building of a platform and infrastructure, as well as the capacity for producers to meet the information needs of the protocols is instrumental in moving forward.

3.2.5 Livestock Management Summary

The livestock management section of this report details potential reductions from 1) beef and dairy cattle emissions reductions, 2) farm energy efficiency, 3) swine reductions, and 4) improved manure management. The following summary covers opportunities and constraints, total theoretical reduction potential, impact of the gaps/constraints on the reduction potential and key messages across these four opportunity areas.

3.2.5.1 Summary of Findings

Beef and dairy cattle emissions reductions are focused mainly on enteric CH_4 reductions, which can be achieved through the use of various nutritional and genetic/cattle management strategies, including: 1) reducing the days on feed (beef); 2) reducing the age to harvest (beef); 3) adding feed supplements (edible oils) to the diet; 4) selecting beef for low residual feed intake (RFI); 5) ration manipulation (ionophores); and 6) reducing replacement heifers. Many of these strategies also reduce manure production, leading to further GHG emission reductions. However, additional research is needed on 1) the combined effects of dietary changes on enteric and stored manure emissions and 2) the impacts of ration manipulation on forage quality. Furthermore, appropriate support infrastructure (i.e. data management and collection systems) and pilot studies in Alberta would be beneficial.

Farm energy efficiency involves improving efficiency and energy conservation in poultry, swine and dairy operations in order to save costs, improve profitability and reduce GHG emissions. Under the Growing Forward Initiative Alberta Agriculture and Rural Development (ARD) is currently running an on-farm energy management program to help improve energy efficiency on agricultural operations. The program has three components: On-Farm Energy Assessments, Energy Efficiency Retrofits and Energy Efficiency Construction. However, there is a lack of available information on the potential cost savings of energy efficiency improvements amongst operators and a decision tool on how to prioritize decision-making.

Since 2001 the pork industry has experienced significant decline. As a result, total GHG emissions have also decreased. Nevertheless, there are still opportunities to decrease emissions from swine. Opportunities that were looked at in this report include: 1) increasing feed conversion efficiency (10%) and 2) decreasing crude protein in feed (15%). The reduction potential of increased feed conversion efficiency on a per operation basis is small and as a result, projects need to be aggregated. Furthermore, tight cost margins and data gaps present challenges to project realization. Pilot demonstrations, incentive programs and data management systems may help address some of these challenges.

Livestock manure produces N_2O and CH_4 emissions during storage, treatment and application. Improved manure management practices aim to reduce these emissions by decreasing the amount of time the manure is stored and by maximizing plant uptake of manure-derived N. Reductions from manure emissions can be achieved using the following improved manure management practices: 1) changing the timing/frequency of emptying (switching from fall to spring); 2) changing the timing of manure application (switching to spring and summer); and 3) changing bedding type. Additional research is needed to refine the emissions reductions potential, and also to quantify the emissions reductions from changing bedding type. Further, a programmatic approach and streamlined data management systems are needed to enhance adoption of improved manure management practices.

The following tables summarize the opportunities and constraints for each of the livestock management reduction opportunities. The tables are broken down into three categories: inputs, activity and outputs; and cover science, technology, markets and policy. The input columns refer to the inputs needed to accomplish the activity/process (i.e. beef cattle emissions reductions). The activity columns refer to the change in practice itself (i.e. adding edible oils, reducing time on feed, etc.). The output columns refer to the product (i.e. beef, milk, pork).

The tables are also color coded. Red indicates an area where there are no issues or there is no opportunity for investment. Yellow represents an area with some potential; however, at present this area is not a priority, and areas shaded in green highlight the best opportunities for investment.

Table 14 – Opportunities and Constraints for the Beef Cattle Sector

	Inputs	Activity	Outputs
Science	No issues.	Research is needed on the combined effect of dietary changes on enteric and manure CH_4 emissions.	Illustrating the quality and synergistic co-benefits of the output.
Technology	No issues.	Data collection and data gaps will need to be identified to support GHG calculations and promote practice change. Supporting infrastructure and platforms for aggregating multiple operations are needed. Lack of blood tests for RFI. Need for an integrated trait index (RFI).	No issues.
Markets	High cost of oils/lipids. Availability of feed supplements.	Market acceptance of the practicality of data management requirements needs to be demonstrated and costs-benefits assessed. More affordable methods of testing bulls for RFI are needed.	Potential impacts on the quality of the beef – positive or negative.
Policy	No issues.	Enforcement of tracking dates of birth. Final approval of RFI protocol pending.	No issues.

Table 15 – Opportunities and Constraints for the Dairy Cattle Sector

	Inputs	Activity	Outputs
Science	The effect of varying supplemental lipids and ionophores on enteric CH_4 needs refinement.	Support for meta-analysis of lipid and ionophore research; increased forage quality work.	Upgrade existing dairy protocol with new synthesized science.
Technology	No Issues.	Support expansion and continuation of the ADFI Dairy Pilot in Alberta (ends 2012); this will provide valuable insight for GHG data platforms and aggregation mechanisms.	Move to a full programmatic approach in implementing dairy GHG reductions in Alberta; building on recommendations from pilot.
Markets	No Issues.	Integration of Energy Efficiency Protocol with Dairy Protocol implementation for greater emissions reductions.	Systematic assessment of potential GHG reductions for dairies (both energy and biologically based).
Policy	No Issues.	Development of integrated data management and aggregation platforms; methods approved by ARD/AEW.	Streamlined implementation resulting in reduced transaction costs.

Table 16 - Opportunities and Constraints for Farm Energy Efficiency

	Inputs	Activity/Process	Outputs
Science	No Issues.	Build a database of energy usage data and farm production data to improve energy efficiency on-farms.	Better information to support cost-benefit information and base energy data; identify and target companion funding programs.
Technology	Agricultural Energy Management Plans.	Build decision support tools for farmers that will use existing programming for farm energy audits.	Recommended energy efficiency and renewable energy measures, with payback times.
Markets	No Issues.	Small tonnage from each farm requires the development of a platform to implement the Energy Efficiency Protocol across a large number of farms; can adapt similar programs being built for Oil and Gas Installations.	Can connect energy efficiency projects with available On-Farm Energy Management Programs under Growing Forward.
Policy	Reticence of Alberta farmers to engage in On-Farm Energy programs since 2007.	Link to ARD's On-Farm Energy Footprint Calculator developed by Don O'Connor to broaden the Energy Efficiency quantification protocol in Alberta.	Incentives to assist farmers in implementing their choices.

Table 17 – Opportunities and Constraints for the Swine Sector

	Inputs	Activity/Process	Outputs
Science	No Issues.	No Issues.	No Issues.
Technology	AgCert activities demonstrated that pork producers will engage.	A pork pilot to identify data gaps, find solutions and develop recommendations to build the needed infrastructure and platforms to aggregate GHG reductions across Alberta pork operations.	Opportunities to streamline implementation of practice changes to reduce GHGs; increase capacity of pork producers to respond.
Markets	Barriers to adopting GHG reducing practices are largely financial.	Pilots to identify opportunities to streamline implementation of the aggregation platform; identify synergies with Energy Efficiency Protocol.	Reduced transaction costs result in greater returns to pork producers; opportunity to co-implement energy efficiency actions for greater returns.
Policy	No Issues.	Development of integrated data management and aggregation platforms for Energy Efficiency and Pork protocols; methods approved by ARD/AEW.	Streamlined implementation resulting in reduced transaction costs.

Table 18 – Opportunities and Constraints for Improved Manure Management

	Inputs	Activity/Process	Outputs
Science	Research on GHG emissions from applying varying forms of manure to land and CH_4 emissions from manure storages under varying conditions.	Develop BMPs to further reduce GHG emissions from land application of manure and CH_4 emissions from storage.	Refined estimates incorporated into Pork and Dairy protocols; upstream emission reduction opportunities incorporated into Anaerobic Digestion protocol.
Technology	No Issues.	Demonstrate the data management and aggregation platforms as part of the Pork and Dairy pilots.	Streamlined implementation of mitigation strategies to reduce emissions.
Markets	Financial barriers to adoption.	No Issues.	No Issues.
Policy	No Issues.	Incentive programs to increase adoption of improved manure management practices; regional anaerobic digesters.	Build synergistic programming with the Alberta Bioenergy Program.

3.2.5.2 Total Theoretical Reduction Potential

Table 19 – Total Theoretical Reduction Potential for Livestock Management

	Opportunity Area	Impact (Mt CO_2e/yr)	Verifiability
Beef and Dairy Cattle Reductions	Reduced Days on Feed	0.13	Modelled
	Reduced Age to Harvest	3.34	Modelled
	Feed Supplement – Edible Oils	0.43	Programmatic Estimation
	Residual Feed Intake	0.056	Programmatic Estimation
	Ration Manipulation (ionophores)	0.064	Modelled
	Reducing Replacement Heifers (30%)	0.072	Modelled
	Total	**4.092**	
Farm Energy Efficiency	Poultry	0.064	Modelled
	Swine	0.072	Modelled
	Dairy	0.005	Modelled
	Total	**0.141**	
Swine Reductions	Increased Feed Conversion Efficiency (10%)	0.02	Modelled
	Decreased Crude Protein in the Feed (15%)	0.09	Modelled
	Total	**0.11**	
Improved Manure Management	Time/Frequency of Emptying – Switching from Fall to Spring	0.062 0.054	Modelled
	Timing of Manure Application – Switch to spring and summer	0.089 0.060	Modelled
	Bedding Type	Unquantified	N/A
	Total	**0.265**	
Livestock Management Overall Total		**4.608**	

3.2.5.3 Impact of the Gaps/Constraints on the Reduction Potential

There are a number of constraints to achieving high potentials in beef and dairy GHG mitigation. In beef, not all breeds and types of cattle will be able to shorten their lifespans since cattle differ in how quickly they fill out their frames. Some types need more time to reach market quality (as indicated by the size of the striploin steak). Further, the current test for selecting for more genetically efficient cattle is based on phenotypic selection of more efficient seedstock/bulls. The investment to test the bulls for lower residual feed intake (RFI) is in the $100 to $150 range and may deter cow-calf operators from engaging in the technology, particularly when beef margins are so low. A blood test is under development at the University of Alberta but is unavailable at this time. Further, feeding cattle ionophores, beta-antagonists or halogenated CH_4 analogues may not fit into the economics of the feedlot or dairy operation, depending on the size. Some of these compounds need to be cycled in the feed for dairy since rumen microbes can habituate and the additives become ineffective for a short time. Lastly, feeding edible oils only becomes economical at about half the price of oil on the market today. The benefits of feeding edible oils to beef not only include reduced CH_4 emissions, there are increases in conjugated linolenic and linoleic fatty acids in the meat (omega 3 and 6 essential oils in human diets), resulting in a product called high CLA beef. Unfortunately, this market is taking time to develop because of the relatively high demand for oils and oilseeds for other purposes.

In the dairy sector, Dyer et al. (2008) reported that efficiency gains are stabilizing, and further activities to increase milk production efficiency will have increasing marginal costs of adoption. Between 1981 and 2001, the dairy cattle population in Canada dropped by 57% (Dyer et al., 2008). This was made possible by increasing the amount of milk produced per cow. These improvements resulted in a corresponding 49% decrease in GHGs per litre of milk produced during the same period (Dyer et al., 2008). It's recognized that financial barriers exist to investing in technologies, barn or field equipment that may increase milk production.

The measuring, monitoring and verification procedures for these kinds of mitigation activities are clearly laid out in the Alberta protocols. The data requirements needed to support mitigation that is real, measurable and verifiable for these activities is significant, requiring for tracking of diets and rations fed to each class of animal or by animal type in their groupings, typically signed off by the nutritionist/veterinarian consulting to the animal operation. Aggregation of farms will need to occur in order to increase viability and implementation. The modeling done by Agriculture and Agri-Food Canada on reducing protein content of rations, can be implemented under the requirements and procedures of the livestock protocols to track diets fed to animals, as well as records of manure application to fields, and so on. The protocols lay out these requirements in detail and are currently being revised to be more explicit, a process that will aid verification.

In swine operations, there are a number of constraints to achieving the full reduction potential reported. The economic benefits of hog production are often threatened by the volatility in oil seed and grain prices. For producers prescribing to a least cost ration formulation, this market volatility may ability to follow a ration formula to reduce related GHG emissions. Further, reducing protein content of diets may be perceived as too risky to hog, dairy or poultry producers, jeopardizing production gains and possibly fertility rates. Also, balancing the protein content with supplemental amino acids is likely not economic for most operations.

Although the manure strategies discussed do not require large capital investments, multiple annual applications of manure require time, labour, and scheduling that may not fit into the operational aspects of the hog farms in question. This limits the likelihood of producers adopting this strategy. Likelihood of adoption is also dependent on cost factors, weather, equipment and perceived risk by producers. In 2003, one company in Alberta was able to contract over 150 hog operations to re-schedule their emptying and spreading of manure to capitalize on pre-compliance carbon credit activities. It has therefore been demonstrated that if it makes sense for producers to engage, they will engage.

3.2.5.4 Key Messages

The main messages for this opportunity are:

- Production efficiencies can reduce emissions on an intensity basis per kg of beef, pork or litre of fat corrected milk produced. An increase in output while holding GHGs steady can result in a reduction in the way the metrics/protocols calculate the outcome.
- Individual animal performance management is evolving, which can result in further reductions; however, in some cases more cost-effective methods are needed (i.e. testing bulls for RFI). Further, integrated feed management software with feeding systems that capture data electronically will need to be implemented in order to improve data quality.
- The maintenance costs of idling cattle (backgrounders, replacement heifers) are large from both an environmental and economic point of view. This presents a significant opportunity to reduce costs and reduce emissions.
- Animal tracking, data management and corresponding acceptance of these practices poses a challenge for implementation; there is a need for an integrated approach and an information platform to aggregate the needed data to calculate emission reductions from the mitigation strategies in the protocol and a framework that strives to improve acceptance and uptake by producers.

- There are more opportunities for reductions with liquid manure than solid manure; more research is needed for application techniques and upstream manure storage and handling emissions.
- Feed management is very important, particularly for ruminants; some further synthesis of the science on lipid supplementation and ionophore action is needed.
- The ADFI–DFC-AB Dairy Pilot in Alberta has demonstrated the value of working strategically with key partners in the dairy sector to test run implementation of the Alberta protocol, engage producers and build capacity in understanding GHG reduction pathways.
- Despite the On-Farm Energy programming from 2007 to now, producers are reluctant to be engaged, even if 100% of the audit costs are covered.
- Time, labor, costs of implementing retrofits or renewable/energy efficiency measures and availability of technologies have all been issues in on farm energy efficiency.
- There is an opportunity to build a co-ordinated effort, with Dairy and Swine, as well as feedlot operations, to co-implement energy efficiency protocol strategies with pilots in other areas, and increase availability and knowledge of Growing Forward programming dollars.

3.3. Transportation

3.3.1 Intermodal Freight Shift

Agricultural and forestry based biological products are generally bulky, heavy and difficult to transport by road. At present, intermodal freight shifting - combining off-road, over-the-road and rail shipment of biological products - is largely limited to bulk grain transportation to ports and shipment of finished lumber, pulp and newsprint to United States markets or ports. Moving the availability of rail freight loading and handling closer to the location of biological production may facilitate greater uptake of modal freight switching for biological products.

3.3.1.1 Literature Review

Science

Intermodal freight shift is seen to have the potential to reduce GHG emissions since several modes of transport are employed, and different modes of transport emit varying amounts of GHGs (Bauer et al., 2009). Until recently, most service network models have been used to plan distance and timing of freight transport, but have not been used to account for the environmental costs (such as GHG emissions). At present, it is difficult to quantify emission reductions associated with intermodal freight shift in Alberta because the data required to calculate GHG emissions from rail transport is unavailable. As well, there is currently no approved quantification protocol for the province.

Technology (Applications/Demonstrations)

Caris et al. (2008), reviewed the problems in modal freight switching by focusing on four "operators" in the intermodal transportation chain - the drayage[3] operator, the terminal operator, the network operator and the intermodal operator. The strength of the linkage to, and control by the intermodal system increases for operators closer to the center of the intermodal system.

In their review they addressed three scales of thought:

- Strategic - focused on policy and infrastructure considerations; for example, intermodal terminal locations and containerization of bulk commodities to facilitate modal shifts.
- Tactical - addressed how modal shifts could be implemented and the role of various goods transport players in implementing modal shift.
- Operational - addressed factors like scheduling and integration of operators.

The authors concluded that drayage operations constitute a large part of the intermodal system and that little research attention has been given to them. For example, freight consolidation for intermodal shift depends on efficient drayage and little attention has been given to how freight bundling and drayage might be integrated.

The technical aspects of optimizing intermodal freight shifts have been addressed conceptually and by model development. Decision support tools can be used to help policy analysts and decision makers evaluate the environmental, economic and energy impacts of mode shifts, and can inform mode selection, policies and investments (Hawker et al., 2010). Decision support tools are invaluable in intermodal freight shift, in that optimizing efficiencies not only produces economic savings, but can lead directly to reductions in GHG emissions.

One such tool is the EMOLITE model, which is used to determine the optimal location of intermodal terminals in Europe (Moreira et al., 1998). The EMOLITE system uses operational modeling to optimize transportation costs, fuel consumption and emissions in the selection of freight terminal sites (Moreira et al., 1998). Another type of decision support system is the Geospatial Intermodal Freight Transportation (GIFT) system. GIFT is an integrated model and tool that combines multiple geospatial transportation networks and models of the environmental, energy and economic impacts of different types of vehicles operating in these networks (Hawker et al., 2010). GIFT allows users to understand the possible impacts of transportation policy decisions, including the impact of different vehicles, target reductions in

[3] Drayage is short distance movement of goods as part of a larger integrated transfer of freight.

environmental emissions, and the impact of infrastructure and capital investments (Hawker et al., 2010).

Markets

In 2004, Alberta Transportation performed a review of all marine and intermodal trade conducted by the province (Government of Alberta, 2004). Alberta's 2004 international rail/marine and intermodal imports amounted to $3.71 billion. By value, the most significant rail/marine and intermodal import commodities transported were machinery, iron or steel products, and organic chemicals. The U.S. was the number one country of origin by value, with $2.28 billion or 61% of Alberta's international rail/marine and intermodal import market. Alberta also imports from countries such as China, the United Kingdom, Italy, and Germany to increase the selection of goods in the province.

Alberta exported $15.45 billion of goods by rail/marine and intermodal transport in 2004. By value, the most significant rail/marine and intermodal export commodities transported were mineral fuels, plastics, and wood, accounting for 84% of the total $15.45 billion. The U.S. was the number one country of destination by value, with $9.93 billion or 64% of Alberta's international rail/marine and intermodal export market. Countries such as China, Japan, South Korea, and Mexico helped to diversify Alberta's rail/marine and intermodal exports.

Internationally, there is continued interest in intermodal transport; however, varying degrees of inefficiency exist that lead to rising costs and reductions in quality of service. Limiting factors include the fragmentation of services that do not allow for standardization and reduction of distribution costs; lack of interoperability as applies to software, brokers, shippers, transporters, etc.; inability to interconnect different modes such as infrastructure and transport equipment; operations and infrastructure use; and services and regulations aimed at individual modes (Vassallo, 2007).

Policy

Recognizing the challenges and higher costs associated with non-standardized intermodal systems, the European Commission put forward a system of integrated infrastructure to create a network of infrastructure and transfer points that are consistent and allow various modes to interoperate and interconnect (Vassallo, 2007). Integration between modes should occur at the level of infrastructure and hardware, operations and services, and regulatory conditions.

Alberta is enhancing its section of the Canada, America and Mexico (CANAMEX) corridor, which links the three countries and stretches about 6,000 km from Anchorage, Alaska to Mexico City, Mexico. The goals of the CANAMEX corridor are to improve access for the north-south flow of goods and people, to increase transport productivity and reduce transport costs, to promote a seamless and efficient inter-modal transport system, and to reduce administration and enforcement costs through harmonized regulations (Government of Alberta, 2011).

Between 2003 and 2004, Transport Canada conducted interviews with representatives of provincial and municipal governments and a wide range of stakeholders to gain a better understanding of intermodal freight issues (2004). The absence of freight movement data in Canada such as highway freight flow, urban freight activity, private trucking and comprehensive air cargo data were identified as issues by the majority of those interviewed. The key message during the interviews was that Intelligent Transport Systems (ITS) are essential in cases where the only realistic option is squeezing the maximum efficiency out of existing systems. This was one area where stakeholders suggested that public sector support and strategic investment could play an important part. Stakeholders also suggested that ITS uptake among smaller players might be constrained by financial considerations, and that this also was one area where public sector support would be helpful.

3.3.1.2 Greenhouse Gas Emission Reduction Potential

Magnitude and Verifiability

Table 20 – Emission Reduction Magnitude and Verifiability for Intermodal Freight Switch

Opportunity Area	Theoretical Provincial Impact (Mt CO_2e/yr)	Verifiability
Intermodal Freight Switch	Unquantified[1]	Modelled

[1] There is significant use of modal freight for bulk commodities at present; however, it is difficult to identify new opportunities for biological products.

3.3.1.3 Gaps and Constraints

Science, Data and Information Gaps: At this time, it is not possible to quantify GHG emissions or estimates of any offsets that may result from the use of intermodal freight shift over single mode transport. This is because the data required to produce reliable estimates of GHG emissions resulting from rail operations is not available. The absence of freight movement data in Canada such as highway freight flow, urban freight activity, private trucking and comprehensive air cargo data were identified by stakeholders as issues reducing efficiency. Little attention has been given to how freight bundling and drayage might be integrated. Drayage operations constitute a large part of the intermodal system and efforts to determine methods of optimum freight consolidation can improve efficiencies in drayage.

Policy Gaps: Currently, there is no approved protocol in Alberta describing the methods to be used to calculate GHG emission reductions from shifting baseline truck freight transport to project rail freight transport.

Technology Gaps: Intermodal freight shift requires collaboration among many operators. Currently available services in intermodal freight shift are fragmented due to a lack of standardization of the transport chains. This is preventing efficiency of the distribution costs.

Each mode is owned, financed, and managed independently. There needs to be more collaboration in the industry with consideration given to infrastructure and transport equipment, operations and infrastructure use, information and communication technology and the sharing of information among modes, and services and regulations aimed at individual modes.

Demonstration Gaps: Efficiency and standardization within intermodal transport chains have been identified as key to successful execution. Once in place, these efficiencies are expected to increase profits and reduce GHG emissions. An assessment of Alberta's intermodal freight system has not been undertaken since 2003. At that time many issues and constraints were identified (see Other Gaps below). It is unknown what efforts have been taken to address these issues, or whether the industry has experienced improvements as a result of standardization since the study was completed.

Metric Gaps: See Policy Gaps (above).

Other Gaps: In 2004, Alberta Transportation published a study of Alberta's Intermodal Freight System, which identified a number of issues and constraints. It is unknown if any of these issues have been resolved. The issues were:

- Terminal Access: lack of terminal access outside of Edmonton and Calgary; limited hours of operation;
- Congestion: congestion at rail terminals resulting in extra transit time and costs;
- Volume/Capacity: road capacity and access issues; lack of intermodal railcars and temperature-controlled equipment; lack of terminal capacity for loading/unloading at inland intermodal terminals;
- Container Handling: lack of truck drivers and equipment; lack of container handling equipment and empty lifting equipment at Edmonton intermodal terminals;
- Customs, Security: US Customs and documentation requirements for vessel ports of call; and
- Other Issues:
    - labour issues and a shortage of drivers in the trucking industry;
    - inadequate rail car equipment availability, and inadequate container availability;
    - reliability and lack of temperature-controlled equipment and services (rail);
    - rail demurrage charges at intermodal terminals;
    - customer service of railways;
    - lack of priority by railways for Alberta inbound cargo;
    - longer transit times by rail than road;
    - high fuel taxes;
    - lack of communication and coordination between system service providers;
    - challenges to full participation from rail due to infrastructure availability;

- high costs associated with increasing rail infrastructure, both for tracks and transfer stations; and
- the direction of shipment and the industrial sector (e.g. forestry vs. agriculture vs. finished goods) may determine applicability of rail shipment.

3.3.1.4 Opportunities to Address the Gaps/Constraints Identified

At this time the information needed to determine GHG emissions from rail transport is not available. Also, there is currently no provincial protocol in place that provides guidance on determining potential offsets that would result from utilizing intermodal freight shift. There is also a need for gathering and disseminating highway, off-highway, and urban freight activity data. Collaboration and open communication between operators in both the private and government sectors has repeatedly been identified as a key factor in the successful and efficient application of intermodal transport. Cooperation between stakeholders is likely to identify opportunities to address many of the current constraints limiting intermodal freight shift.

3.3.2 Fuel Efficiency

For heavy transport trucks, air quality emission regulations and mandated engine fuel economy changes have had the largest impact on fuel efficiency, and thus GHG emissions, in the transportation sector over the last few decades. However, these regulated changes are slowly realized over vehicle replacement cycles of approximately 10 years. Additional technologies for increasing fuel efficiency for transportation of biological goods generally falls into four categories – aerodynamics, driver training, low rolling resistance tires and switching to automatic transmission. Individually each of these changes are incremental, however when large distances are traveled the result is a quantifiable reduction in GHG emissions. With proven technologies available, application and implementation of fuel efficiency technologies is the barrier to achieving GHG reduction opportunities.

3.3.2.1 Literature Review

Science

Due primarily to the critical economic importance of the transportation industry in North America, considerable information on transportation fuel efficiency technology exists. More recently, the large contribution of GHG emissions attributable to transportation have facilitated even more research and study on efficiency (e.g., Mui et al., 2012; Cooper et al., 2009). This somewhat overwhelming wealth of available data includes well supported programs to test and quantify technologies and strategies that purport to increase transportation fuel efficiency. The most notable of these programs is the US Environmental Protection Agency (EPA) SmartWay Technology Program. The SmartWay Program,

> "reviews strategies and verifies the performance of vehicles, technologies and equipment that have the potential to reduce greenhouse gases and other air pollutants from freight transport. The program establishes credible performance criteria and reviews test data to ensure that vehicles, equipment and technologies will help fleets improve their efficiency and reduce emissions (United States Environmental Protection Agency, 2011)."

The Canadian version of the US SmartWay Program, SMARTWAY Canada, is set to begin in early 2012 and will offer services in both official languages[4]. Companies that partner with the SmartWay Program can market technologies or services as being SmartWay tested and approved. For example SmartTruck[5] offers aerodynamic modifications including under-tray systems and top and side fairings that are SmartWay tested and verified to provide a 5% increase in fuel efficiency. Similarly, a large number of low rolling resistance tires have been verified to yield up to a 3% reduction in fuel use (United States Environmental Protection Agency, 2012).

Driver training is a known, but difficult to quantify fuel efficiency opportunity. Driver training is one of the important factors identified in the Natural Resources Canada (NRC) report titled *Fuel Efficiency Benchmarking in Canada's Trucking Industry*[6]. The NRC has developed fuel efficiency training as part of its FleetSmart — ecoEnergy program. Driver training for improved fuel efficiency is well established and is provided locally by most professional organizations (e.g., the Alberta Motor Transport Association[7]). The critical elements of driver training for fuel efficiency include speed, route planning, and efficient vehicle operation. Several technological aids that may be employed in addition to driver training are available including speed limiters and other engine performance modifications, fuel economy display systems, and monitoring technologies or computer downloads.

The switch to automatic transmissions has not shown consistent fuel efficiency gains (Carme, 2005). A long term multi-driver comparison of manual and automatic transmissions conducted by Surcel (2008a) found a 2.93% reduction in overall fuel consumption with a slight increase in fuel consumption for log trucks off-highway and a slight reduction in fuel consumption for chip trucks on-highway when using automatic transmissions.

Technology (Applications/Demonstrations)

Numerous reports and technology demonstrations are available for application of aerodynamic and low rolling resistance tire technology (e.g., Surcel, 2008b; Bradley, 2003; Michaelson, 2007). Though the technology is proven, quantification of fuel and GHG reductions attributable to the

[4] http://oee.nrcan.gc.ca/transportation/business/fleetsmart/2696
[5] http://smarttrucksystems.com/
[6] http://oee.nrcan.gc.ca/transportation/business/reports/884
[7] http://www.amta.ca/index.html

application of the technology remains a challenge due to the relatively small impact achieved at the individual truck level. On a small scale (individual project) basis, no acceptable methodology for establishing baseline fuel efficiency exists in Alberta. A transportation fuel efficiency protocol is under development at this time for the province. Once completed (late 2012 or early 2013, personal communication) the protocol will provide methods for establishing a baseline fuel efficiency and for quantifying project emissions.

At the provincial scale, GHG emission mitigation through the application of fuel efficiency technology can be estimated using published transportation sector emissions and SmartWay verified improvements.

Markets

The proven nature of fuel efficiency technology virtually guarantees a cost savings through reduced fuel purchase requirements; however, the critical factor for technology implementation is the rate of return on investment. As fuel costs continue to increase it is likely that use of fuel efficiency technology will also increase, but the rate of change will be moderated by a relatively long vehicle replacement (turnover) rate of approximately 10 years. Some technologies (e.g., SmartTruck) are applied to the trailer and will have different replacement cycles; however, the rate of return on investment remains the market driver.

Policy

The province of Alberta supports several programs to improve transportation efficiency and encourage GHG emission reductions. A memorandum of understanding (MOU) is in place between Alberta Environment and Water (AEW formerly AENV), Alberta Transportation (TRANS) and the Alberta Motor Transport Association (AMTA) to facilitate actions to reduce GHG emissions and help Alberta meet the targets set out in the 2008 Climate Change Strategy and the Provincial Energy Strategy[8]. Under this MOU, the province agrees to work with, consult and support the AMTA to improve fuel efficiency and reduce GHG's. Other provincially supported programs include those managed by Climate Change Central (C3)[9]. Specifically, the Trucks of Tomorrow Program[10] offered rebates for commercial vehicles that installed aerodynamic devices or other fuel saving technologies.

No policy barrier exists for the deployment of fuel efficiency technologies, when done for cost/fuel savings or for other related business purposes. However, ability to generate and market transportation related carbon offsets is limited by the lack of approved protocols and higher verification and baseline setting requirements now in place for the Alberta Offset System.

[8] http://www.transportation.alberta.ca/Content/docType235/Production/3PartyMOUwithAMTA.pdf
[9] http://www.climatechangecentral.com/
[10] http://www.trucksoftomorrow.com/pages/trucking/index.php

3.3.2.2 Greenhouse Gas Emission Reduction Potential

Magnitude and Verifiability

Table 21 – Emission Reduction Magnitude and Verifiability for Fuel Efficiency

Opportunity Area	Theoretical Provincial Impact (Mt CO_2e/yr)	Verifiability
Fuel Efficiency	0.75[1]	Programmatic Estimation

[1] Heavy trucks only, aerodynamics, driver training, low rolling resistance tires – used ⅓ of ∑ AB heavy truck Emissions.

Justification

The estimate of the GHG reduction potential from increased fuel efficiency in the transportation of biological goods was based on the most recent transportation emission values for Alberta (Mt CO_2e/yr from Natural Resources Canada, transportation historical database accessed November 2011). Potential emission reductions from individual technologies are primarily from SmartWay program test results with the most conservative reported value selected for use in the estimation. The following sources and assumptions were used:

- Included aerodynamic improvement at a 4.5% reduction potential (cab and tank fairings, trailer skirts, boat-tails), low rolling resistance tires at a 4.0% reduction potential, and engine sizing at a 5.0% reduction potential. Note: aerodynamic improvement has been shown to reduce GHG emissions by 9%; however, to be conservative only 50% of this potential or 4.5% was accounted for.
- The reduction potential was estimated as 50% attainment of low rolling resistance tires and aerodynamic improvement, 30% attainment of engine "right-sizing" and full attainment of driver improvement. No effect was given to transmission changes.
- The reduction potential was applied to $^1/_3$ of Class 8 truck emissions for AB to reflect transportation of biological products. The $^1/_3$ of emissions was based on the estimate that Class 8 log trucks generated $^1/_6$ of AB Class 8 emissions (FERIC data for log trucks compared to NIR). The $^1/_6$ was doubled to include Class 8 trucks used for transportation in the agriculture sector.

3.3.2.3 Gaps and Constraints

Science, Data and Information Gaps: Dispersed data sets and the complexity of reduction have proven to be problematic. The expected incremental improvements realized with the application of fuel efficiency technologies require detailed monitoring and are subject to reversal due to variable conditions including terrain, driver skill/training, climate, and road and traffic conditions.

Policy Gaps: Policy gaps in fuel efficiency requirements, vehicle performance/maintenance, and support for other initiatives (market-based incentives to promote efficient vehicle technology, etc.) currently exist. Current programs are expiring (e.g., Trucks of Tomorrow Program) without a commitment to additional funding or an extension to program timelines. As well, there is difficulty in building alignment between policy and vehicle manufacturers (e.g. engine standards, aerodynamic improvements, etc.)

Technology Gaps: No significant technology gaps exist. Research is focused on improvements to existing technologies. However, the effect of the automatic transmission on fuel efficiency is inconsistent.

Demonstration Gaps: It is challenging to apply technology across commodities and sectors (e.g. drag reduction panels between wheels on trailers may not be as easily installed on some styles of trailers). The lack of real world experience also presents challenges. Though proven, the technologies have not been field tested under sufficiently diverse conditions to permit accurate estimations of GHG reductions. Driver training can result in significant fuel savings (up to 20%) but may not yield consistent results. Implementation of driver training in conjunction with other technologies to monitor or change behaviour is required.

Metric Gaps: The dispersed nature of the offset project opportunities makes implementation and monitoring difficult. Protocols for transportation efficiency are currently under development for the Alberta Offset System, and methods for offset aggregation will be required.

Other Gaps: None identified.

3.3.2.4 Opportunities to Address the Gaps/Constraints Identified

The greatest challenge in addressing the identified gaps is demonstrating fuel efficiency gains in an Alberta context. The small incremental changes in efficiency achieved with fuel efficiency technology require that studies be undertaken with large sample sizes over long periods of time. The memorandum of understanding (MOU) that is in place between AEW, TRANS and the AMTA to facilitate actions to reduce GHG emissions offers the opportunity to focus research and real world studies to fill the gaps. Many of the technologies and actions discussed above are explicitly included in the scope of the MOU. In addition, the MOU brings together the relevant government agencies and industry representatives required for:

- Better alignment of policy and technology;
- Initiating comprehensive studies of multiple technologies; and

- Focussing initiatives on proven technology and marketing these technologies.

The most significant constraint for offset project developers is the lack of approved Alberta Offset System protocols for transportation efficiency. Protocols are currently being developed.

3.3.3 Fleet Management

Fleet management refers to a number of technologies and actions undertaken at the fleet level to reduce GHG emissions by improving transportation efficiency. These technologies and actions are not exclusive to the transportation of biological products. Technologies and actions include continuous loop hauling, multi-function trailers, improved route planning, and reduced idling. Though not consistently applied, other aspects of fleet management including the right sized vehicles and vehicle tracking are now standard in the transportation industry and are not included in this report. As with other transportation technologies or actions taken to improve fuel efficiency (see section 3.3.2), the results of improved fleet management are often small and incremental when viewed at the individual truck level, but may be substantial across larger fleets and/or distances.

Due to the effects of rising diesel fuel prices on the economics of the transportation industry, most operations have already embraced some form of fleet management (i.e., rising costs is the driver of transportation efficiency).

3.3.3.1 Literature Review

Science

As with fuel efficiency (discussed above in section 3.3.2), the science behind achieving GHG reductions from improved fleet management is proven and well established. A plethora of studies and data to support improved fleet management is available from the United States, Europe and, to a lesser extent, Canada. The foundation for all fleet management improvements is an increase in the amount of freight moved per unit of fuel consumed. Most fleet management projects focus on reducing the amount of distance traveled without a payload (i.e., deadheading or empty return trips), maximizing use of cargo space or increasing cargo capacity, reducing the distance traveled, and reducing the engine run time when not in motion (e.g., reduce idling). However, the gains achieved with improved fleet management are subject to reversal due to uncontrolled factors such as climate, terrain and road network, as well as controlled factors like driver behaviour, and poor project implementation.

Technology (Applications/Demonstrations)

A number of fleet management tools and software packages are commercially available[11]. Many of these packages include sophisticated route planning and vehicle tracking capabilities as well as payload and other logistics management tools. Automated vehicle data systems are also available that can be used to provide vehicle operation data, some in real time, that can be used to improve fleet efficiency by providing information on idling times, as well as load and engine power requirements and driver performance. Specific guidance regarding reduced idling and driver training is included in the NRC Fleetsmart program[12].

Demonstrations of specific fleet management technologies are available. For example, FPInnovations (formerly the Forest Engineering Research Institute of Canada - FERIC) has been studying and promoting the use of multi-function trailers (dual-commodity trailer) since the 1990's (Brown and Michaelsen 2003); including demonstrations in Alberta where substantial GHG reductions have been shown[13].

Markets

Fleet management systems and fleet management training of some type are becoming standard industry practice. As fuel costs continue to increase it is likely that the use of fleet management technology and training will also increase. However, the transportation of biological products does not lend itself to many of the fleet management technologies or techniques described in this report. Transportation of biological products often originates in remote areas (e.g., forestry) and from areas with limited route options (e.g., farms). This negates the advantages of fleet technologies like multi-function or larger trailers, and prevents route modification as well as continuous loop hauling.

Policy

The province of Alberta supports several programs to improve transportation efficiency and encourage GHG emission reductions. A memorandum of understanding (MOU) is in place between Alberta Environment and Water (AEW formerly AENV), Alberta Transportation (TRANS) and the Alberta Motor Transport Association (AMTA) to facilitate actions to reduce GHG emissions and help Alberta meet the targets set out in the 2008 Climate Change Strategy and the Provincial Energy Strategy[14]. Under this MOU, the province agrees to work with, consult and support the AMTA to improve transportation efficiency.

No policy barrier exists for deployment of fleet management technologies or strategies when done for cost/fuel savings or for other related business purposes. However, the ability to generate and market transportation related carbon offsets is limited by the lack of approved

[11] see list at http://www.canadatransportation.com/
[12] http://fleetsmart.nrcan.gc.ca/
[13] http://www.tc.gc.ca/media/documents/programs/fpinnovation-trailers_1.pdf
[14] http://www.transportation.alberta.ca/Content/docType235/Production/3PartyMOUwithAMTA.pdf

protocols and higher verification and baseline setting requirements now in place for the Alberta Offset System. An anti-idling protocol and a transportation efficiency protocol are currently under development for the Alberta Offset System.

3.3.3.2 Greenhouse Gas Emission Reduction Potential

Magnitude and Verifiability

Table 22 – Emission Reduction Magnitude and Verifiability for Fleet Management

Opportunity Area	Theoretical Provincial Impact (Mt CO_2e/yr)	Verifiability
Fleet Management	0.3[1]	Programmatic Estimation

[1] Continuous loop hauling, multi-function trailers, route planning, reduced idling – used ⅓ of ∑ AB heavy truck emissions plus $^1/_{10}$ of ∑ AB medium truck emissions.

Justification

The estimate of the GHG reduction potential from improved fleet management for the transportation of biological goods were based on the most recent transportation emission values for Alberta (Mt CO_2e/yr from Natural Resources Canada, transportation historical database accessed November 2011) and the following assumptions:

- Assumed 15% attainment of continuous loop hauling, 10% attainment of multi-function trailers, 15% attainment of route planning and full attainment of reduced idling.
- The reduction potential was applied to $^1/_3$ of Class 8 and $^1/_{10}$ Medium truck emissions for AB to reflect transportation of biological products. The $^1/_3$ of emissions was based on the estimate that Class 8 log trucks generated $^1/_6$ of AB Class 8 emissions (FERIC data for log trucks compared to NIR). This number was then doubled to include Class 8 trucks used for transportation in the agriculture sector.

3.3.3.3 Gaps and Constraints

Science, Data and Information Gaps: Dispersed data sets and the complexity of reduction have proven to be problematic. The expected incremental improvements realized with the application of fuel efficiency technologies require detailed monitoring and are subject to reversal due to variable conditions including terrain, driver skill/training, climate, and road and traffic conditions.

Policy Gaps: Internal fleet management policies and expectations may differ. There is also difficulty in fleet management control when vehicles (semi-trucks) may be individually owned, while trailers are fleet-owned.

Technology Gaps: No significant technology gaps exist.

Demonstration Gaps: Climate and condition variability may be problematic in that there may be variation in adherence to anti-idling expectations in winter vs. summer. Successful fleet management will rely on implementation and enforcement of maintenance schedules to maximize optimal functions. The lack of real world experience also presents challenges. Though proven, the technologies have not been field tested under sufficiently diverse conditions to permit accurate estimations of GHG reductions.

Metric Gaps: Protocols for transportation efficiency and anti-idling are currently under development for the Alberta Offset System, and methods for offset aggregation will be required.

Other Gaps: None identified.

3.3.3.4 Opportunities to Address the Gaps/Constraints Identified

The greatest challenge in addressing the identified gaps is demonstrating fleet management efficiency gains in an Alberta context. The small incremental changes in efficiency achieved with fleet management technology require that studies be undertaken with large sample sizes over long periods of time. The memorandum of understanding (MOU) that is in place between AEW, TRANS and the AMTA to facilitate actions to reduce GHG emissions offers the opportunity to focus research and real world studies to fill the gaps. Many of the technologies and actions discussed above are explicitly included in the scope of the MOU. In addition, the MOU brings together the relevant government agencies and industry representatives required for:

- Better alignment of policy and technology;
- Initiating comprehensive studies of multiple technologies; and
- Focussing initiatives on proven technology and marketing of these technologies.

The most significant constraint for offset project developers is the lack of approved Alberta Offset System protocols for transportation efficiency and for anti-idling. Protocols are currently being developed.

3.3.4 Load Management

Load management is the modification of freight or cargo, often accompanied by a change in trailer size, to improve transportation efficiency. Load management opportunities include load densification, and haulage efficiency changes that reduce the GHG emissions per unit of transportation service delivered. Generally, the transportation service is measured in tonnes but it may also be measured in the volume of product transported. Load management is best applied where the size or weight of the freight is the factor limiting efficient use of the transport vehicle (i.e., the load is bulking out or the load is overweight).

Examples of load management practices include densification of bulky cargo and drying to reduce weight. Load management typically involves modifications that occur prior to loading and transportation, but may also include modifications that are integrated with loading and transportation. Examples of modifications that occur prior to loading and transportation of biological goods are hay compaction and log drying. An example of an integrated load modification is portable chipping. With portable chipping the logs are chipped and blown directly into waiting trucks (load modification and vehicle loading are a single step).

3.3.4.1 Literature Review

Science

Load management is straightforward and does not require application of complex scientific formulae or models. The benefits of load management are also straightforward and easy to quantify. Projects that increase the density of the freight often see an increase in fuel consumption per truck load; however, through load modification more is transported and fewer trips are required. Thus, load management must be quantified using a measure of productivity. The hay baler is an example of load management that is now standard throughout the agriculture industry. The hay baler produces a compact round or square bale from lose hay or straw. The bales are easy to handle and transportation efficiency is increased further by the use of custom or modified trailers.

Densification of biomass to improve transportation efficiency is of growing interest with studies currently underway (e.g., Agricultural Biomass Research in Ontario[15]) or completed (Sokhansanj & Fenton, 2006). The driver behind much of this research is the increasing use of biomass as a feedstock for biofuel or bioenergy production. This includes products such as switch-grass and crop residues that benefit greatly from densification. Biomass pelletization or briquetting are other examples of densification used to both improve transportation and handling efficiency and for fuel energy efficiency.

[15] http://www.omafra.gov.on.ca/english/engineer/biomass/projects.htm

Technology (Applications/Demonstrations)

The technologies used in load management are generally proven and technology demonstrations are numerous. Any project that wishes to employ a specific technology will be required to quantify the energy used for load modification. This information is lacking in the literature.

Markets

As with other transportation technologies the market is driven by increasing fuel costs and not by GHG offset potential.

Policy

Load management policy is integrated with other transportation efficiency policies. However, load management often involves product specific technologies that are not necessarily considered in government policy other than in general road and transportation safety regulations (e.g., size and weight of trailers, road weight restrictions).

No policy barrier exists for the deployment of load management technologies or strategies when completed for cost/fuel savings or for other related business purposes. However, the ability to generate market transportation related carbon offsets is limited by the lack of approved protocols and higher verification and baseline setting requirements now in place for the Alberta Offset System. A transportation efficiency protocol is currently under development for the Alberta Offset System.

3.3.4.2 Greenhouse Gas Emission Reduction Potential

Magnitude and Verifiability

Table 23 – Emission Reduction Magnitude and Verifiability for Transportation Efficiency

Opportunity Area	Theoretical Provincial Impact (Mt CO_2e/yr)	Verifiability
Load Management	0.3[1]	Programmatic Estimation/ Modelled

[1] Load densification, haulage efficiency – used ⅓ of the ∑ of AB Heavy Truck Emissions plus $^{1}/_{10}$ of the ∑ of AB Medium Truck Emissions.

Justification

The estimate of the GHG reduction potential from improved efficiency in the transportation of biological goods was based on the most recent transportation emission values for Alberta (Mt CO_2e/yr from Natural Resources Canada, transportation historical database accessed November

2011). Potential emission reductions from individual technologies are from reported test results with the most conservative value selected. The following sources and assumptions were used:

- Load Management emission reductions were based on load densification - including hay compression (10%), log drying (10%), resizing trailers (5%), and portable chipping.
    - The portable chipping assumption was based on Daishowa-Marubeni International Ltd. (DMI) - Peace River Pulp Division, which recently completed a direct emission reduction offset project that was scaled up to the other Kraft pulp mills in Alberta that may apply the technology.
- Assumed 15% attainment in forestry and agriculture.
- The reduction potential was applied to 1/3 of Class 8 and 1/10 of Medium truck emissions for AB to reflect the transportation of biological products.

3.3.4.3 Gaps and Constraints

Science, Data and Information Gaps: Data on the energy required for load modification (e.g., densification) is generally lacking and is required for project implementation. Project specific monitoring will be required.

Policy Gaps: None identified.

Technology Gaps: None identified.

Demonstration Gaps: The energy required for load management, including densification is not consistently provided and is required.

Metric Gaps: Protocols for transportation efficiency are currently under development for the Alberta Offset System and methods for offset aggregation will be required.

Other Gaps: None identified.

3.3.4.4 Opportunities to Address the Gaps/Constraints Identified

The critical gap for load management projects is the quantification of the energy required to modify the load. Energy used to modify the load can be monitored at the project level and does not present a significant impediment to project development. However, in the case of biomass densification projects, the energy for densification may exceed the energy saved in fuel from transportation efficiencies. Increased energy consumption from load modification may be considered acceptable due to improved economic benefits despite the potential elimination of GHG offset potential.

3.3.5 Fuel Switching

Fuel switching opportunities include complete or partial switching to lower GHG emitting fuels. Current opportunities for fuel switching include moving to compressed natural gas (CNG) or liquefied natural gas (LNG). Biofuel opportunities (biodiesel) are not included in this section.

3.3.5.1 Literature Review

Science

For most medium and light duty applications of fuel switching, the switch from diesel or gasoline to CNG is possible with little, if any, change in productivity. For heavy duty applications, because CNG is a less energy dense fuel, it is often required that engine size and capacity be increased to maintain the same horsepower. Alternatively, a switch to LNG results in a performance closer to diesel fuel. A variety of engine options exist with support and calibration services provided by manufacturers (e.g., Westport Innovations[16]).

Two models are widely used and accepted for predicting well to wheel GHG emissions for different transportation fuels. These are the GHGenius model[17] and the GREET model[18]. In Alberta the GHGenius model has been accepted for use in GHG projects.

Though several pilot projects have been undertaken for fuel switching across the transportation industry, the only large and long term project was conducted by the United Parcel Service (UPS). UPS has been testing CNG vehicles since the late 1980s, and began a large-scale pilot program in 1996. The US Department of Energy released a final report on these first generation CNG delivery trucks operated by UPS and found that carbon emissions were approximately 7% lower than use of comparable diesel fuelled trucks; however, modifications were required to overcome the lower energy efficiency and horsepower (United Parcel Service, 2002). The expected emission reductions from newer generation engine technology are up to 25% for CO_2 and 35-60% for N_2O emissions (United States Environmental Protection Agency, 2002), though this is higher than the well to wheel estimations from the GHGenius model.

Applications/Demonstrations (Technology)

Applications and demonstrations of lower GHG emitting CNG or LNG fuel for transportation of biological products are limited by the lack of CNG and LNG fuel infrastructure. In Alberta, EnCana Natural Gas Inc. recently opened a CNG station in Strathmore, Alberta. The station

[16] http://www.westport.com/
[17] http://www.ghgenius.ca/
[18] http://greet.es.anl.gov/

supports 39 EnCana vehicles converted to run on CNG and will be ready to service other commercial fleets beginning in 2012. There are currently more than 960 natural gas vehicle fuelling stations in the United States fuelling about 110,000 natural gas vehicles. Canada has a network of approximately 80 public fuelling stations in five provinces (Encana, 2011).

Markets

The benefits of fuel switching may be highly project dependent. Fuelling requirements, fuel storage, changes in energy efficiencies, and logistical constraints may cause projects to be uneconomical despite providing reduced GHG emissions. For transportation of biological goods no comprehensive market study has been conducted for GHG mitigation potential with fuel switching; however, general highway transportation studies are available. For other transportation applications, modeling suggests (Johnson, 2010) that switching from diesel to CNG is likely to be profitable only for larger transit and refuse fleets (75+ vehicles) as long as vehicle miles traveled do not drop below 41,800 km/year (transit) or 22,500 km/year (refuse). Fuel switching in school bus fleets was found to be only marginally profitable for all configurations tested.

Policy

No policy barrier exists for deployment of load management technologies or strategies when done for cost/fuel savings or for other related business purposes. However, the ability to generate and market transportation related carbon offsets is limited by the lack of approved protocols and higher verification and baseline setting requirements now in place for the Alberta Offset System. A fuel switching protocol for mobile sources is currently under development.

3.3.5.2 Greenhouse Gas Emission Reduction Potential

Magnitude and Verifiability

Table 24 – Emission Reduction Magnitude and Verifiability for Fuel Switching

Opportunity Area	Theoretical Provincial Impact (Mt CO_2e/yr)	Verifiability
Fuel Switching	0.3[1]	Programmatic Estimation/ Modelled

[1] Fuel switching – used 15% switch to CNG/LNG and applied to $^1/_3$ of Class 8 and $^1/_{10}$ Medium truck emissions for the ∑ of AB Heavy Truck emissions in forestry and agriculture.

Justification

The estimate of the GHG reduction potential from fuel switching for the transportation of biological goods was based on the most recent transportation emission values for Alberta (Mt

CO_2e/yr from Natural Resources Canada, transportation historical database accessed November 2011) and the following sources and assumptions:

- Fuel Switching emission reductions were estimated based on the switch from diesel to CNG/LNG fuels.
- Biofuels were excluded.
- Fifteen percent attainment in forestry and agriculture was assumed.
- The reduction potential was applied to $^{1}/_{3}$ of Class 8 and $^{1}/_{10}$ of Medium truck emissions for AB to reflect the transportation of biological products.

3.3.5.3 Gaps and Constraints

Science, Data and Information Gaps: None identified.

Policy Gaps: None identified.

Technology Gaps: No significant technological gaps were defined.

Demonstration Gaps: Lack of production and fuelling infrastructure limits the opportunity to demonstrate the technology and GHG mitigation potential in Alberta.

Metric Gaps: A protocol for fuel switching is currently under development for the Alberta Offset System, and methods for offset aggregation will be required.

Other Gaps: None identified.

3.3.5.4 Opportunities to Address the Gaps/Constraints Identified

Demonstration of fuel switching from diesel to CNG or LNG fuels for the transportation of biological products is lacking in Alberta. In particular, any additional energy required to compress, store and dispense CNG or LNG fuels must be demonstrated so that project proponents can make informed decisions on the GHG mitigation potential. Demonstration is limited by the lack of infrastructure to supply CNG and LNG fuel.

3.3.6 Transportation Summary

The transportation section of this report includes reductions from 1) intermodal freight switch, 2) improved fuel efficiency, 3) fleet management, 4) transportation efficiency and 5) fuel switching. The following summary covers opportunities and constraints, total theoretical reduction potential, impact of gaps/constraints on the reduction potential and key messages across these five areas.

3.3.6.1 Summary of Findings

Opportunities found included improved fuel efficiency through truck technology (aerodynamics and rolling resistance), driver training and engine efficiency, and reductions in fuel consumption (through improved fleet management). Other improvements can come from changing loading practices (such as load densification, trailer sizing and route planning) and refining the application of intermodal freight systems to biologically based products (in particular moving the use of intermodal freight movement closer to the production end of the value chain).

The Fuel Efficiency emission reductions were based on NIR transportation emission values and included: aerodynamic improvement of cab and tank fairings, trailer skirts, boat-tails, low rolling resistance tires, and engine sizing. The Fleet Management emission reductions were based on continuous loop hauling, multi-function trailers, route planning, and reduced idling. Load Management emission reductions were based on load densification - including hay compression, log drying, resizing trailers, and portable chipping. Finally, Fuel Switching emission reductions were based on a switch to CNG/LNG fuels.

The following table summarizes the opportunities and constraints across the transportation reduction opportunities. The table is broken down into three categories: inputs, activity and outputs; and covers science, technology, markets and policy. The inputs column refers to the inputs needed to accomplish the activity/process (i.e. intermodal system). The activity column refers to the change in practice itself. The outputs column refers to the product/service (transportation of biological products).

The table is also color coded. Red indicates an area where there are no issues or there is no opportunity for investment. Yellow represents an area with some potential; however, at present this area is not a priority. Areas shaded in green highlight the best opportunities for investment.

Table 25 – Opportunities and Constraints for the Transportation Sector

	Inputs	Activity	Outputs
Science	Largely in place[1]. Tested under controlled conditions.	On-going research, models being developed.	Theoretical or on-highway estimates require calibration for off-highway[2] use. Intermodal quantification is difficult.
Technology	Require adjustment and fitment to off-highway application[3] or development and parameterization[4]. Local sources and technological conversion of fleet is limiting adoption[5]. Data to support intermodal shift is not available.	FPInnovations is developing tools and systems[6] to foster adoption. Agriculture sector lags due to slower turnover of fleet. Rail support on intermodal-data and willingness to develop infrastructure is lacking.	Active support of intermodal by railways is absent. Linkages between reduction in fuel consumption and GHG emission reduction need to be made routine. Extension and aggregation tools are required.
Markets	Review of the SmartWay program suggests limited adoption in off-highway applications.	Suppliers[7] are beginning to use GHG reduction estimation and quantification as selling features.	Largely theoretical at present. Minimal market pull from users – limited by economic constraints and relatively high capital value/dispersed nature of "fleets" resulting in slow turnover.
Policy	Federal policy supports SmartWay program and application to forestry use. Program provides international credibility.	Protocols are under development in Alberta and Saskatchewan.	Refinement of quantification of aggregated and integrated activities is needed.

[1] Models and predictive methods are in place for fuel use reduction and GHG quantification. Models and tools to refine application and effectiveness of intermodal freight shift for biological commodities are needed.
[2] Off-highway refers to all off pavement use and therefore includes both forestry and agricultural trucks.
[3] Fuel efficiency technology and other technologies covered by the SmartWay program.
[4] Intermodal freight shift management and quantification systems.
[5] Fuel switching to lower emission intensity hydro-carbon fuels.
[6] Adaptation and refinement of Smartruck programs to calibrate for and foster application to forest industry use.

3.3.6.2 Total Theoretical Reduction Potential

Table 26 – Total Theoretical Reduction Potential for Transportation

Opportunity Area	Theoretical Provincial Impact ($Mt\ CO_2e/yr$)	Verifiability
Intermodal	Unknown	Programmatic Estimation
Fuel Efficiency	0.75	Metered or Measured
Fleet Management	0.3	Metered or Measured
Load Management	0.3	Metered or Measured
Fuel Switching	0.3	Metered or Measured
Total	**1.65**	

3.3.6.3 Impact of the Gaps/Constraints on the Reduction Potential

The potential opportunities for GHG mitigation are not limited by scientific or technological barriers, but by the lack of protocols and methods to quantify and verify GHG offsets.

3.3.6.4 Key Messages

The main messages for this opportunity are:

- Calibration/adaptation of SmartWay technologies to off-highway use has the shortest path to realization.
- Load management and intermodal shift requires development of infrastructure and extension to speed realization.
- Fleet management and intermodal freight would benefit greatly from the development of a model - data management system to plan and document implementation.
- The lapse in provincial protocol development is a limiting factor.
- All pathways would benefit from extension to hasten adoption in both sectors but especially in agriculture. To foster adoption key messages are:
    - Fuel saving is the core message - GHG mitigation is an ancillary benefit.
    - Need tools to integrate operational and capital expenditures to support more rapid and cost-efficient fleet turnover to realize mitigation potential.
    - Need to provide guidance on quantification and aggregation.

3.4. Waste Management

3.4.1 Avoided Methane Emissions

Emissions from landfills and waste storage facilities (including wastewater or manure lagoons and manure piles) are the two main sources of methane emissions associated with waste management. These emissions result from natural anaerobic processes that occur at the storage sites. Two effective strategies in preventing these emissions are:

1. Avoiding CH_4 formation by eliminating anaerobic conditions; and
2. Oxidizing the methane through active microbial activity.

These two processes can be engineered and managed to optimize their capacity. On average, in Alberta manure is stored on site for 6 months. Methane emissions can therefore be avoided by cutting this storage time or preventing CH_4 formation in the first place. It is worth noting that reducing GHG emissions through CH_4 oxidation at landfill sites where CH_4 is captured for destruction or power generation is not economically feasible.

3.4.1.1 Literature Review

Science

Methane Oxidation: Landfill CH_4 can be oxidized by microorganisms in the soil utilizing oxygen that has diffused into the cover layer from the atmosphere. Microorganisms that can oxidize CH_4 gas to produce CO_2 and water are referred to as methanotrophs. Methanotrophs have been reported to occur at significant rates in many natural environments and soils; and can act as sinks for CH_4 from the atmosphere (Adamsen & King, 1993; Whalen, Reeburgh, & Sandbeck, 1990). Microbial mediated CH_4 oxidation has been recognized as being globally important and accounts for approximately 80% of global CH_4 consumption (Reeburg, Whalen, & Alperin, 1993). Thus, it can play an important role in reducing emissions of CH_4 to the atmosphere. When soil or microbial growing media are exposed to elevated CH_4 concentrations they develop a high capacity for CH_4 oxidation; in particular, if preselected methanotrophic bacteria are introduced the process can be accelerated (Whalen et al., 1990).

Avoiding methane formation: Aerating wastewater and manure lagoons has been well researched. Wastewater and manure lagoons can be aerated through mechanical aspirating aerators (Agitation & Aeration Equipment, 2011; Aeration of Liquid Manure, 2011) or a number of other mechanical devices. In particular, windmills have been recognized as a cost-effective and low maintenance device to control odor and CH_4 formation in wastewater facilities or lagoons.

Technology (Applications/Demonstrations)

Methane Oxidation: Microbial mediated methane oxidation converts CH_4 into CO_2 and H_2O in soil or organic media. This process is often referred to as bio-filtration and has been successfully demonstrated to be a cost-effective technology for decades (Yang et al., 2002; Zeiss, 2002). The CH_4 oxidation process is controlled by several environmental factors. Through a properly designed system, CH_4 can be degraded effectively before it moves out of the soil or cover layer. Across Canada there are a few pilot systems that have demonstrated bio-filtration can be a cost effective method of avoiding CH_4 emissions from landfills.

Avoiding methane formation: Floating windmills have been used extensively to aerate wastewater and manure lagoons, thereby avoiding CH_4 formation in these systems. However, a systematic experimental evaluation has not been well documented.

Markets

Methane Oxidation: Market uptake depends on the recognition of reduced GHG emissions resulting from CH_4 oxidation methods, under an emissions credit program. This is particularly important for landfill sites where CH_4 emissions capture is not yet economically feasible. An intent to Develop an Alberta Offset System Quantification Protocol (*Quantification Protocol for Biological Methane Oxidation*) has been developed. Any effort that helps encourage the rapid development of this protocol will enhance market up take.

Avoiding methane formation: Shortening manure or other bio-waste storage times is a straightforward practice; however, standard procedures to monitor and audit the practice are needed. A standard protocol that recognizes CH_4 avoidance from the application of mechanical devices or windmills in wastewater or manure lagoons would accelerate market uptake of these techniques.

Policy

Government policy is needed to encourage livestock producers to shorten manure storage times and to aerate lagoons using simple, self-operated and cost effective windmill devices. Further, standard protocols are needed to quantify GHG emissions reductions from: 1) methane oxidation at landfills (through well-managed bio-cover or bio-filtration systems); 2) reduced manure storage times; and 3) the use of windmills to avoid methane formation at wastewater or manure lagoons. In order for this to be accomplished, standard design and operation procedures need to be developed.

3.4.1.2 Greenhouse Gas Emission Reduction Potential

Magnitude and Verifiability

Table 27 – Emission Reduction Magnitude and Verifiability for Avoided Methane Emissions

Opportunity Area	Theoretical Provincial Impact (Mt CO_2e/yr)	Verifiability
Avoided Methane Emissions	3.2	Programmatic Estimation

Justification

The above theoretical provincial potential was calculated based on the following assumptions:

- Total emissions from Canadian municipal solid waste are equal to 27.9 Mt CO_2e/yr (Haugen-Kozyra et al., 2010). Using Alberta's population as a percentage of the total Canadian population to adjust this potential and applying 75% efficiency, the provincial potential from this opportunity (CH_4 oxidation-landfill) would be 2.35 Mt CO_2e/yr.
- The total amount of collectable liquid and solid manure in Alberta is based on the Canadian and Albertan livestock inventory and the Canadian GHG emission inventor (see Table 28). Using these figures the emission reduction for shortened solid manure storage was calculated to be equal to 0.37 Mt CO_2e/yr.
- Assuming 50% market uptake and 75% efficiency, emission reductions from avoided methane formation from wastewater and liquid manure lagoons were calculated to be 0.29 + 0.19 Mt CO_2e/yr.

The figures shown in table 28 below were used to estimate available feedstock for Alberta in the calculations.

Table 28 - Available feedstock in Alberta (from Haugen-Kozyra et al., 2010)

Feedstock	Total Mass (tonnes/yr)	Total GHG Emissions (Mt/yr)
Beef manure	6,392,850	0.95
Poultry manure	24,976	0.02
Dairy manure	266,916	0.07
Hog manure	181,271	0.45
Subtotal	6,866,013	1.49
Municipal wastewater	240,500	0.11
Food processing wastewater	1,783,400	0.78
Municipal solid waste	2,168,200	3.13
Total	8,889,913	5.50

3.4.1.3 Gaps and Constraints

Science, Data and Information Gaps: Although the science is robust, a pilot demonstration plant, where a standard engineering design is employed (taking into consideration Alberta conditions), is needed to document and verify the benefits of these techniques.

Policy Gaps: Currently, there are no approved protocols under the Alberta Offset System for quantifying GHG reductions associated with avoided methane emissions.

Technology Gaps: Standard engineering design and operation/monitoring procedures need to be developed.

Demonstration Gaps: Demonstration sites are needed to collect experimental data and address the technology gaps mentioned.

Metric Gaps: There is no comprehensive approach for quantifying and monitoring the benefits from these techniques. Systematically designed and well-managed demonstration projects could address the data and technology gaps presented and accelerate market realization of this opportunity.

Other Gaps: Public awareness of the benefits of these techniques is lacking. Education and outreach to municipalities (particularly small municipalities) is needed.

3.4.1.4 Opportunities to Address the Gaps/Constraints Identified

In order to address the gaps and constraints identified, pilot projects must be conducted to develop design standards and determine the most critical parameters to monitor. Along with these demonstration projects, GHG mitigation protocols should be developed.

3.4.2 Methane Capture and Destruction

This opportunity involves capturing methane and destroying it in order to reduce emissions into the atmosphere. The feedstock for this opportunity is the same as that for section 3.4.1 and includes closed class II landfill sites, wastewater from municipal and food processing waste, and liquid and solid manure.

3.4.2.1 Literature Review

Science

In order to capture landfill gas for flaring or utilization a network of pipelines must be installed. This piping network should extend through the landfill and be connected to a pump that creates a suction to capture the gas, thereby reducing the amount of gas escaping into the atmosphere. Once captured, the CH_4 in the landfill gas can be destroyed through flaring or be used to displace grid electricity or fossil fuel derived heat (when economically feasible). The latest national inventory of landfill gas capture projects identified 51 sites in Canada (Haugen-Kozyra et al., 2010). Emission reductions associated with these facilities were estimated to be 6.9 Mt CO_2e in 2007.

Similar principles can be applied to other types of waste as well (see Table 28 in section 3.4.1 for a list of additional sources of waste) either through simple membrane coverage for lagoons or engineered enclosing systems. Methane emissions can be quantified using the Tier 2 regional approach applied in Canada's National Inventory Report (NIR) (Environment Canada, 2010). The NIR approach employs the best available science (peer reviewed research results) in combination with the best practice guidance (IPCC Tier 2 approach) and produces conservative GHG emission estimates for Canada (Mariner et al., 2004).

Technology (Applications/Demonstrations)

Methods of capturing and destroying CH_4 from landfills are well known, readily available and already in use. Methane can be destroyed through combustion by a flare, industrial combustion or electric generation.

Methane capture and destruction from covered manure storage sites is in the developmental stage. As a result, demonstrations plants are still needed to further develop and mature the technique.

Markets

In Alberta, there are close to 2000 operations with uncovered liquid manure storage and 400 wastewater lagoons. This represents a significant potential to create agricultural offsets. Marketing strategies that promote environmental stewardship in the management of wastes as well as the opportunity to generate carbon credits will help accelerate market uptake.

Policy

An intent to Develop an Alberta Offset System quantification protocol for covered manure storage has been submitted to Alberta Environment and Water (AEW). In addition to the "too good to waste" strategy developed by AEW, a strategy to eliminate Alberta's 4400 wastewater and liquid manure lagoons will accelerate market uptake of this opportunity.

3.4.2.2 Greenhouse Gas Emission Reduction Potential

Magnitude and Verifiability

Table 29 – Emission Reduction Magnitude and Verifiability for Methane Capture and Destruction

Opportunity Area	Theoretical Provincial Impact (Mt CO_2e/yr)	Verifiability
Methane Capture and Destruction	4.12	Metered / Measured / Modelled

Justification

The amount of available feedstock for Alberta used in this calculation is the same as that used in section 3.4.1 and presented in Table 28. The calculation is also based on the following assumptions:

- Total emissions from Canadian municipal solid waste are equal to 27.9 Mt CO_2e/yr (Haugen-Kozyra et al., 2010). Using Alberta's population as a percentage of the total Canadian population to adjust this potential and applying 75% efficiency, the provincial potential from this opportunity (CH_4 capture and destruction) would be 2.35 Mt CO_2e/yr.
- The total amount of collectable liquid and solid manure in Alberta is based on the Canadian and Albertan livestock inventory and the Canadian GHG emission inventor (Table 28).
- Assuming 75% efficiency, the capture and destruction potential for Alberta is approximately 4.12 Mt CO_2e/yr.

3.4.2.3 Gaps and Constraints

Science, Data and Information Gaps: Although there is a well-developed and adapted GHG mitigation protocol for landfill gas capture, there are still many critical data gaps for manure storage facilities and covered lagoon systems. In order to ensure the development of scientifically robust GHG mitigation protocols for these facilities, field experimentation is required. These field studies should investigate the impact of Alberta's climatic conditions on the amount of CH_4 generated at these facilities and identify the critical parameters required to accurately calculate reduction potential.

Policy Gaps: Three main policy gaps need to be filled: 1) it needs to be specified that open wastewater and manure lagoons are no longer considered acceptable sustainable practices; 2) a standard engineering design for waste storage systems is needed to help the sector meet environmental challenges such as GHG emissions, odor and pathogen contamination of our water bodies; and 3) the currently approved protocol under the Alberta Offset System for quantifying GHG reductions from food processing wastewater needs to be expanded to include manure lagoons and other wastewater storage facilities.

Technology Gaps: Standard engineering design and operation/monitoring procedures need to be developed.

Demonstration Gaps: Demonstration projects are needed to improve current designs and to collect experimental data. In particular, there is a need for data on the effects of temperature on solid destruction. This will improve the accuracy of CH_4 destruction calculations.

Metric Gaps: There is no comprehensive approach for quantifying and monitoring the benefits of covered manure storage for either solid or liquid manure. Systematically designed and well-managed demonstration projects will address these data and technology gaps and accelerate market realization of this opportunity.

Other Gaps: There is a lack of public awareness on the co-benefits of using CH_4 capture and destruction to reduce our environmental footprint; in particular, odor reduction and pathogen elimination.

3.4.2.4 Opportunities to Address the Gaps/Constraints Identified

Many of the gaps presented above could be addressed through the implementation of pilot projects. These projects would aid in the development of standard monitoring procedures and would help validate the environmental benefits of covered lagoons. Further, these projects could contribute to the development of a realistic and acceptably accurate model for predicting methane production potential. This model would be based on the systems operation conditions and the properties of the feed materials.

Next, guidelines for the proper operation of a flare system are needed. These guidelines should include specifications on operation conditions such as minimum gas flow rate, wind and temperature for increased flare efficiency. Finally, a GHG mitigation protocol for covered manure or wastewater lagoons needs to be developed. This should be fairly easy to accomplish since a wastewater treatment protocol for food processing waste already exists.

3.4.3 Pyrolysis/Biochar

The production and use of biochar offers great potential for GHG emission reductions. Biochar can remove CO_2 from the atmosphere (by carbon capture and sequestration) and be used for renewable energy production. Two strong co-drivers, environmental impact mitigation and soil enhancement, are important factors associated with this opportunity for GHG emissions offset. The mechanisms for achieving emission reductions from the production and use of biochar extend across the projects lifecycle (Haugen-Kozyra et al., 2010).

Potential feedstocks for biochar include forestry and agriculture crops and residues, municipal solid wastes (the organic component), livestock wastes, and other sources of organics. Feedstock can originate from waste-diverted materials, can be produced from surplus biomass from agriculture, or can be produced from other marginal lands.

Feedstocks are processed with heat in the absence of oxygen (the process of pyrolysis) to render a significant portion of the carbon in the material stabilized as solid biochar. The stabilized carbon has a mean residence time in soils in the order of 1,000 to 10,000 years. During the pyrolysis process, various energy-rich gas and liquid streams can also be produced. These energy streams may be used to offset the use of fossil fuels, to produce electricity or to fuel the biochar pyrolysis process.

Biochar can be used as a remediation agent in agriculture or other land management activities. In an agricultural context, biochar can be applied to soils to improve soil quality by enhancing nutrient and water retention and stimulating microbial activity. Other uses of biochar include, but are not limited to:

- A product for turfgrass establishment;
- A substitute for peat or coconut shells in horticultural applications;
- A reclamation agent for land restoration; and
- A filtration material for mitigating water pollution (Haugen-Kozyra et al., 2010).

In each scenario, the biochar - which contains stabilized carbon - can be considered to have permanently sequestered the carbon found within it. In some cases, the biochar may be stored permanently as fill in mining or in applications similar to traditional carbon capture and storage (CCS) techniques. The use of biochar as a solid biofuel does not sequester carbon and therefore would not be considered to be applicable to these project types.

3.4.3.1 Literature Review

Science

Pyrolysis research is largely focused on the production and characterization of biochars from specific feedstock under differing process conditions. Generalized conclusions indicate that optimal biochar volumes are achieved from conditions of slow pyrolysis (lower temperatures over longer residence times). Additionally, changing feedstocks or differing pyrolysis conditions (using the same feedstock) can result in variations in biochar quality.

Research on biochar applications has primarily focused on its agricultural enhancement potential, particularly for poor soils. Application of biochar into soils has been shown to increase pH, increase soil carbon content, and therefore increase crop productivity. In addition, it has also shown promise in reducing emissions of N_2O and CH_4 (other GHGs) from soils, and in increasing water holding capacity (Karhu et al., 2011; Novak et al., 2009; Warnock et al., 2007). Stability of biochar in soil has also been studied to a certain extent (Lehmann et al., 2009).

Other research has investigated:

- The potential for using biochar as a solid fuel source (for partial coal replacement in traditional coal fired power plants);
- The ability of biochar to act as a precursor to activated carbon (added value product);
- Using biochar as a remediation mechanism in polluted soils (old mines or wellsites); and
- Using biochar as a remediation mechanism in polluted water sources (tailings).

Further research is required to identify and verify the exact mechanism(s) of interaction between biochar and soil properties under different climate conditions (Verheijien et al., 2010).

Technology (Applications/Demonstrations)

Pyrolysis techniques can generally be described as follows:

1. Slow pyrolysis is characterized by lower temperatures and longer residence times. Optimal biochar production is achieved through slow pyrolysis.
2. Fast pyrolysis is characterized by higher temperatures and shorter residence times. This process optimizes energy production, primarily in the form of bio-oil production.
3. Flash pyrolysis sits in the middle between slow and fast pyrolysis. It produces, under pressure, higher yields of biochar with higher temperatures and shorter residence times.
4. Gasification produces the smallest volume of biochar while maximizing gas production.
5. Hydrothermal conversion is the newest of these processes, converting a wet feedstock to a less stable char – but with a higher biochar yield.

In addition to the above pyrolysis techniques, emerging alternative methods such as microwave pyrolysis show promise, but are still in early stages of development (Zhao et al., 2010). These technologies have been proven through small-scale projects, while functionality and viability of commercial scale facilities have yet to be proven over the long term.

Markets

Without policy and proven pilots, a market for biochar products and biochar production technology has not been firmly established. Policy supporting the production and characterization of biochar would help in establishing a market price and general awareness of the uses and application techniques for biochar products. Policy and a protocol qualifying biochar as a mechanism for generating carbon credits would provide significant stimulation to this emerging market. Until then, current opportunities in Alberta are primarily limited to small-scale agricultural use.

Policy

There are no approved quantification protocols available for biochar projects in North America. However, there is currently an initiative (Biochar Protocol Development, 2010) for the development of a protocol under the Voluntary Carbon Standard (VCS) and Alberta Offset System. The science and quantification approaches under this initiative draw on aspects of existing protocols and current best practice.

Globally, policy surrounding biochar is in various states of development. In November 2010, the US Natural Resources Defense Council released a paper that concluded:

> "Development of meaningful U.S. policy on biochar awaits further research. Before a policy can be developed, we need increased confidence in the performance parameters of various biochar production systems, a better sense of the types of biochars that potential feedstocks will yield, better strategies for transporting and incorporating biochars into soils, and expanded knowledge of how various biochars perform from an agronomic and carbon sequestration perspective….the conclusion of field trails will be available in approximately eight years (Brick & Wisonsin, 2010)."

The International Biochar initiative (IBI) refuted some of the findings in the above report, but did not comment on the policy agenda.

3.4.3.2 Greenhouse Gas Emission Reduction Potential

Magnitude and Verifiability

Table 30 – Emission Reduction Magnitude and Verifiability for Pyrolysis/Biochar

Opportunity Area	Theoretical Provincial Impact (Mt CO_2e/yr)	Verifiability
Pyrolysis/Biochar	8.27[1]	Metered / Measured

[1] Municipal solid waste (plastics/papers), forest waste, surplus straw from agricultural land and solid manure; slow pyrolysis for biochar production only.

Justification

Under business as usual circumstances, the feedstock used for biochar is either burned or left to decompose. Improper disposal of feedstock can release CO_2 and other GHGs, while decomposition can result in the release of CO_2 (if decomposition occurs under aerobic conditions), CH_4 (if decomposition occurs under anaerobic conditions) or N_2O (under fluctuating conditions - aerobic/anaerobic). Biochar production stabilizes organic carbon sources so that decomposition happens over thousands of years (1,000 to 10,000 years), resulting in the avoidance of these harmful emissions.

Calculations for the emission reduction potential of biochar should ideally include: 1) the diversion of organic waste from landfills and 2) the sequestration of carbon in the biochar. However, for the purposes of this study - which focuses on reduction - sequestration was left out. The method of calculating benefits of diverting organic waste from landfills is similar to that which would be used for composting, anaerobic digestion and incineration. ICF Consulting (2005) estimated the emission reduction potentials for composting, anaerobic digestion and incineration to be 1.04 tonnes CO_2e/tonne, 0.9 tonnes CO_2e/tonne and 0.78 tonnes CO_2e/tonne respectively from the diversion of organic waste.

The theoretical provincial reduction potential given above (8.27 Mt CO_2e/yr) was calculated based on the availability of the following feedstock in Alberta:

Table 31 - Feedstock in Alberta

Feedstock	Dry Weight (tonnes)
Agricultural Straw	4,300,000
Forest Residues	725,000
Mill Residues	171,500
MSW (Municipal Solid Waste)	1,110,000
Solid Manure	6,417,826
Total	12,724,326

The estimated figure for agricultural surplus straw was taken from the Levelton Report commissioned by the Alberta Government (2006). Although fossil fuels are initially needed to start the pyrolysis process, once started the production of biochar is considered to be a carbon-neutral since the biochar and its associated by-products (gas and bio-oil) can be used as carbon neutral energy inputs to fuel the rest of the process.

The emission reduction potential of converting the biomass listed in Table 31 above to biochar would be calculated as follows:

Mass of Biomass:	12.7 Mt/yr
Conversion Factor:	24%
Average Carbon Content:	74%
Carbon to CO_2e Conversion:	44/12
Emission reduction:	8.27 Mt CO_2e

This estimate does not include avoided GHG emissions from upstream and downstream changes in waste management practices.

3.4.3.3 Gaps and Constraints

Science, Data and Information Gaps: Biochars differ in their stability and longevity in soils. The consistency of feedstock, energy production, char quality/market are all variable depending on the production methodology and technology used. A characterization produced by the IBI is currently under review by the scientific community. Testing the stability of biochars in Canadian soils is of critical importance.

Policy Gaps: A lack of relevant policy for biochar producers is the most pressing policy gap. Methodologies currently exist for calculating emission reductions and a draft biochar protocol has been written, but has not been published. There are no approved quantification protocols available for biochar projects in North America. However, there is currently an initiative (Biochar Protocol Development, 2010) for the development of a protocol under the Voluntary Carbon Standard (VCS) and Alberta Offset System. The science and quantification approaches under this protocol initiative draw on aspects of existing protocols and current best practice.

Technology Gaps: The long-term viability and reliability of commercial scale biochar production facilities represents a significant technology gap. Few industrial scale biochar projects are in operation in Canada.

Demonstration Gaps: There are very few pilot and commercial scale biochar projects in operation in Canada or elsewhere in North America and a critical lack of comprehensive pilot projects in Alberta. Without implementation of these types of projects, the ability to create a market for biochar will be limited. The lack of pilot and commercial scale biochar systems directly correlates to a shortage of biochar supply in Alberta for field-testing and other research and development (R&D) activities.

Metric Gaps: A standardized set of practices for small pyrolysis production is needed in order to regulate the processing procedure and support the classification of biochar and its corresponding emissions reduction values. Methodologies exist for calculating emission reductions and a draft biochar protocol has been written, but still needs to be published. In addition, a consistent standard to determine biochar quality, stability and longevity in soils as well as more data on energy input for biochar processing and GHG emissions for transport are needed so that emissions reduction can be examined using a life cycle approach.

Variability in feedstock availability also presents a problem for estimating theoretical/actual values of biochar and resulting emissions reductions. The distribution of feedstock is spread across the province and the quality of feedstock varies season-to-season. These variations make standardization difficult across feedstock sources. Further, there are competing uses for the available feedstock. For example, a portion of the available feedstock will be applied directly to land, composted or digested anaerobically for nutrient recycling.

Other Gaps: There are limited markets for biochar as a soil amendment and/or for other uses. The benefits of biochar have not yet been demonstrated to producers.

3.4.3.4 Opportunities to Address the Gaps/Constraints Identified

In order to address the gaps/ constraints identified there needs to be: 1) support for the development of biochar markets through research into its efficacy and stability in soils; 2) recognition of the GHG environmental benefits of biochar production; 3) support for projects that are commercializing the range of potential production technologies; 4) widespread acceptance of a biochar characterization method (such as the one in development by the IBI) in order to help develop both the market and policy; 5) scientific study on the effects of biochar on soils (i.e. which soils benefit the most from biochar application and what types of biochar have the greatest effects) in order to help develop a commercial market for their use in agriculture; and 6) life cycle analysis (LCA) or carbon footprint studies on the current and alternative feedstock and production systems. Further, pilot projects (both small and commercial scale) would be helpful across all sectors.

3.4.4 Anaerobic Digestion / Nutrient Recovery

Anaerobic digestion (AD) is a promising option for treating bio-waste; particularly since the by-products of AD can be used as a source of energy for cogeneration and the production of electricity. While these benefits of AD are often acknowledged, unfortunately the benefits of using the bio-waste components to produce multiple value-added products are frequently overlooked. For example, bio-wastes can be used to produce nutrient-dense, slow-release bio-fertilizers for the organic food industry, golf courses and/or traditional crop production. To date, broader application of biogas technology has been thwarted in part due to the fact that many of these added-value opportunities remain unexplored.

Recently, an International Energy Agent task force on bioenergy (IEA Task 37) was formed to address this issue.

Opportunities to address Alberta's environmental, social and economic issues associated with waste include:

1. *Municipal Organic Wastes and Wastewater* - Food wastes from homes and restaurants, lawn clippings, fallen leaves, and other organics produced by municipalities are potential sources of bio-wastes that could become valuable resources for the production of biogas and bio-fertilizer. The European Union has completely banned the disposal of organic wastes in landfills in order to protect land and water resources and avoid GHG emissions. Newly raised issues of pharmaceuticals, hormones, and other endocrine disrupters in municipal wastewater have triggered municipalities to revisit the quality of wastewater being discharged into receiving streams.

2. *Manures* - Manures have generated intense social reaction in recent years because they are not only odorous but are also sources of pathogens, nutrients, and other contaminants that can end up in the water supply. Land application is the most widely used method of manure disposal. To minimize nutrient accumulation, confined feeding operations are required to apply nutrients only at levels that match crop requirements. An extensive land base is needed to achieve this "dilution". Further, as distance increases from the site of manure concentration, costs of disposal rise. Land application can benefit crop production and improve soil quality, but also has economic, environmental and social drawbacks.

3. *Food Processing Wastes, Renderings and Specified Risk Materials* - Food processors find themselves in a tight cost-price squeeze and are looking for ways to increase their bottom line. Food processing wastes are either land-filled or increasingly disposed of via composting. Processors are looking for some return on their waste products (at the very least removing the disposal fees for land-filling). If proximity was optimal, the utilization of processing wastes for biogas production could be an economic advantage for food processors. Specified risk materials (SRMs), removed as part of the rendering process to ensure customers receive bovine spongiform encephalitis (BSE) prion-free meat products, are the most challenging food processing waste to deal with. Currently, they are disposed of in landfills or buried on farmland. New Canadian Food Inspection Agency regulations now require the treatment of SRMs using one of two methods prior to land-filling: incineration or thermal/alkaline hydrolysis. These treatment methods not only eliminate prions, but also eliminate all bio-value of the SRMs. End products of these treatment processes include GHG's and residuals, which must be land-filled. This creates environmental hazards in place of potential health hazards. AD offers an alternative that can eliminate prions while also capturing energy and other nutrient values.

The above list of waste types makes up the most suitable feedstock for the anaerobic digestion process. One way their value can be realized is by using biogas and nutrient recovery technologies.

3.4.4.1 Literature Review

Science

Anaerobic digestion is a natural process where micro-organisms decompose organic materials in the absence of oxygen to produce biogas (mainly CH_4 and CO_2) and digestate. A wide variety of materials can be used as feedstock and processed through an anaerobic digestion system, or through biogas technology. The feedstock types (also referred to as substrate) highlighted in section 3.4.4 can be used separately or as a mixture of two or more types, while some feedstock must be used as a co-substrate only. One common AD system is the "wet" digestion system, where less than 15% feedstock is used. This type of biogas technology has been used worldwide for centuries; including areas with extremely cold climatic conditions.

Municipal wastewater treatment systems frequently employ AD processes to reduce the amount of organic solids in the wastewater. However, existing facilities do not maximize use of the biogas generated from the treatment process. Further, much of the N present in wastewater is lost to the atmosphere through de-nitrification. Thus, there is an opportunity to improve upon current practice, by fully utilizing the biogas being produced and by capturing and recycling plant nutrients. This will result in significant reductions in GHG emissions while also eliminating pathogens (Pang et al., 2009, personal communication).

For solid bio-waste, including solid manure and municipal solid waste, "dry" digestion systems are more suitable. These systems can use up to 30% solids as feedstock (Li et al., 2008). The digestate from this system will have a high solid content and will be easier to process.

After the energy is produced, approximately 40-50% of the biomass remains as digestate. Nutrients are concentrated in the digestate, which can be further processed into bio-fertilizer or a soil organic amendment. AD technology provides the opportunity to recycle nutrients in bio-fertilizers. Bio-fertilizers are more compact, have lower weight, higher nutrient concentrations and higher value than raw materials. As a result, they can be applied more economically. Further, the resistance of organic carbon in processed bio-fertilizers means that little of the soil carbon sequestration potential of bio-waste is lost in the AD process.

Since the beginning of the "green revolution" or discovery of N fertilizers, there has been a worldwide increase in the use of inorganic fertilizers to increase crop production and meet the needs of a growing population. However, during the past decade the price of inorganic fertilizer has doubled, impacting the use of oil-based fertilizers. Therefore, packaging digestate into condensed and compacted bio-fertilizer is critical for both advancing biogas technology and offsetting the financial and environmental costs associated with the use of mineral fertilizer. For this reason and in order to accelerate the use of environmentally sound and cost competitive biogas technology, the IEA bioenergy task force 37 recently (2011) issued guidelines for utilizing digestate from biogas plants as bio-fertilizer. Processing bio-waste using combined biogas and bio-fertilizer production technologies has the potential to both sustain land productivity and to contribute substantially to future energy demands. Additional co-benefits of the AD process include odor reduction and elimination of pathogens, particularly when processing dead livestock carcasses (Eckford & Gao, 2009; Pell, 1997).

Technology (Applications/Demonstrations)

Wet AD technology is reaching a mature stage of development; however, due to the challenges associated with nutrient recovery, the digestate remains an environmental burden for AD uptake. The following three technologies are critically needed:

1. Dry digestion systems that use municipal solid waste and are well adapted to Alberta conditions;
2. Solid and liquid separation technology and;
3. Effective nutrient recovery technology to process digestate from biogas plants.

Markets

Once the value of bio-fertilizers is recognized, uptake of biogas technology is anticipated to accelerate. Further, bio-fertilizer production technology will be quickly developed and deployed. Policy supporting the production and characterization of bio-fertilizer would help establish a market price and help build awareness of its value. In addition, policy and a standard protocol for quantifying carbon credits generated from bio-fertilizer use would stimulate this emerging market. There is also an opportunity for Alberta to pilot dry digestion and nutrient recovery systems.

Policy

A basic GHG mitigation protocol for AD has been developed; however, further consideration of upstream and downstream waste management is needed. To date, mechanisms for reducing GHG emission associated with bio-waste include:

- Reducing the retention time in storage under current systems;
- Displacing electricity and fossil fuel consumption with bioenergy;
- Displacing inorganic fertilizer use and improving fertilizer efficiency; and
- Enhancing soil carbon sequestration.

Under Alberta’s Offset System there are three protocols that currently relate to the quantification of emission reductions associated with these mechanisms: the *Anaerobic Decomposition of Agricultural Materials Biogas Quantification Protocol*, the *Anaerobic Treatment of Wastewater Quantification Protocol* and the *Agriculture Nitrous Oxide Emissions Reductions (NERP) Quantification Protocol*.

3.4.4.2 Greenhouse Gas Emission Reduction Potential

Magnitude and Verifiability

Table 32 – Emission Reduction Magnitude and Verifiability for Anaerobic Digestion/Nutrient Recovery

Opportunity Area	Theoretical Provincial Impact (Mt CO_2e/yr)	Verifiability
Anaerobic Digestion / Nutrient Recovery	6.31 + 2.31 (power + fertilizer)[1]	Programmatic Estimation/ Modelled

[1] Digestate from anaerobic digestion including N, P, K and stable carbon

Justification

The theoretical provincial value is estimated based on the availability of the following feedstock and assumptions:

Table 33 – Available Feedstock in Alberta

Feedstock	Dry Weight (tonnes)
Manure	6,866,013
Municipal wastewater	240,500
Food processing wastewater	1,783,400
Municipal solid waste	1,073,000
Total	9,962,913

Assumptions:

- The total for manure in Table 33 above includes collectable manure from beef cattle, dairy cattle, hogs and poultry in Alberta.
- The figures for municipal wastewater, food processing waste and municipal solid waste in Table 33 above were calculated by scaling national figures to Alberta based figures using provincial population (Haugen-Kozyra et al., 2010).
- The average energy value for these bio-wastes is 960 kWh_e/tonne.
- It was assumed that 50% of the bio-waste solids were turned into energy, leaving 50% for bio-fertilizer production.
- The N, P, K content in bio-waste is 3%, 2% and 2%, respectively.
- The GHG emission offset potential for renewable electricity is 0.65 tCO_2e/MWh.
- The GHG emission factor for N, P and K inorganic fertilizer is 0.48 tonne /tonne bio-fertilizer with 6% nitrogen (Wood & Cowie, 2004).

Using the feedstock presented in Table 33 for anaerobic digestion and nutrient recovery systems would produce approximately 9,651 TWh_e of electricity annually and approximately five million tonnes (dry base) of bio-fertilizer. Based on the above assumptions this would result in a GHG offset of 8.62 Mt CO_2e/yr

3.4.4.3 Gaps and Constraints

Science, Data and Information Gaps: There is a rich body of research on AD processes; however, the benefits of digestate and bio-fertilizer have not been fully realized. For example, the bio-fertilizer produced from the bio-waste presented in Table 33 contains approximately 297,000 tonnes of N. In addition to the total GHG offset calculated in section 3.4.4.2 (from replacing inorganic fertilizer with bio-fertilizers), the lower N_2O emissions associated with bio-fertilizers could lead to further reductions. The IPCC Tier 1 emission factor for N_2O is 1% of fertilizer N applied. Nitrous oxide emissions from bio-fertilizer are lower than those from inorganic fertilizer. Assuming a 50% reduction, replacing 297,000 tonnes of inorganic N would result in an added reduction of 0.46 Mt CO_{2e}/yr. However, at present there is very little data available on this for Canadian conditions. Further, well-designed field experiments are required to verify this added offset.

Policy Gaps: Major policy gaps include the need for an updated AD protocol and the lack of a GHG mitigation protocol for bio-fertilizers. In addition, protocols that address reductions in retention time of waste (onsite and in storage to reduce GHG emissions), the displacement of inorganic fertilizer, and soil carbon sequestration offsets are needed. Currently, government regulations limit manure application in excess of nutrient limits, hindering further expansion of the industry.

Technology Gaps: Significant gaps exist in our ability to refine the solid/liquid separation-drying process and in the development of nutrient recovery. In addition, the livestock industry requires new and innovative technologies to manage waste. Anaerobic digestion in combination with bio-fertilizer production offers promise in addressing this issue; however, in order to kick-start this industry and help it reach critical mass, proper policy incentives are needed.

Another significant barrier is the capital costs tied with the adoption of AD technology ($2500 – $5000/kw). MacGregor (2010) suggested that governments could provide the right economic environment for commercial uptake of AD technology through financial incentives and through the development of the carbon market, or feed-in-tariffs. In the meantime, technical enhancements that improve efficiency and develop the market for by-products such as bio-fertilizer and heat energy will improve the feasibility and therefore uptake of AD technology.

Demonstration Gaps: Case studies demonstrating nutrient recovery technology and field studies spanning a minimum of three years that validate bio-fertilizers are lacking. Such studies would aid in the development of a commercial market. Further, there is a need for case studies that demonstrate the high solid digestion system (between 25% and 30% solids) that is suitable for beef cattle manure and municipal solid waste. Digestate from high solid digestion systems can easily be used to produce bio-fertilizer.

Metric Gaps: A standard practice for bio-fertilizer production along with quantification of benefits of bio-fertilizer is required to accelerate biogas and bio-fertilizer production. Variability in feedstock availability also presents a problem for estimating theoretical/actual values of biogas and bio-fertilizer and resulting emissions reductions. The distribution of feedstock is spread across the province and the quality of feedstock varies season-to-season. Thus, these variations make optimization difficult across the various feedstock sources. Further, a percentage of total available feedstock is being used to recycle nutrients through incorporation directly to land, composting and pyrolysis, creating competition for the feedstock.

Other Gaps: Uncertainty in the availability of feedstock, particularly its distribution across the province, is an important risk factor. Industrial facilities require a steady supply of feedstock. This risk can be mitigated by properly managing Alberta's marginal land. Biomass produced from these lands can be used as co-substrate for biogas and bio-fertilizer production.

3.4.4.4 Opportunities to Address the Gaps/Constraints Identified

Opportunities to address the gaps include: 1) establishing pilot facilities to demonstrate high solid digestion and bio-fertilizer production; 2) revising current AD protocols to include upstream and downstream management practices so that avoided emissions can also be calculated from these areas; 3) providing estimates of GHG reductions under AD management and improving ability to compare multiple scenarios from a carbon footprint and economic perspectives; 4) investing in training programs for AD operators at colleges or institutions; 5) investing in colleges or institutions to produce a national inventory of bio-waste by size, geographic distribution and energy/nutrient potential; and 6) providing incentives for applying bio-fertilizers and using existing quantification protocols for GHG emission offsets or feed-in tariff programs.

3.4.5 Waste Management Summary

The waste management section of this report includes reductions from 1) avoided CH_4 emissions, 2) CH_4 capture and destruction, 3) pyrolysis and biochar and 4) Anaerobic Digestion and Nutrient Recovery. The following summary covers opportunities and constraints, total theoretical reduction potential, impact of gaps/constraints on the reduction potential and key messages across these four opportunity areas.

3.4.5.1 Summary of Findings

Emissions from landfills and waste storage facilities (including wastewater or manure lagoons and manure piles) are the two main sources of methane emissions associated with waste management. These emissions result from natural anaerobic processes that occur at the storage sites. Two effective strategies in preventing these emissions are: 1) avoiding methane formation by eliminating anaerobic conditions; and 2) oxidizing the methane through active microbial activity. Shortening manure or other bio-waste storage times is a straightforward practice; however, standard procedures to monitor and audit the practice are needed, along with government policy. Further, standard protocols and running pilot projects are needed to quantify GHG emissions reductions.

Building on emissions avoidance, the CH_4 capture and destruction opportunity involves capturing methane and destroying it to reduce emissions entering the atmosphere. The feedstock for this opportunity is the same as for avoided CH_4 emissions, and includes closed class II landfill sites, wastewater from municipal and food processing waste, and liquid and solid manure. In order to capture landfill gas a network of pipelines must be installed. This piping network extends through the landfill and is connected to a pump that creates a suction to capture the gas, thereby reducing the amount of gas that escapes into the atmosphere. Once captured the CH_4 in the landfill gas can be destroyed through flaring or be used to displace grid electricity or fossil fuel derived heat. Challenges include many data gaps for manure storage facilities and covered lagoon systems, a lack of operating pilots, and several critical policy gaps.

The production and use of biochar offers great potential for GHG emission reductions through the removal of CO_2 from the atmosphere (by carbon capture and sequestration) and renewable energy production. Pyrolysis research is largely focused on the production and characterization of biochars from specific feedstock under differing process conditions. Biochars differ in their stability and longevity in soils. The consistency of feedstock, energy production, char quality/market are all variable depending on the production methodology and technology used. Variability in feedstock availability also presents a problem for estimating theoretical/actual values of biochar and resulting emissions reductions.

There is a rich body of research for Anaerobic Digestion process; however the benefits of digestate and biofertilizer have not yet been fully realized. Municipal wastewater treatment systems frequently employ AD processes to reduce organic solids in the wastewater. However, existing facilities do not maximize use of the biogas generated from the treatment process. Further, much of the N present in wastewater is lost to the atmosphere through de-nitrification. Thus, there is an opportunity to improve upon current practice, by fully utilizing the biogas being produced and by capturing and recycling plant nutrients. The ability to refine the solid/liquid separation-drying process and the development of nutrient recovery technologies are two major industry gaps. Another major barrier is the capital cost barrier ($2500 – 5000/kw) for adopting the AD technology.

The following tables summarize the opportunities and constraints for each of the four waste management reduction opportunities. A separate table is used for each reduction area under waste management in order to effectively capture the diversity in science, technology, markets and policy found within this sector. The tables are broken down into three categories: inputs, activity and outputs; and cover science, technology, markets and policy. The inputs column refers to the inputs needed to accomplish the activity/process (i.e. pyrolysis).The activity column refers to the change in practice itself and the outputs column refers to the product (i.e biochar).

The tables are also color coded. Red indicates an area where there are no issues or there is no opportunity for investment. Yellow represents an area with some potential; however, at present this area is not a priority and areas shaded in green highlight the best opportunities for investment.

Table 34 – Opportunities and Constraints for Methane Avoidance, Capture and Destruction

	Inputs	Activity/Process	Outputs
Science	No issues.	Ready to deploy; but depends on other waste utilization technologies.	No issues.
Technology	No issues.	Need for a standardized system design.	Monitoring procedure needed to document CH_4 and odor reduction.
Markets	Environmental pressure; public awareness driven.	Need to provide education on avoidance strategies and develop a method for marketing reduction attributes.	Marketing strategies to promote environmental stewardship.
Policy	Too good to waste; but requires clear policy to enforce.	Develop GHG mitigation protocol and waste management policy.	Need methods for quantifying carbon credits and measuring environmental impacts.

Table 35 - Opportunities and Constraints for Pyrolysis and Biochar

	Inputs	Activity/Process	Outputs
Science	No issues – materials handling is well understood.	Science of biochar composition and properties needs to be better understood.	Knowledge on applications for biochar is relatively new.
Technology	Feedstock sustainability standards are needed.	Pyrolysis technology needs to be piloted at various scales, particularly systems that process approximately 10,000 tonnes feedstock/year; standardize the operation procedure.	Standards for measuring biochar and bio-oil quality are needed. Post-processing technologies to be tested for application.
Markets	Competing and seasonal markets to be defined. Agricultural residues need to be secured.	Technology needs to be promoted.	Markets need to be developed and acceptance of biochar promoted. Need commercial volumes. Carbon sequestration potential needs to be measured/verified to sell offsets.
Policy	Need to regulate landfills for organic material collection/diversion.	Develop GHG mitigation and offset protocols for biochar/bio-oil.	Land application rules to be tested.

Table 36 – Opportunities and Constraints for Anaerobic Digestion (AD) and Nutrient Recovery

	Inputs	Activity/Process	Outputs
Science	No issues.	Develop cost-effective nutrient recovery process. Document benefits of bio-fertilizer.	No issues.
Technology	AD technology is well developed. Nutrient recovery technology is at an early development stage.	Refine solid/liquid separation-drying process; develop nutrient recovery technologies.	Bio-fertilizer packaging to meet fertilizer standards.
Markets	No issues.	Make system more cost effective/economically viable. Need to establish market value for product.	Promote market acceptance of bio-fertilizer. Measurement standards needed to determine quality of bio-fertilizer.
Policy	Enforcement of phosphate loading limit.	Develop GHG mitigation and offset protocol for using bio-fertilizers.	Land application rules to be tested for bio-fertilizer.

3.4.5.2 Total Theoretical Reduction Potential

Table 37 – Total Theoretical Reduction Potential for Waste Management

Opportunity Area	Impact (Mt CO_2e/yr)	Verifiability
Avoided Methane Emissions	3.2[1]	Programmatic Estimation
Methane Capture and Destruction	4.12[2]	Metered / Measured / Modelled
Pyrolosis and Biochar	8.27[3]	Metered / Measured
Anaerobic Digestion and Nutrient Recovery	6.31[4] + 2.31[5] (power + fertilizer)	Programmatic Estimation / Modelled
Total	**19.95-21.24[6]**	

[1] CH_4 oxidation-landfill, shorten solid manure storage, 75% efficiency.
[2] CH_4 capture/destruction: landfill, manure/wastewater, 75% efficiency.
[3] Municipal solid waste (plastics/papers), forest waste, surplus straw from agricultural land and solid collectable manure; slow pyrolysis for biochar production only.
[4] Manure, biologically digestible municipal solid wastes, wastewater from municipal and food processing sectors;
[5] Digestate from anaerobic digestion including N, P, K and stable carbon;
[6] Total includes biochar, anaerobic digestion and nutrient recovery and either CH_4 oxidation or CH_4 capture/destruction, since both of these use the same feedstock.

3.4.5.3 Impact of the Gaps/Constraints on the Reduction Potential

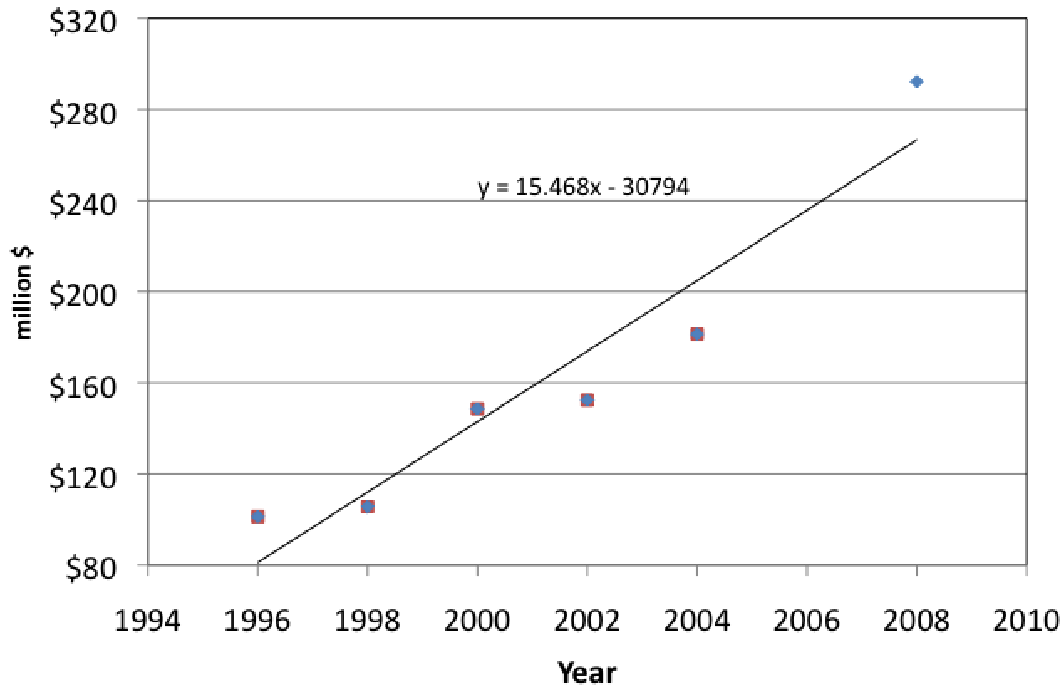
Lack of protocols and standard methods for quantifying and verifying GHG offsets are the two major constraints in realizing the mitigation potential from waste management. Demonstration of the following technologies would accelerate protocol /standard development and help realize waste management mitigation opportunities:

- High solid anaerobic digestion;
- Nutrient recovery and bio-fertilizer production; and
- Integrating waste utilization technologies with feedstock productions.

3.4.5.4 Opportunities for Innovation

Waste management has become increasingly important due to climate change concerns and increased public pressure to protect and sustain our environment. Much of what we do with our waste, from household waste and animal waste to food processing waste, needs to be changed to meet our goal of sustainability. In particular, consumption habits of the average Canadian, often referred to as the "throw away society", resulted in Canada being ranked last out of 17 countries with a "D" grade on municipal waste generation by the United Nations (Conference Board of Canada).

Each Canadian, on average generates 791 kg per capita of municipal waste each year. Furthermore, this number has been steadily increasing since 1980. In addition, modern livestock operations and the food processing industry also generate a significant amount of waste. Given this, it is not surprising that the cost of handling municipal waste has increased each year over the past decade (see Figure 2 below).



Source: "too good to waste"-gov.ab.ca /Statistic Canada

Figure 2 – Cost of Handling Municipal Waste in Alberta (1996 – 2008)

Many technologies and solutions have been developed and used to address waste management issues. One thing that is clear is there is no "silver bullet" solution since wastes are generated with widely different properties and characteristics. Composting, anaerobic digestion and pyrolysis all have been used for handling these wastes with varying degrees of success. In the case of organic waste - with significant energy and nutrient value - an integrated approach may be the best option.

Anaerobic digestion technology has many demonstrated advantages:

- It converts waste with its associated disposal problems into a resource that generates profits (see the livestock management waste section for more information);
- It can convert waste into valuable fuel;
- It can significantly reduce the need for synthetic fertilizer by nutrient recovery (see the bio-fertilizer section for more detail);
- Recovered nutrients can be processed into bio-fertilizer, which has considerably higher nutrient values, making it economical to be transported and applied over long distances and providing a solution to the problem of excess soil nutrients around intensive livestock operation sites; and

- Most importantly it can be used as a hub to integrate a number of other waste treatment technologies, livestock production and other bioprocess facilities.

Figure 3, adopted from Alberta's bioenergy program, illustrates this integration concept.

For example, if both anaerobic digestion and nutrient recovery systems were deployed together to treat municipal wastewater and solid waste, it would significantly reduce operation costs and energy requirements. As a result, GHG emissions would also be reduced.

Consider Edmonton's wastewater treatment facility (Gold Bar) and municipal solid waste composting centre:

> Gold Bar: consumes at least 5 MW of electrical power.
>
> Composting facility: consumes at least 1.5 MW of electrical power annually to process 200,000 tonnes of MSW and 25,000 tonnes of waste water treatment sludge.

If this waste was first processed with AD, it would provide at least 8.3 MW of electrical power and produce the same amount of compost, while also reducing GHG emissions. Further, the heat generated from such a system could be used to run both the AD system and bio-fertilizer production.

Integrated Bioprocessing System for Agricultural and Municipal Waste: Closing the Value-Sustainability Loop

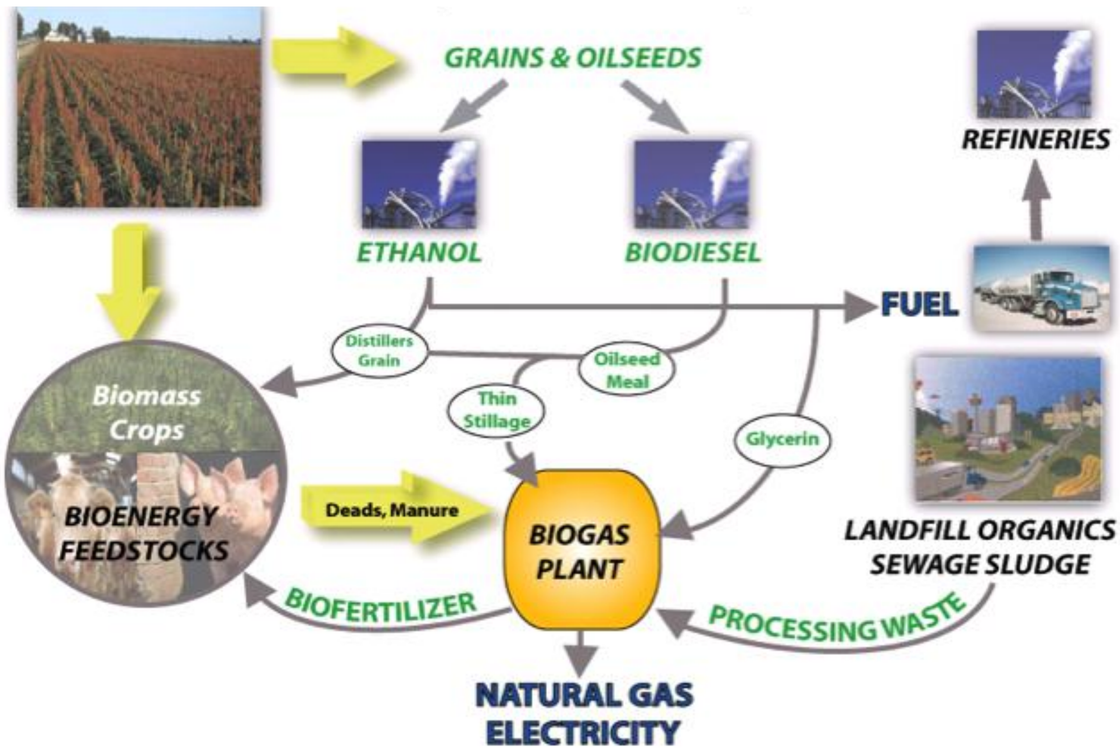


Figure 3 - A Conceptual View of an Integrated Bioprocessing System for Agricultural and Municipal Waste

If AD technology were integrated with feedlot operations and bio-ethanol production, energy consumption from ethanol production could be reduced by 30%, the operating cost of ethanol production could be decreased by 10%, water consumption associated with ethanol production could be reduced by at least 50% and GHG emissions reduced by 50% (Jenson & Li, 2003). Further, the cost of transporting animal feed would also decline.

As food-for-thought, consider the following example. We throw away vast quantities of organic waste including our household organic waste (solid waste and wastewater), animal waste, and wastewater from the Canadian food processing industry (not including solid waste from this industry). A great deal of money and energy are expended to treat this waste and we complain about how it is negatively impacting our environment. If instead this waste were used as feedstock for anaerobic digestion, nutrient recovery, bio-fertilizer production and gasification, it would be enough to generate 1800 kWh/yr of electrical power per person. This is equivalent to our per capita household electrical power consumption. At the same time, this would provide over 500 kg of bio-fertilizer/soil organic amendments, which would support approximately 360 kg of barley or wheat production. Our household power and food could therefore be produced from our waste while at the same time reducing **464 kg CO_2e** of GHG emission per capita per year.

3.4.5.5 Key Messages

The main messages for this opportunity are:

- Waste management can reduce GHG emissions while also addressing Alberta's 140+ landfill sites, 400 wastewater earth lagoons and phosphorus overloading in southern Alberta soils.
- A successful project requires multiple drivers including an integrated approach to market development, technology standardization and product valuation.
- There is an opportunity to capitalize on the multiple environmental co-benefits associated with waste management. For example, methane capture and destruction also provide a means of managing odors.
- The market for products produced through waste management activities needs to be further developed. There are dual benefits of market development and product valuation in the waste management sector: marketable products and carbon credits.
- There is a need for mitigation and offset protocols for methane avoidance, capture and destruction, biochar / bio-oil and bio-fertilizers.
- There is no single technology or solution that will address all waste issues.
- An integrated approach is crucial to achieving the government's goal of reducing GHG emissions and environmental footprint while providing opportunities for the development of value-added production.

3.5 Forestry

3.5.1 Changes in Harvesting Practice

Forest harvesting in Canada generates substantial GHG emissions. These include hydrocarbon emissions that arise primarily from compression ignition engines (typically burning diesel fuel), while biogenic emissions arise from burning the unused portion of harvested trees and unusable trees captured in the harvesting process. Canadian regulations regarding sulphur in diesel fuel have required off-road users of diesel fuel to adopt low and ultra-low diesel fuel somewhat later than on-road users. Table 38 shows sulphur limits for Canadian diesel fuel from 1998 through to 2012.

Table 38 - Sulphur Limits for Canadian Diesel Fuel (1998-2012) (Source: Environment Canada, 2011)

Sulphur Limit (mg/kg) On-Road Diesel Fuel		On-Road Diesel Fuel	Off-Road Diesel Fuel	Rail and Marine Diesel Fuel
500	Production or Import	Since 1998	June 1, 2007	June 1, 2007
	Sales	Since 1998	October 1, 2007[2]	October 1, 2007[2]
22	Sales	September 1, 2006	N/A	N/A
15	Production or Import	June 1, 2006[1]	June 1, 2010	N/A
	Sales	October 15, 2006	October 1, 2010[3]	

[1] September 1, 2007 in the Northern Supply Area
[2] December 1, 2008 in the Northern Supply Area
[3] December 1, 2011 in the Northern Supply Area

The Canadian engine emission regulations require that off-road compression ignition engines meet Tier IV emission standards by 2015. A phase-in period from 2011 to 2015 is laid out in the regulation (thus Canada is moving to align emission standards with US Environmental Protection Agency regulations).

Transportation of wood feedstocks comprise the single largest cost in Canadian forestry operations; as a result forest harvesting practices have moved to ensuring only usable portions of the harvested tree are hauled to the mill. Practices like shortwood harvesting and portable chipping are representative of this trend – they affect both harvesting emissions and product recovery.

Shortwood or cut-to-length harvesting involves using a log processor instead of a delimber. The processor is used to cut the harvested tree into standard length bolts - generally the maximum length the sawmill can use. Most commonly the processor is located at the roadside; this system is called cut-to-length at roadside. However, the processor can be built into the harvester or on a forwarder called cut-to-length at stump. Only full length bolts with the smaller end of usable diameter are cut. Thus, all pieces are usable but there is generally a piece of usable diameter less than log length attached to the top. An increase in energy is required as processors use approximately 40% more fuel than a delimber on an intensity basis. In balance harvest energy consumption for full tree and cut-to-length at roadside logging systems are essentially the same; cut-to-length at stump results in approximately 16% less energy consumption than full tree logging. Shortwood harvesting results in modest reductions in transportation fuel use; and in a substantial reduction in electrical energy consumption at the mill due to there being no need for a "cutoff" saw. Conversely, shortwood harvesting substantially increases harvest debris (slash) loading in cutblocks. Slash burning, while not counted in IPCC reporting due to its biogenic origin is the second largest emission source (after forest fires) in Canadian forests.

Portable chipping, largely confined to harvesting for pulp production, replaces stationary chipping at the pulpmill with mobile chippers used at the point of harvest. Portable chipping is used to reduce transportation costs – log trucks and chip vans both carry approximately 42 tonnes of cargo; however, the 42 tonne load of chips is functionally equivalent (in pulping terms) to 54 tonnes of logs – a greater than 20% increase in transportation efficiency. The emission reductions arising from the improved transportation efficiency of portable chipping are somewhat offset by the higher emission intensity of portable chippers. However, portable chipping also facilitates capturing more of the harvested tree – substantially reducing slash loading. This effect is more pronounced with hardwood species than with softwoods due to the broadly spreading form of many hardwood tree species.

3.5.1.1 Literature Review

Science

FERIC (Forest Engineering Research Institute of Canada) papers tend to be strongly operational in focus and emphasize cost as a metric of process improvement. The use of cost as a measure of performance is likely related to forest harvesting being largely a contracted activity. That is, the forest companies who participate in FERIC view harvesting as a bundled activity and therefore have focused research on total cost. Only very recently have larger forest companies begun to pay for diesel fuel used by contractors to buffer harvest prices from fuel price volatility. This means that forest companies, until recently, were more interested in the effects of changes in harvest practice on total cost and not on a single component of cost like fuel.

Interestingly, despite the relatively large contribution of transportation to the cost of forest products feedstocks, relatively little attention has been given to fuel consumption. Webb (2002) evaluated changes in trailer configuration and two-way hauling quantifying cost effectiveness of these approaches, but did not quantify fuel consumption independent of the overall cost of transportation. Likewise, Parker (2002) and Blair (2001) evaluated tridem drive configurations, but did not quantify fuel consumption. Fraser (2002) evaluated the effects of reduced tire pressures on transportation efficiency and road maintenance, but did not quantify fuel consumption.

Canadian literature on the mechanics and emissions of forest harvesting tends to be “grey” largely due to the fact that the primary research institute for forest harvesting research in Canada is a government – industry collaboration that is funded, in part, by voluntary industry participation and the Forest Engineering Research Institute of Canada (FERIC). FERIC policy was to undertake research by member request and frequently, to limit distribution of results to FERIC "members". Although this research is generally of high quality, it cannot be considered peer reviewed in the conventional sense. As a result, Canadian forest engineering literature is highly targeted; papers frequently address specific operational questions or regulatory concerns or requirements.

Technology (Applications/Demonstrations)

Evaluations of changes in harvesting practice have generally focused on efficiency; comparing hours of machine use per m^3 harvested, but have not quantified fuel consumption. For example, the economics of portable chipping were examined in detail (Araki, 2004) while an overview of productivity and costs associated with fuel consumption and emissions were not addressed. While some estimates of fuel consumption might be drawn from the literature, it would not be robust as fuel consumption varies with load and the studies have not addressed how loading of the engine might have changed with changes in process.

Sambo (2002) assessed energy consumption and emissions by forest harvesting and transportation for four logging systems across seven regions of western Canada. This paper provides generic baseline fuel consumption for harvesting (3.5 L/m^3) and transportation (3.6 L/m^3). Sambo converts these values into GHG emission estimates of 10.039 kg CO_2e/m^3 and 10.424 kg CO_2e/m^3 for harvesting and transportation respectively.

Markets

Forestry products extracted using the changes in harvesting practice discussed above may have added value in environmental markets due to the reduced GHG emissions. One opportunity may be to target local markets such as developers building Leadership in Energy and Environmental Design (LEED) certified buildings. LEED guidelines specify that lumber used in construction must be sourced from an area within a certain radius of the construction site.

Policy

There is a *Direct Reductions in Greenhouse Gas Emissions Arising from Changes in Forest Harvest Practices Protocol* available for use in the Alberta Offset System.

3.5.1.2 Greenhouse Gas Emission Reduction Potential

Magnitude and Verifiability

Table 39 – Emission Reduction Magnitude and Verifiability for Changes in Harvesting Practice

Opportunity Area	Theoretical Provincial Impact (Mt CO_2e/yr)	Verifiability
Changes in Harvesting Practice	<0.1[1]	Modelled

[1] Tier IV engine technology.

Justification

When assessed at the level of individual harvest block, the GHG reduction potential from changes in harvest practice are typically small and subject to reversal. Depending on the business as usual conditions, some operations may benefit greatly from changes in harvest practice while others will experience only incremental reductions or increased GHG emissions. When assessed from a provincial scale, changes in harvest practice that result in a GHG emission reduction often shift emissions (leakage) to another source or increase emissions upstream or downstream of the change in practice. Thus, the emission reduction potential of a change in harvest practice is likely neutral or near neutral with current technology when assessed across the entire industry. However, application of improved heavy duty diesel engine technology will result in GHG reductions that are not subject to reversal or leakage. US Environmental Protection Agency (EPA) data (Anonymous, 2007) indicates a modest reduction in GHG emissions from Tier IV diesel engines; as most of the improvements mandated by Tier IV emission standards focus on reduction of particulate matter (PM) and N_2O.

3.5.1.3 Gaps and Constraints

Science, Data and Information Gaps: Quantitative information about activity-specific fuel consumption by forest harvesting equipment is lacking. This limits ability to set quantitative baselines and to identify best opportunities for emission reduction.

Policy Gaps: Emission reduction standards for diesel engines and fuel regulations focus on reducing PM, sulphur and N_2O. Broadening standards to consider GHG’s is suggested.

Technology Gaps: Current engine monitoring equipment is under-utilized – forest companies could use this to better monitor fuel consumption and identify operators who use excessive amounts of fuel. Technology development or assessment research should include GHG emissions as a standard metric.

Demonstration Gaps: There are discontinuities that limit the ability to demonstrate technology. Logging contractors interact with equipment manufacturers far more regularly than forest company staff. Conversely, forest engineering researchers interact with forest companies not logging contractors. These discontinuities act to buffer technology transfer and development within the industry. This buffering is exacerbated by the competitive nature of logging contracting where contractors seek to identify, implement and hold secret improvements in process. Likewise, forest companies tend toward competition not collaboration – seeking to use advantages in harvesting activities to provide advantages in a commodity production industry. Fleet turnover times for forest harvesting and transportation equipment are approximately 10 years - extension tools that factor fuel efficiency improvement effects on operating costs and in turn how these might hasten fleet turnover are suggested.

Metric Gaps: Newer equipment is fitted with engine monitoring equipment that will provide details of engine loading, fuel consumption, use patterns, etc., all of which facilitate quantitative evaluation of GHG emissions. Older equipment lacks these refinements and is therefore less suited to quantitative monitoring. Protocols for information collection and aggregation are lacking – this limits the ability to collect and assemble information at a broader scale. Likewise, reductions in GHG emissions at the contractor or forest company woodlands level are likely to be quite modest requiring methods for data assembly/aggregation across enterprises or time. Dispersal of harvesting, transportation and reforestation across several contractors within a forest company exacerbates this challenge.

Other Gaps: The forest industry, until recently, has had a “sequestration focus” when thinking about woodlands. Exclusion of forestry activities from IPCC National Inventory Reporting has fostered this perception. Thus, awareness of the potential to reduce woodlands operations emissions is low.

3.5.1.4 Opportunities to Address the Gaps/Constraints Identified

Changes in harvesting practice showed only a small potential to reduce emissions - particularly when a life cycle analysis (LCA) approach is used to evaluate the effect across harvesting and product processing. Therefore, it would not be advisable to invest resources in addressing gaps or constraints at this time.

3.5.2 Improvements in Product Recovery

This opportunity involves using a larger portion of harvested trees (i.e. cut-off tops and other harvest debris) for other processes (i.e. woodchips).

3.5.2.1 Literature Review

Forest tenure and cutting allocations in Canada are generally associated with a forest products processing facility. In Alberta, most tenures are associated with stand-alone facilities that produce a single product or suite of products (e.g. pulpmills, sawmills, oriented strand board plants). Termed appurtency, this factor somewhat limits capturing all fibre in the harvested tree as sawmills tend to harvest only the portion of the tree useful for production of dimensional lumber. This is reflected by the fact that *all softwood sawmills* except one in the province harvest to 15/10 or 15/11 utilization standards (the first number describes required minimum stem diameter for harvest measured 30 cm above the ground; the second number describes maximum top diameter). The sole exception is an integrated sawmill - pulpmill facility which harvests to a 13/7 utilization standard. Thus, most sawlog harvesting leaves a substantial portion of harvested trees behind as cut-off tops. Likewise, smaller trees cut incidental to harvesting larger trees may be left behind entirely. A recent case study (unpublished, author data) determined that a softwood sawlog harvest of approximately 350,000 m^3 resulted in harvest debris disposal emissions of almost 50,000 t CO_2e.

A seemingly simple solution is to use a larger portion of harvested trees. This might be accomplished by allocating some of the "unusable" portion of harvested trees to another process. Alberta has led Canada in exploring this approach - with most sawmills in the province using remnant solid wood pieces (tops too small to produce lumber) to produce wood chips ("chips") for sale to pulp producers. Initiated in the late 1980's by the Alberta Forest Service (forerunner of Alberta Sustainable Resource Development) this approached fostered development of substantial softwood pulp production without increasing softwood harvest levels. The mechanism for accomplishing this was to move utilization standards from 30/16 to 15/8 and to support trades of logs for chips and to allow chip sales.

3.5.2.1 Greenhouse Gas Emission Reduction Potential

Magnitude and Verifiability

Table 40 – Emission Reduction Magnitude and Verifiability for Improvements in Product Recovery

Opportunity Area	Theoretical Provincial Impact (Mt CO_2e/yr)	Verifiability
Improvements in Product Recovery	1.25 [1]	Modelled

[1] Improved utilization standards.

Justification

This estimate is based on operational data and is not supported by the literature - in fact we were unable to find literature that specifically explored the role of utilization standards in the generation of harvesting debris and hence GHG emissions arising from debris disposal.

Mountain pine salvage and prevention harvest activities have moved utilization standards from 15/8 to 15/10 or 15/11. This translates into approximately 12.5% greater debris loads (author data). Applying a conservative estimate of a 10% increase in debris to Alberta's approximately 13,500,000 m^3 of harvest level trees, results in an increase of approximately 1,350,000 m^3. This, in turn, translates into an increased emission of approximately 1.35 Mt.

3.5.2.2 Gaps and Constraints

Science, Data and Information Gaps: Science has not focused on how changes to harvesting practices, in response to mountain pine beetle (MPB) damage, will change forest debris and disposal thereof. This is likely due to the less than catastrophic nature of MPB effects in Alberta. Instead of massive deforestation, as has occurred in British Columbia, damage has been localized and varies from intense to sporadic. Alberta has focused on pre-emptive harvest of stands at high risk of MPB infestation resulting in less beetle damaged or killed wood requiring harvest; thus, rendering most of the MPB literature somewhat less pertinent.

Policy Gaps: Forest management policy has fostered this change due to a primary emphasis on proactive MPB control. It is unlikely that current climate change policy would recognize a return to pre-MPB utilization standards as additional. A better integration between forest management - protection policy and climate change policy is clearly needed.

Technology Gaps: There are no operational technology gaps as this would entail a change back to previous practice or at most overlying previous practice on MPB salvage planning. There is a lack of repeatable, verifiable quantification technology for harvest debris. At present, post capture weighing is the only means of determining mass of debris captured and modeling is the only method of predicting the effect of changing utilization standards. A recent comparison of the Canadian Biomass Inventory mapping application and a detailed forest inventory recompiled to biomass revealed substantial discrepancies (Author data). This suggests that light detection and ranging (LiDAR) forest inventory technology may be the most appropriate tool for pre-harvest quantification and projection of debris loading.

Demonstration Gaps: There is no need to demonstrate the technology. However, there is significant need to extend information to the forest industry to help them understand the GHG implications of MPB salvage and how this might impact their business. If slash burning emissions become reportable under changed National GHG Inventory Reporting standards and Alberta's Specified Gas Emitter threshold is lowered, slash burning would result in most woodlands operations being classified as large emitters. Increased debris levels exacerbate that exposure.

Metric Gaps: See technology gaps above.

Other Gaps: Current utilization standards boost the profitability of the forest industry in the currently difficult forest products economy. Improving utilization could render already marginal enterprises unsustainable in the current business climate.

3.5.2.3 Opportunities to Address the Gaps/Constraints Identified

Markets for Alberta's traditional forest products - softwood lumber, kraft pulp, and oriented strand-board (OSB) suffered a catastrophic downturn in 2008. While pulp has rebounded to some extent the softwood lumber and OSB markets remain at historically low levels. Conversely, a variety of "novel" product producers are seeking cellulose-based feedstocks to produce solvents, biofuels and other products. The "traditional" forest industry is showing mixed responses to these initiatives. Some forest companies are engaging with novel product producers, others are setting out to develop novel processes of their own, and yet others continue to pursue their traditional product mix. Thus, there has been an unprecedented reduction in market size for traditional forest products. New markets are emerging that will likely replace some of the traditional forest products mix. For individual forest based enterprises the lack of markets is somewhat a function of how willing (or fiscally able) an enterprise is to embrace transformational change.

LiDAR forest inventory is revolutionizing the ability of forest enterprises to predict forest volume and distribution of tree sizes at the stand level. At present, research on LiDAR technology focuses on estimation of parameters surrounding traditional forest products - wood quality, pulping quality and piece size from a harvesting and transportation cost perspective. With effort and financial support, LiDAR interpretation technology could effectively quantify all potential product streams prior to harvest.

Post-harvest quantification poses more challenges. Traditional log scaling could be used but is onerous, costly and somewhat subjective.

3.5.3 Reductions in Waste Streams

If the actions suggested in section 3.5.2 are taken, pieces left behind after harvest will be small enough to limit cost effective bark removal rendering them of little value for chip production. If utilization of cut trees is to be further improved to reduce burning of harvest debris, other uses for remnant pieces must be identified. It is almost axiomatic that Canadian forest harvesting generates substantial amounts of material suitable for biomass energy production, but Canadian harvest site to processing facility distances render this material uneconomic. Given this, the literature review sought to determine the scale of the harvest debris opportunity and to identify novel approaches to transporting debris.

3.5.3.1 Literature Review

Science

Estimates of harvest debris vary widely - from as little as 20% of recovered biomass (Baxter 2002, 2004a, 2004b, 2004c, 2010; Forrester 2003) through 27% (Lindroos *et al*, 2011) to more than 30% (author, unpublished data). Variation in estimated debris levels reflect species (or species mix) harvested, harvest method (see previous section) and utilization standards. Variability is exacerbated by salvage harvests intended to capture value from mountain pine beetle killed stands (debris values ranging from 14 to 55% of original biomass (Lindroos *et al,* 2011)).

Recent research examining harvest and transportation options for woody biomass recovery (MacDonald 2001; MacDonald 2004; Lindroos *et al* 2011) provides more data on fuel consumption and emissions per unit of production.

Technology (Applications/Demonstrations)

Lindroos *et al* (2011), explored the application of operational biomass recovery practices from Scandinavia to western Canada. Specifically, they examine how biomass to energy feedstocks might be drawn from stands harvested to salvage mountain pine beetle killed trees. They evaluated three methods of slash recovery: transportation of unmodified slash, hog fuel system (roadside comminution (grinding) of slash) and bundling where slash is bundled and compressed at roadside. Evaluation criteria included costs, GHG emissions and energy balance over transportation distances ranging from on-site use through 300 km.

All methods showed a strong dependence on distance between capture and use regardless of evaluation parameter and weaker dependence on amount of biomass available. Likewise, costs and emissions for both hog fuel and bundling system were sensitive to changes in load size with increases in allowable load size, increasing effectiveness of both systems. Bundling was found to be the most effective system for moving smaller quantities of slash long distances. Given the substantial energy - GHG cost of hog fuel production, bundling and hog fuel production are generally similar when compared on these criteria. Hog fuel production is more effective than bundling when moving large amounts of slash up to 100 km. This aligns with current operational practices in Alberta. The authors suggest that an energy value of $16/MWh would provide a 20% profit margin to hog fuel based biomass salvage operations which is similar to natural gas based electrical production costs of $13.5 to $16.2 per MWh for gas prices of $3.75 and $4.50 per Gj based on Alberta Gas pricing[19]. At present, seven biomass fuelled cogeneration facilities operate in Alberta (Alberta Energy data[20]). Of these seven all but two are associated with kraft pulpmills and thus use black liquor or other pulpmill waste as a primary fuel source.

Markets

MacDonald (2001) examines cost of debris disposal in coastal sort yards (Sort yards are used to gather logs from dispersed harvest areas and allocate them to specific users). In this examination he explores the GHG emissions and costs of debris disposal finding that total emissions were lowest when debris was chipped for pulp production or turned into hog fuel as appropriate to the size and condition of the debris. This was also the lowest dollar cost method of debris disposal. Converting all the debris into hog fuel with a hog fuel grinder was the second most effective disposal alternative in GHG emission terms, but was equal in cost to the most costly method of disposal. Thus, deriving mixed product values was the most cost effective way to manage debris.

This approach suggests the greatest opportunity for forest fibre based GHG mitigation is likely to develop integrated multiple product systems. These could rely on development of sort yards with year round transportation access - preferably to both highway and rail transportation. Whole logs - with only the fine top (<7-cm) and foliage removed would be hauled to the sort yard (this system would best suit coniferous trees as removing large branches is necessary for hauling aspen). The trees would be separated into feedstocks for two or more processes in the sort yard. For example, sawlog material might be cut from the tree then the remainder further separated and processed into pulp chips and hog fuel. This approach would lend itself to improved transportation efficiency through drying of the tree, effectively "densifying" feedstocks prior to transportation and/or to intermodal freight switching to facilitate moving lower value feedstocks (pulp chips and hog fuel) longer distances.

At present, aspen harvesting is less amenable to the entire application of this approach, but the two largest harvests of aspen in Alberta use portions of it. DMI uses portable chipping which results in a substantial increase in utilization of the harvested tree co-implemented with hog fuel capture using a hog grinder within an economically determined radius of their biomass to energy facility. Alberta Pacific Forest Industries delays hauling logs for six to eight months after

[19] http://www.gasalberta.com/pricing-market.htm
[20] http://www.energy.gov.ab.ca/Electricity/682.asp

harvest, storing them on the landing at harvest and hauling them the following winter after they have had a summer to dry.

Policy

There is currently no protocol for reductions in waste streams under the Alberta Offset System. Further, under current Alberta Sustainable Resource Development policy carbon ownership falls to the party who harvest the tree, once it has been harvested. If trees were to be partitioned for various use streams, policy would be needed to clarify how carbon ownership would be assigned amongst actors.

3.5.3.2 Greenhouse Gas Emission Reduction Potential

Magnitude and Verifiability

Table 41 – Emission Reduction Magnitude and Verifiability for Reductions in Waste Streams

Opportunity Area	Theoretical Provincial Impact (Mt CO_2e/yr)	Verifiability
Reductions in Waste Streams	4.0	Modelled to Metered / Measured

Justification

To estimate the potential impact of reductions in waste streams a forest residue case study was used. The case study (shown below) includes both coniferous and deciduous harvest as well as the additional emissions for transportation of waste from the harvest site to the mill.

Table 42 – Forest Residue Capture Case Study

Factor	Amount	Units	Data Source
Annual Allowable Cut – FMA and Quota			
Deciduous	10,662,000	m^3	AFPA Data, 2007
Coniferous	15,506,000	m^3	AFPA Data, 2007
Residue Load			
Deciduous	27	%	FERIC Advantage Paper Vol.3, No.49
Coniferous	22	%	Lindroos et al. (2011), adjusted for improved utilization
Percent of Residue – Foliage, Fine Branches			
Deciduous	7	%	Unpublished – Author Data
Coniferous	5	%	Unpublished – Author Data
Available Residue - Volume			
Deciduous	2,677,228	m^3	
Coniferous	3,240,754	m^3	=Annual Allowable Cut x (Residue Load – Fine Residues)
Density			
Deciduous	360	kg/m^3	USDA Forest Service - Aspen
Coniferous	400	kg/m^3	USDA Forest Service – White spruce, lodgepole pine
Available Residue - Mass			
Deciduous	963,802	T	= Available Residue Volume x Density
Coniferous	1,296,302	T	= Available Residue Volume x Density
Emission Factor for Residue Burning (EF_B)	1,827	g/kg	1996 NIR
Deciduous	1,760,867	T	= Available Residue – Mass x EF_B
Coniferous	2,368,343	T	= Available Residue – Mass x EF_B
Transportation Emissions			
Fuel use per m^3	3.6	L	Feric Advantage Paper Vol.3 No.29 (Araki, 2002)
Fuel Use Transport Deciduous	9,638,022	L	
Fuel Use Transport Coniferous	11,666,714	L	= Available Residues – Volume X Fuel Use
Emission Factor Off-road Diesel (EF_D)	2790	g CO_2e/L	2011 NIR
Emissions Deciduous	26,890	T	= Fuel Use X EF_D
Emissions Coniferous	32,550	T	= Fuel Use X EF_D
Potential Emission Reductions			
Deciduous	1,733,976	T	
Coniferous	2,335,793	T	
Total	4,069,769	T	

3.5.3.3 Gaps and Constraints

Science, Data and Information Gaps: See previous discussion - primary science-data gap is the availability of reliable, stand-level (i.e. operationally applicable) inventory data. LiDAR based inventory modelling shows promise to address this gap, but is currently highly developmental for obtaining piece-size information (Canadian Wood Fibre Centre and several forest inventory consulting firms are all seeking to develop piece-size inventory systems).

Policy Gaps: Current Alberta Sustainable Resource Development policy[21] interprets carbon ownership and by inference offsets accruing from the use of the tree as the property of the actor harvesting the tree. This policy will require refinement to support partitioning of trees prior to processing among two or more users. Current partitioning of the tree occurs after processing of the "primary" product. A paradigm where a sort yard is used to separate trees and parts of trees into various use streams would require clarification as to how carbon ownership would be assigned among actors.

Transportation efficiency opportunities are limited by railroad operator reluctance to support intermodal switching at the small scale associated with forest harvesting - even when the entire harvest of a medium sized forest management agreement area is included in the effort. Thus, there is a need for policy to incent or support railroad participation.

Technology Gaps: Transportation costs are substantial and are exacerbated by separating product streams at the landing. This increases handling costs and makes residue pieces more difficult to transport. Current facility-based processing technology is product specific - sawmills produce lumber and pulp chips, pulpmills produce pulp chips and OSB plants produce OSB feedstock. This limits the ability to exchange product streams. Presently, multiple product technology does not exist. Early efforts at generating multiple product streams are focusing primarily on integrating existing technology such as:

- Portable cut-off saws for separation of trees into component pieces;
- Portable de-barker/chippers to generate pulp chips; and
- Portable hog fuel grinders to produce hog fuel.

While functional, this approach does not support the full integration of process and product streams that would result in the greatest energy efficiency and GHG mitigation. For example, portable pellet mills capable of producing torrefied wood pellets. Technology focusing on production of emerging forest products with higher potential value and GHG mitigation potential (e.g. fermentation derived feedstocks, rayon, etc.) is developmental and generally substantial in size and cost - there is little apparent effort on developing portable feedstock processing.

[21] http://www.srd.alberta.ca/LandsForests/ForestBusiness/BioproductsFromForestFibres/documents/ForestBiofibreCarbonSequestionBenefitsApr2010.pdf

Demonstration Gaps: At present, integration of product streams is largely conceptual. Demonstration is needed to test policy, technology and operability.

Metric Gaps: Inventory for planning and estimating project outcomes is lacking - LiDAR may fill this gap. Metrics to integrate GHG effects across multiple users, projects and processes are almost entirely lacking. For example, the current forest harvesting protocol specifically excludes quantification of cutblocks where hog fuel grinding occurred.

Other Gaps: Market pull is currently lacking, for example:

- Biomass to energy facilities are generally operation specific in scale;
- Novel forest product production is somewhat speculative, at present;
- Co-firing capability of existing or planned coal fired power generation is largely unexplored;
- Infrastructure to utilize substantial heat products from combined heat and power (CHP) facilities is lacking; and
- Electrical transmission infrastructure is needed to move electrical production to point of use.

Financial constraints arise from the lack of market pull, including:

- Lack of capital to support increasing the capacity of existing biomass to energy or CHP facilities;
- Lack of funds to support integrated transportation systems - e.g. sidings and material handling to support intermodal freight shift.

3.5.3.4 Opportunities to Address the Gaps/Constraints Identified

Policy gaps could best be addressed through facilitated discussion between forest industry, policy makers (in both forest management and climate change) and agencies active in facilitating biological opportunity development.

Technology gaps could be addressed by emphasis on GHG mitigation efforts in forest operations research and by making data more generally available (Many forest companies have abandoned participation in FERIC due to perceived high membership costs. This makes the opaque FERIC research model limiting.

Demonstration gaps would be best addressed by initiating a transparent demonstration between two or more industrial partners, the railroad, Alberta Sustainable Resource Development (ASRD), Alberta Environment and Water (AEW) and other interested parties to explore the mechanics, policy and operation of an integrated wood supply system.

Metric gaps are being addressed through on-going LiDAR development[22] for project planning. Tools to integrate GHG outcomes across multiple users and processes need to be developed.

Other gaps, while not insuperable, are substantial in scale and cost. It is likely that some of them will be overcome by existing infrastructure projects (e.g. electrical transmission capacity) while others will require partnerships between industry sectors (e.g. forestry and coal-fired electrical generation or forestry and users of high value wood feedstocks). Others will require capital ventures between the forest industry and municipalities.

3.5.4 Forestry Summary

The forestry section of this report includes reductions from 1) Changes in harvesting practice, 2) Improvements in product recovery and 3) Reductions in waste streams. Evaluation specifically excluded GHG mitigation at processing facilities as these have been regulated to substantially reduce emissions and incented to do so by both the Green Transformation[23] program and by the Forest Products Association of Canada[24].

The following summary covers opportunities and constraints, total theoretical reduction potential, impact of the gaps/constraints on the reduction potential and key messages across these three opportunity areas.

3.5.4.1 Summary of Findings

Changes in harvesting practice showed only a small potential to reduce emissions - particularly when a life cycle analysis (LCA) approach was used to evaluate the effect across harvesting and product processing.

Improvements in product recovery had a reasonable mitigation potential and are likely most easily realized from a technical perspective as it focuses on improved use of current harvest levels. Unfortunately, this opportunity is difficult to realize from a financial perspective as it would substantially impact the profitability of the forest industry.

Reductions in waste streams, while similar to the previous opportunity, have substantially larger reduction potential because they permit a more integrative approach to mitigation activity and

[22] http://foothillsresearchinstitute.ca/pages/home/Blog.aspx?id=2437
http://www.feric.ca/en/index.cfm?objectid=3EAB15F6-C299-54C5-1E5509D63985E846
http://www.tesera.com/index.php/forest-resource-planning-projects/82-lidar-based-forest-inventory-to-support-enhanced-forest-management-to-minimize-damage-from-mountain-pine-beetle-infestations
[23] http://cfs.nrcan.gc.ca/pages/231
[24] http://www.fpac.ca/index.php/en/environmental-progress/

may support a more profitable overall approach. This approach relies on integration of feedstock flows between forest-based processing facilities, somewhat decoupling the direct link between forest and processing facility. Further, it seeks to allocate feedstocks to the most profitable and most energy efficient use while incorporating much of current waste streams into low cost product streams. Similarly, it proposes integration of transportation efficiency (densification) and modal freight switching to enhance movement of lower value components to locations with the capacity to use them. This opportunity requires substantial technical and policy support to realize, as it effectively seeks to shift the paradigm of how forest harvesting and forest product processing interact, re-defining current forest wastes as part of an integrated feedstock plan.

The following table summarizes the opportunities and constraints across all three forestry reduction opportunities. The table is broken down into three categories: inputs, activity and outputs; and covers science, technology, markets and policy. The inputs column refers to the inputs needed to accomplish the activity. The activity column refers to the change in practice itself and the outputs column refers to the product.

The table is also color coded. Red indicates an area where there are no issues or there is no opportunity for investment. Yellow represents an area with some potential; however, at present this area is not a priority and areas shaded in green highlight the best opportunities for investment.

Table 43 - Opportunities and Constraints for the Forestry Sector

	Inputs	Activity	Outputs
Science	Narrow focus[1]. Emphasis on waste recovery not value capture.	Somewhat de-emphasized due to a perceived "glut" of wood.	Accurate estimates exist, but potential is essentially unrealized.
Technology	Largely follows science.	Industry players seek to develop their own technology emphasizing biomass to energy, pyrolysis, or integrated product capture[2].	None to date. Industry explorations remain experimental and the potential unrealized.
Markets	Numerous bio-mass and cellulosic feed stock processes require supply (e.g. cellulosic ethanol, pyrolysis, high value fuels, rayon).	Numerous negotiations underway. Largely confidential and experimental. Developmental technologies are being calibrated by industry collaborations.	Mill wastes have effectively met needs of biomass to energy interests. Novel products sector interested in "commercial wood" not "waste." Value of "waste" does not support transportation in a conventional approach.
Policy	GHG policy supports engagement. Forest management policy enables engagement. Forest industry development also supports.	Some protocols are in place. Need to clarify the potential and role of more novel processes (e.g. pyrolysis, cellulosic ethanol, etc.)	Clarification on stumpage is needed, particularly across multiple users of a single tree. Brokering of value of "commercial wood" between existing fibre-based industry and emergent bio-industries.

[1] Research has waited until logging is completed and then addresses capturing waste.
[2] Harvest the entire tree less limbs and foliage. Move the tree to an intermediate processing facility and draw sawlog, pump and biomass from it.

3.5.4.2 Total Theoretical Reduction Potential

Table 44 – Total Theoretical Reduction Potential for Forestry

Opportunity Area	Impact (Mt CO_2e/yr)	Verifiability
Changes in Harvesting Practice	<0.1	Modelled
Improvements in Product Recovery	1.25	Modelled
Reductions in Waste Streams	4.0	Modelled to Metered / Measured
Total	**<5.35**	

3.5.4.2 Impact of the Gaps/Constraints on the Reduction Potential

Constraints effectively reduce improvements in product recovery to negligible levels. Likewise, current realization of reduction in waste streams is less than 0.5 Mt per year. The forest industry does not realize that the scale of debris disposal emissions constitute an uncontrolled risk. This has led to interest in how these emissions might be reduced so industry engagement in resolving constraints is likely to be high.

3.5.4.3 Key Messages

The main messages for this opportunity are:

- Market pull is high for "easy-to-use" fibre; the pull for current waste streams is lower. This depresses the value of currently "non-merchantable" fibre. Current value is less than cost of procurement (principally transportation).
- Integration of product flows may provide a path forward:
    1. Allocate portions of the tree prior to harvest - e.g. lower bole to sawlog production, mid-bole to novel cellulose-based process, upper bole to biomass to energy process.
    2. Integrate harvest and transport to meet all supply stream requirements.
    3. Seek transportation efficiencies to overcome lower product values. For example:
        - Move limbed, but otherwise whole trees to a sort yard with highway and/or rail access.
        - Separate boles into components (as discussed above).
        - Allow sawlogs to dry for several months to reduce weight (i.e. densification).

    - Process other portions of the stem into usable feedstocks.
    - Ship using the most cost and emission effective method (e.g. transportation efficient trucks, rail).
- Need to clarify how harvested wood that is being directed to multiple industrial processes will have stumpage and ownership assigned.

The best opportunities for this area are to:

- Integrate improvements in forestry into broader initiatives.
    - e.g. untopped tree sortyards to dry down trees, remove tops and change them into product instead of waste.
- Improve integration between forest entities. This will yield the greatest reductions.
    - e.g. whole tree to sortyard – sawlog to sawmill, top to pulpmill, chips from sawmill to pulpmill, sawdust/shavings and pulpmill sludge to cogeneration.
- Integrate forestry tree use efficiency with transportation efficiency through load densification and modal freight switching.

3.6 Peatlands

3.6.1 Avoided Peatland Disturbance and Improved Peatland Management

Disturbed peatlands are potentially a significant source of GHG emissions. Alberta peatlands contain an estimated 13.5 Pg of carbon (Vitt, 2006), with the most common peatland types, wooded and shrubby fens, possessing a carbon density of 0.055 ± 0.003 g C cm^{-3} (Vitt et al., 2000). The need for improved peatland management in the face of increasing disturbance by oil and gas development has long been recognized (e.g., Vitt, 2006) but substantial research still needs to be done (Osko, 2010). A peatland criteria for Alberta that recognizes carbon sequestration as a valued function is urgently needed, as is the development of methods to measure or quantify the desired carbon function (Locky, 2011).

Improved peatland management has the potential to mitigate GHG emissions through avoided peatland disturbance, including avoiding peatland types known to have a greater impact on GHG emissions, and through improved peatland reclamation and water management. At this time, these opportunities for GHG mitigation are not sufficiently supported by science and established procedures. Once established, improved peatland management has a substantial mitigation potential as it represents a pool of carbon several orders of magnitude higher than any other biological source in Alberta.

3.6.1.1 Literature Review

Basic science is lacking for some peatland types, and the literature is often contradictory. Climate change (warmer and drier) was found to improve carbon sequestration in a northern Alberta treed fen while the reverse was true for an eastern bog (Canadian Carbon Program, 2011). Basic quantification of GHG's, particularly CH_4, is not available in a standardized format suitable for developing a mitigation project for most types of peatlands. For example, it is known that CH_4 fluxes are lower from bogs with thick acrotelm (a live layer of moss at the surface where oxidation occurs) and permafrost than from fens (Vitt et al., 2000), but how much lower and what role other factors such as temperature and moisture play are not well defined. It is estimated that approximately 50 years is required to compensate for CH_4 releases by natural disturbance such as fire (i.e., the break-even point). The break-even point for anthropogenic disturbances is unknown.

The literature shows that not all peatlands are consistent sinks for carbon. Treed and shrubby fens are more productive and have the greatest potential for carbon sequestration (Canadian Carbon Program, 2011) and bogs are generally slower to accumulate carbon and may be emission sources during warm and dry years. Therefore, lowering the water table typically increases carbon sequestration on treed or shrubby fens but may increase carbon emissions from bogs. Raising the water table has the opposite effect and often kills woody vegetation and alters the moss community.

In addition to avoided disturbance, rapid reclamation of disturbed peatlands to restore the carbon sequestration function (Vitt, 2006), and avoided conversion to upland may be desirable GHG mitigation strategies. Depending on the peatland type (i.e., treed or not, fen or bog, permafrost present or no permafrost), conversion to upland will reduce the carbon sequestration potential and may increase CH_4 release from buried peat. In order to implement rapid restoration and/or avoided conversion to upland, proven reclamation techniques are needed.

Two peatland reclamation techniques are currently being trialed in Alberta for oil and gas surface disturbances that have potential for GHG mitigation. The first is the approach of Vitt *et al* (2011) that establishes plants directly on wet mineral soil left over from well pads to begin the process of paludification (accumulation of dead organic material) and, over time, re-establishes a peatland. The second approach being trialed is the North American Approach (Rochefort et al., 2003). This approach has proven successful on peat mined lands in eastern Canada and for fens (Cobbaert et al., 2004). The North American Approach involves the transfer of live moss from donor sites and has the best potential to achieve the desired rapid restoration of peatland function; including carbon accumulation and CH_4 oxidation.

3.6.1.2 Gaps and Constraints

Basic science is lacking for some peatland types, and the literature is often contradictory. Also, reclamation methods and strategies are still in early testing stages and the long-term viability of reclaimed peatlands is unknown.

3.6.1.3 Opportunities to Address the Gaps/Constraints Identified

The substantial mitigation potential for peatlands cannot be realized until the required science and reclamation methods are in place. Opportunities exist to support collection of basic science and to expand upon existing research and monitoring programs in Alberta. In addition, the high cost of reclamation is limiting the number of peatland reclamation trials underway (i.e., the North American Approach). The science must be further established and the technologies for reclaiming peatlands proven to support future GHG mitigation projects.

3.6.2 Peatlands Summary

Opportunities for GHG mitigation are not sufficiently supported by science and established procedures. Once established, improved peatland management has a substantial mitigation potential as it represents a pool of carbon several orders of magnitude higher than any other biological sources in Alberta.

A number of key findings have been identified:

Key Learnings:

- Alberta peatlands contain an estimated 13.5 Pg of carbon.
- Contradictory trends in response to climate change have been observed for different peatland types.
- Basic science is lacking.
- Peatland avoidance and improved management have huge climate change mitigation potential.

The best opportunities for this area are to:

- Support collection of basic science.
- Support existing and new or additional monitoring across the range of peatland types.

4. Summary and Conclusions

This report built on previous work completed for Climate Change and Emissions Management Corporation (CCEMC) on biological greenhouse gas (GHG) mitigation. Specifically: 1. *Enhancing Biological GHG Mitigation in Canada: Potentials, Priorities and Options* and; 2. *Biological Opportunities for Alberta.* These reports concluded that in order to meet the GHG reduction targets being contemplated in North America by 2020, Alberta requires a "next wave" of GHG reduction and mitigation. Biological capture and fuel replacement strategies were seen as the most efficient mitigation options readily available for Alberta.

This report directs the potential possibilities for development of an investment road map on how to efficiently engage the biological sector in achieving meaningful GHG reductions. Areas covered included:

1. *Nitrogen Management* – includes reductions related to soil nitrogen management (integrated BMPs variable rate technology), irrigation management and switching to bio-fertilizers;
2. *Livestock Management* – includes beef and dairy cattle emission reductions, farm energy efficiency improvements, swine reductions and improved manure management;
3. *Transportation* – includes intermodal freight shift, improved fuel efficiency, fleet management, transportation efficiency and fuel switching;
4. *Waste Management* – includes avoided methane emissions, methane capture and destruction, pyrolysis/biochar and anaerobic digestion/nutrient recovery;
5. *Forestry* – includes changes in harvesting practice, improvements in product recovery and reductions in waste streams and;
6. *Peatlands* – includes avoided peatland disturbance and improved peatland management.

The area that showed the largest emission offset potential was Waste Management, with a potential of 19.95-21.24 Mt CO_2e. The lowest total emission reduction potential would be achieved with changes in Transportation. In total these practice changes were estimated to provide only 1.65 Mt CO_2e in potential emission offsets. The report was unable to quantify the potential offset of peatland reclamation and avoidance, due to a lack of available scientific data. However, the offset potential is assumed to be of significant value.

4.1 Technology Development Opportunities

The following section evaluates technology development opportunities for each sector of biological GHG reductions covered in this report. In particular, emphasis is placed on technology development opportunities that may offer breakthrough solutions for biological GHG reductions.

4.1.1 Nitrogen Management

To accelerate deployment of N_2O emission reductions in the cropping sector of Alberta, there is a need to invest in demonstrating the benefits of variable rate technologies, from a yield perspective, saved input costs and decreased GHG emissions/revenues from carbon offsets. By supporting enabling projects which can implement the Alberta *Nitrous Oxide Emission Reduction Protocol* across a number of participating farms, producers will have the opportunity to engage in an aggregation platform that will bring forward the ability to choose flexibility in implementation and realize market potential from the sale of carbon offsets. The information and knowledge generated by these demonstrations will inform larger programmatic approaches to implementing emission reductions across a larger scale.

4.1.2 Livestock Management

The metrics/protocols are largely in place to enable emission reductions from the cattle, dairy and swine sectors. What is needed to achieve large reductions at scale, is assistance to livestock operators in implementing the changes in practices and outcomes necessary for meaningful GHG mitigation in their sectors. Livestock operators and their advisors will need the appropriate supportive infrastructure to help them correctly implement the mitigation strategies in the protocols, and provide the catalyst for developing these into aggregated platforms to achieve cost-effective reductions. New kinds of support from other sources of infrastructure are needed, and can be evolved into a programmatic approach, while helping to build the data management and collection platforms needed for verifiable GHG reductions. Such infrastructure is only beginning to emerge, and accessing this emerging infrastructure is not commonplace for livestock operators (as was found in the Dairy Pilots currently underway in Alberta). The lack of, or limited access to, such infrastructure is a barrier to adoption. Undertaking livestock pilots, similar to the Dairy Pilots in Alberta, would identify the data and farm record gaps in implementing the protocols, and allow solutions to emerge, while building capacity in the sector in the short to medium term.

4.1.3 Waste Management

In order to accelerate technology development in the waste management sector and capture this market opportunity, demonstration projects in the following three areas are critically needed:

1. Deployment of high solid anaerobic digestion
2. Nutrient recovery and bio-fertilizer production
3. Integrating waste utilization technologies with feedstock production

Data from these demonstration projects could then be used to develop standardized designs and monitoring protocols for waste management activities. Further, economic assessment guidelines for other technology developers could be created.

4.1.4 Transportation

Technological development is not a significant barrier to GHG reductions from transportation of biological products. The SmartWay Program and the soon to be released SMARTWAY Canada program include mandates to test and verify the numerous technologies already available in the marketplace for improving transportation efficiency. Technologies for load management, including densification, are also common in the marketplace. However, it is likely that existing technologies will require modification to meet the needs of diverse biological products, particularly agriculture products. Transportation of agricultural products often poses additional challenges in transportation and handling due to the delicate and/or time sensitive nature of many of the products, as well as the higher standards required if the products are for human consumption or animal feed.

4.1.5 Forestry

Several developmental technologies would support GHG mitigation in forestry. LiDAR based forest inventory - refined to reliably predict piece size at the stand level - is of great importance as it would support pre-harvest optimization of product streams. This would facilitate a reduction of waste and provide an accurate estimate of waste (at present, there are several LiDAR technologies advertised as producing accurate projections of piece size. An objective evaluation and reporting on these technologies would be most beneficial. Wood moisture content determination tools designed for use with decked logs would support the "densification" approach outlined in this report. Many of the transportation technologies discussed under Transportation Efficiency (see Section 3.3) could be refined for combined off-road/over the road use allowing them to be co-implemented with the product stream integration and "densification" approach discussed.

4.1.6 Peatlands

The greatest technological challenge for mitigating GHG emissions with improved peatland management is the lack of established and proven reclamation techniques to restore desirable functions; including carbon sequestration and CH_4 oxidation. In particular, successfully adapting the North American Approach of peatland reclamation for use with oil and gas disturbance has huge potential due to the backlog of thousands of well-sites and roads waiting to be reclaimed. Peatland reclamation trials currently underway are of limited scope and/or without the replication required to properly assess the techniques being trialed. In addition to establishing techniques for peatland reclamation, it is foundational that the scientific knowledge gaps regarding peatland response to disturbance be filled.

4.2 Engaging the Biological Sector

This section provides recommendations on how to effectively engage Alberta's biological GHG sectors through communication activities, strategic partnerships and effective information sharing. The recommendations are broken down by each of the sectors covered in this report.

4.2.1 Nitrogen Management

A strategic partnership involving entities like The Canadian Fertilizer Institute (sponsoring entity of the Alberta Protocol), the Alberta Extension and Research Council, Alberta Agriculture and Rural Development, existing project developers/aggregators in the Alberta system who provide agronomic and extension services to producers, along with the firms who provide the technical services to implement the *Nitrous Oxide Emissions Reduction Protocol* will need to be coordinated to achieve success. Further, engagement with the Alberta Institute of Agrologists (AIA) to provide the qualified professionals required to sign-off on the 4R Nitrogen Plans will need to occur. The AIA is currently organizing a Practice Standard for Agrologists in the Carbon Marketplace, starting with the cropping sector.

4.2.2 Livestock Management

Large gains in emission reductions can be achieved through large scale implementation of the beef protocols; less so from Dairy and Pork given the relative size of the sectors. The Dairy Pilot in Alberta has demonstrated the kinds of strategic partnership needed to roll out a successful pilot. Endorsement and support of the national and provincial Milk Board chapters, as well as supporting third party data management entities (Milk recording agencies) in the Dairy sector has enabled rapid enrolment of producers and engendered an atmosphere of trust and willingness to discover the solutions to implementing emission reduction strategies on Alberta dairy farms. For the Beef Sector, engagement with third party data managers like Feedlot Health Management Services, Alberta Beef, Canadian Cattlemen's Association, and CCIA will be critical. The Cattle Feeder Association and the RFI testing labs will also be needed. Alberta Agriculture and Rural Development's Traceability Initiative, Agriflexibility funding and the Alberta Meat and Livestock Agency can also provide additional funding to support engagement in the beef sector.

4.2.3 Waste Management

There is an immediate need for an Alberta based biomass/bio-waste inventory and bioenergy assessment. If this need were fulfilled it would help engage the biological sector. The goal of this inventory/assessment should be to identify, categorize and geographically map potential bio-resources in Alberta including field residues, animal manures, forestry residues, food packing/processing waste and municipal wastes. Once created, this type of inventory could be used to calculate potential energy production through anaerobic digestion/nutrient recovery, pyrolysis and/or other conversion technologies. Data on biomass and bio-waste type and geographic distribution is therefore critical in determining project feasibility. It is recommended that this project be designed by a group of experts and tendered out through an RFP. Further, the resulting inventory should be made publicly available.

There is also a critical gap in bio-fertilizer and biochar policy development and market uptake. In order to begin to address these gaps, long term studies on the benefits of bio-fertilizers and biochar on land productivity and GHG emissions need to be conducted. It is recommended that this research be led by a University, but managed by a steering committee. Further, the experimental design and data analysis should be developed in consultation with industry. Ideally, any field data resulting from this research would be made publically available.

Education and outreach activities could be conducted in collaboration with Alberta's educational institutes such as NAIT, SAIT, Lakeland College and Olds College. In particular, existing programs such as NAIT's Renewable Energy Program and Lakeland College's Renewable Energy and Conservation Program could be engaged to develop training courses on waste to energy and other value-added products. It is recommended that these training programs be targeted for specific certifications in operating waste-to-value-added facilities. There is also an opportunity to work with producer groups, the Alberta Association of Municipal Districts and Counties and other rural Alberta organizations to conduct workshops that use case studies to present Alberta's biological opportunities.

4.2.4 Transportation

At the scale of an individual project or operation, the GHG mitigation potential from transportation is relatively small due to the gains in transportation efficiency already achieved over the last few decades. However, due to the considerable amount of transportation that is required for biological products, substantial GHG reductions can still be achieved. Due to the critical importance of transportation to the economy of Alberta, programs and policies are already in place to communicate and provide accurate and reliable information on technologies. The extent of adoption or awareness of these technologies in the transportation of biological products is unclear. Communication strategies that promote the potential fuel savings rather than GHG reductions will have a better chance of success. GHG mitigation is an ancillary benefit of fuel saving and will remain so until GHG reduction can be monetized. As fuel costs continue to increase, additional opportunities to engage the transportation sector with proven fuel saving technologies will occur. Once protocols and methods for quantifying GHG reductions are in place, existing industry organizations can be engaged in a meaningful way.

4.2.5 Forestry

Alberta's forest industry has largely shifted its focus on woodlands GHG mitigation from sequestration through reforestation to direct reduction. This has been prompted by a growing awareness that slash burning for woodlands waste disposal results in substantial GHG emissions. While these emissions are not considered under current IPCC accounting rules, they do present a significant reduction opportunity provided transportation hurdles associated with moving relatively low value material long distances can be overcome. Slash burning also presents a significant risk should IPCC rules change and Alberta's Specified Gas Emitter Regulation hurdle level be reduced. If the transportation challenge can be met, any net income realized would contribute greatly to forest industry stability in the face of unprecedented low forest commodity prices. Concurrently, there is significant market pull for wood fibre as feedstock for "novel" products different from the existing commodity product streams. Finally, there are numerous possibilities to improve fibre transport (see Section 3.3). Thus, forest industry engagement might best be gained through integration of these disparate economic factors into a more coherent approach that assists the industry in better understanding how these opportunities and challenges might be combined into company or sector specific plans to reduce GHG emission exposure and add value.

4.2.6 Peatlands

The GHG mitigation potential from improved peatland management is limited by fundamental gaps in our understanding of the effects of disturbance on peatlands and of effective reclamation techniques. To collect the required foundational science, support for existing programs operating in Alberta (e.g., Canadian Carbon Program) or of researchers and programs located at Alberta universities and colleges will be required. To ensure results, it will be necessary to structure support in a manner that ensures research objectives and outcomes yield the desired information. In addition, support for expanding reclamation trials to develop techniques that restore key peatland functions is required. At present, a numbers of individual companies, industry research groups and researchers are supporting an array of research and trials. The small scope and narrow objectives of most of these trials will not provide the necessary information; however, it may be possible to build upon these existing programs. Building upon existing programs is preferable to supporting new initiatives because of the logistical constraints and high costs of peatland reclamation.

4.3 Recommendations

The above report presented The Prasino Group and Associates findings on the gaps and opportunities for advancing meaningful biological greenhouse gas (GHG) reductions in Alberta. A number of opportunity areas across the biological sector were discussed and opportunities/constraints identified. In this section each of these opportunity areas is evaluated based on its reduction potential, verifiability and whether or not the tools (i.e. protocols) are in place for validating and verifying the project type. Based on these three factors each opportunity area was given one of three project classes:

1. *Enabler* – Opportunity areas that are ready for demonstration and have a total reduction potential of greater than 1 Mt CO_2e/yr across the biological reduction sector.

2. *Accelerator* – Opportunity areas that either have a small total reduction potential (less than 1 Mt CO_2e/yr) or do not have all the necessary measurement tools in place for project validation and verification (i.e. protocols)

3. *Technology Opportunity* – Opportunity areas lacking the science and/or data to calculate a theoretical reduction potential and the necessary tools for project validation and verification. A significant amount of work is still needed in these areas before they will be ready for further development.

The vast majority of the opportunity areas under one biological reduction sector are assessed as a group. However, in the cases of Nitrogen Management and Improved Manure Management this was not possible due to the presence of an opportunity area under these sectors that lagged significantly behind in terms of level of development. As a result, under these two biological reduction areas, opportunity areas are assessed separately. Table 45 below presents the results.

Table 45 – Summary of Total Theoretical Reduction Potentials Across all Opportunity Areas

Biological Reduction Sector	Opportunity Area	Reduction Potential (Mt CO_2e/yr)	Verifiability	Protocol in Place	Project Class
Nitrogen Management	4R's Variable Rate Technology	Basic – 0.58 Advanced – 0.97	Modelled	Yes	Enabler
	Irrigation Management	Unquantified	Unquantified	No	Technology Opportunity
	Bio-fertilizers	0.97	Metered or Measured	No	Accelerator
	Total	**1.55 to 1.94**			
Livestock Management - Beef & Dairy Cattle	Reduced Days on Feed	0.13	Modelled	Yes	Enabler (opportunity to build on dairy pilot)
	Reduced Age to Harvest	3.34	Modelled	Yes	
	Feed Supplement – Edible Oils	0.43	Programmatic Estimation	Yes	
	Residual Feed Intake (RFI)	0.056	Programmatic Estimation	No[25]	
	Ration Manipulation (ionophores)	0.064	Modelled	Yes	
	Reducing Replacement Heifers (30%)	0.072	Modelled	Yes	
	Total	**4.092**			
Livestock Management – Farm Energy Efficiency	Poultry (fans, lighting)	0.064	Modelled	Yes	Accelerator (enabler if linked with dairy, swine and beef pilots)
	Swine (fans, lighting, creep heating)	0.072	Modelled	Yes	
	Dairy (fans, pre-coolers, VS vacuum pump, scroll compressor)	0.005	Modelled	Yes	
	Total	**0.141**			
Livestock Management - Swine	Increased Feed Conversion Efficiency (10%)	0.02	Modelled	Yes	Accelerator (enabler if linked with farm energy efficiency)
	Decreased Crude Protein in Feed (15%)	0.09	Modelled	Yes	
	Total	**0.11**			

[25] A protocol for RFI is currently pending final approval

Livestock Management – Improved Manure Management	Time/Frequency of Emptying – Switching from Fall to Spring	0.062 0.054	Modelled	Yes	Accelerator (opportunity to co-implement with dairy and swine)
	Timing of Manure Application – switch to spring and summer	0.089 0.060	Modelled	Yes	
	Bedding Type	Unquantified	N/A	No	Technology Opportunity
	Total	**0.265**			
Transportation	Intermodal Freight Shift	Unquantified	Programmatic Estimation	No	Accelerator
	Fuel Efficiency	0.75	Metered or Measured	No	
	Fleet Management	0.3	Metered or Measured	No	
	Load Management	0.3	Metered or Measured	No[26]	
	Fuel Switching	0.3	Metered or Measured	No[27]	
	Total	**1.65**			
Waste Management	Avoided Methane Emissions	3.2	Programmatic Estimation	No	Enabler
	Methane Capture / Destruction	4.12	Metered / Measured / Modelled	Yes[28]	
	Pyrolysis / Biochar	8.27	Metered / Measured	No	
	Anaerobic Digestion / Nutrient Recovery	6.31 + 2.31 (power + fertilizer)	Programmatic Estimation / Modelled	Yes	
	Total	**19.95 – 21.24**			
Forestry	Changes in Harvesting Practice	<0.1	Modelled	Yes	Accelerator
	Improvements in Product Recovery	1.25	Modelled	No	
	Reductions in Waste Streams	4.0	Modelled to Metered / Measured	No	
	Total	**<5.35**			

[26] A transportation efficiency protocol is currently under development.
[27] A fuel switching protocol for mobile sources is currently under development.
[28] An intent to develop an Alberta Offset System protocol for covered manure storage has be submitted to AEW.

Peatlands	Avoided Peatland Disturbance and Improved Peatland Management	Unquantified	N/A	No	Technology Opportunity
	Total	**N/A**			

Priority actions for each biological reduction sector were already presented in the Opportunities and Constraints tables and the Key Messages sections at end of each portion of the report (in the summaries). The Opportunities and Constraints tables were broken down into inputs, activity and outputs; and into science, technology, markets and policy. Each cell was then color coded based on the items readiness for investment. Red indicated an area where there were no issues or no opportunity for investment. Yellow represented an area with some potential; however, at present this potential is not a priority. Finally, areas shaded in green highlighted the best opportunities for investment and as such are presented again here. Tables 46 and 47 summarize the priority action items identified (green areas) for Enabler and Accelerator projects respectively[29]. These areas are the most ripe for investment.

Table 46 – Priority Actions for the Enablers

	Items for Action
Nitrogen Management – 4R Variable Rate Technology	• Research is needed on the impacts of reduced N fertilizer use on yields. • Demonstration of variable rate technologies on-farm; precision application of fertilizers/ pesticides, tools for measuring emissions and nutrient recovery technology are needed.
Livestock Management - Beef & Dairy Cattle	**Beef Cattle:** • Illustrating the quality and synergistic co-benefits of the output. • Data collection and data gaps need to be identified to support GHG calculations and promote practice change. • Supporting infrastructure and platforms for aggregating multiple operations are needed. • Due to the lack of blood tests for RFI there is a need for an integrated trait index (RFI). Further, more affordable methods of testing bulls for RFI are needed. • Market acceptance of the practicality of data management requirements needs to be demonstrated and costs-benefits assessed. • Research on the potential impacts on the quality of the beef – positive or negative.

[29] Note: areas categorized as a technology opportunity are not included due to the fact that they are still in the very early stages of development.

	• Enforcement of tracking dates of birth. **Dairy Cattle:** • Upgrade existing dairy protocol with new synthesized science. • Support expansion and continuation of the ADFI Dairy Pilot in Alberta; this will provide valuable insight for GHG data platforms and aggregation mechanisms. • Move to a full programmatic approach in implementing dairy GHG reductions in Alberta; building on recommendations from the pilot. • Integration of Energy Efficiency Protocol with Dairy Protocol for greater emissions reductions. • Systematic assessment of potential GHG reductions for dairies (both energy and biologically based). • Development of integrated data management and aggregation platforms; methods approved by ARD/AEW. • Streamlined implementation resulting in reduced transaction costs.
Waste Management	**Methane Avoidance, Capture and Destruction:** • A monitoring procedure needed to document CH_4 and odor reduction. • Need to provide education on avoidance strategies and develop a method for marketing reduction attributes. • Marketing strategies to promote environmental stewardship. • Develop GHG mitigation protocol and waste management policy. • Need methods for quantifying carbon credits and measuring environmental impacts. **Pyrolysis and Biochar:** • Science of biochar composition and properties needs to be better understood. • Pyrolysis technology needs to be piloted at various scales, particularly systems that process approximately 10,000 tonnes feedstock/year; standardize the operation procedure. • Standards for measuring biochar and bio-oil quality are needed. Post-processing technologies to be tested for application. • Markets need to be developed and acceptance of biochar promoted. Need commercial volumes. Carbon sequestration potential needs to be measured/verified to sell offsets. • Land application rules to be tested. • Develop GHG mitigation and offset protocols for biochar/bio-oil. • Need to regulate landfills for organic material collection/diversion. • Competing and seasonal markets to be defined. Agricultural residues need to be secured.

	Anaerobic Digestion and Nutrient Recovery • Refine solid/liquid separation-drying process; develop nutrient recovery technologies. • Bio-fertilizer packaging to meet fertilizer standards. • Make system more cost effective/economically viable. Need to establish market value for product. • Promote market acceptance of bio-fertilizer. Measurement standards needed to determine quality of bio-fertilizer. • Develop GHG mitigation and offset protocol for using bio-fertilizers. • Land application rules to be tested for bio-fertilizer.

Table 47 – Priority Actions for the Accelerators

	Priority Actions
Nitrogen Management – Bio-fertilizers	• Distribution of bio-fertilizers is limited to the immediate area around its source. • A protocol is needed for bio-fertilizers.
Livestock Management - Farm Energy Efficiency	• Better information to support cost-benefit information and base energy data; identify and target companion funding programs. • Build decision support tools for farmers that will use existing programming for farm energy audits. • Small tonnage from each farm requires the development of a platform to implement the Energy Efficiency Protocol across a large number of farms; can adapt similar programs being built for Oil and Gas Installations. • Can connect energy efficiency projects with available On-Farm Energy Management Programs under Growing Forward. • Link to ARD’s On-Farm Energy Footprint Calculator developed by Don O’Connor to broaden the Energy Efficiency quantification protocol in Alberta.

Livestock Management - Swine	• A pork pilot to identify data gaps, find solutions and develop recommendations to build the needed infrastructure and platforms to aggregate GHG reductions across Alberta pork operations. • Opportunities to streamline implementation of practice changes to reduce GHGs; increase capacity of pork producers to respond. • Pilots to identify opportunities to streamline implementation of the aggregation platform; identify synergies with Energy Efficiency Protocol. • Reduced transaction costs result in greater returns to pork producers; opportunity to co-implement energy efficiency actions for greater returns. • Development of integrated data management and aggregation platforms for Energy Efficiency and Pork protocols; methods approved by ARD/AEW. • Streamlined implementation resulting in reduced transaction costs.
Livestock Management - Improved Manure Management (Excluding Bedding Type)	• Research on GHG emissions from applying varying forms of manure to land and CH_4 emissions from manure storages under varying conditions. • Develop BMPs to further reduce GHG emissions from land application of manure and CH_4 emissions from storage. • Refined estimates incorporated into Pork and Dairy protocols; upstream emission reduction opportunities incorporated into Anaerobic Digestion protocol. • Demonstrate the data management and aggregation platforms as part of the Pork and Dairy pilots. • Streamlined implementation of mitigation strategies to reduce emissions. • Incentive programs to increase adoption of improved manure management practices; regional anaerobic digesters. • Build synergistic programming with the Alberta Bioenergy Program.
Transportation	• Protocols are needed. • Theoretical or on-highway estimates require calibration for off-highway use. Intermodal quantification is difficult. • Require adjustment and fitment to off-highway application or development and parameterization. Local sources and technological conversion of fleet is limiting adoption. Data to support intermodal shift is not available. • Agriculture sector lags due to slower turnover of fleet. Rail support on intermodal-data and willingness to develop infrastructure is lacking. • Development of a model - data management system to plan and document implementation is needed. • Active support of intermodal by railways is absent. Linkages between reduction in fuel consumption and GHG emission reduction need to be made routine. Extension and aggregation tools are required. • Minimal market pull from users – limited by economic constraints and

	relatively high capital value/dispersed nature of "fleets" resulting in slow turnover. • Refinement of quantification of aggregated and integrated activities is needed. • Calibration/adaptation of SmartWay technologies to off-highway use
Forestry	• Accurate estimates exist, but potential is essentially unrealized. • Numerous bio-mass and cellulosic feed stock processes require supply (e.g. cellulosic ethanol, pyrolysis, high value fuels, rayon). • Clarification on stumpage is needed, particularly across multiple users of a single tree. Brokering of value of "commercial wood" between existing fibre-based industry and emergent bio-industries. • Some protocols are in place. Need to clarify the potential and role of more novel processes (e.g. pyrolysis, cellulosic ethanol, etc.) • Need to clarify how harvested wood that is being directed to multiple industrial processes will have stumpage and ownership assigned. • Need to integrate improvements in forestry into broader initiatives, improve integration between forest entities and integrate forestry tree use efficiency with transportation efficiency through load densification and modal freight switching.

References

Aeration of Liquid Manure. (2011). Retrieved February 2012, from Ontario Ministry of Agriculture, Food and Rural Affairs: http://www.omafra.gov.on.ca/english/engineer/facts/04-033.htm

Adamsen, A., & King, G. (1993). Methane consumption in temperate and subarctic forest soils: rates, vertical zonation, and responses to water and nitrogen. *Applied Environmental Microbiology, 59*, 485-490.

Agitation & Aeration Equipment. (2011). Retrieved February 2012, from Manure Manager: http://www.manuremanager.com/content/view/1473/38/

Agricultural Research Extension Council of Alberta. (2010). *Precision farming and variable rate technology, a resource guide.*

Akiyama, H., Yan, X., & Yagi, K. (2010). Evaluation of effectiveness of enhanced-efficiency fertilizers as mitigation options for N_2O and NO emissions from agricultural soils: meta-analysis. *Global Change Biology, 16*(6), 1837-1846.

Alberta Agriculture and Rural Developement. (2010). *On-Farm Energy Management*. Retrieved March 9, 2012, from Government of Alberta Agriculture and Rural Development: http://www.growingforward.alberta.ca/ProgramAreas/EnhancedEnvironment/EnergyEfficiency/On-FarmEnergyManagement/index.htm

Alberta Forest Products Association (AFPA). (2007). Log haul operations hazard assessment report revalidation 2007. Prepared by UGM Engineering Ltd. Toronto, Ontario, Canada.

Alberta Pork. (2010). *Alberta Pork 41st Annual Report.*

Araji, A. A., & Stodick, L. D. (1990). The economic potential of feedlot wastes utilization in agricultural production. *Biological Wastes, 32*, 111-124.

Araki, D. (2002). Comparing chips made in a woodroom to chips made by a portable system. *FERIC Advantage Reports, 3*(49).

Araki, D. (2004). Economics and recovery of aspen chips produced from an in-woods chipping operation in northern Alberta. *FERIC Advantage Reports, 5*(22).

Basarab, J. A., Baron, V. S., & Okine, E. K. (2009). *Discovering nutrition related opportunities in the carbon credit system for beef cattle.*

Bauer, J., Bektas, T., & Crainic, T. (2009). Minimizing Greenhouse Gas Emissions in Intermodal Freight Transport: An Application to Rail Service Design. Montreal, QC, Canada: Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation (CIRRELT).

Baxter, G. (2002). Management of harvesting debris along the eastern slopes of Alberta's Rocky Mountains. *FERIC Advantage Reports, 3*(42).

Baxter, G. (2004a). Management of harvesting debris in east-central Alberta. *FERIC Advantage Report, 5*(4).

Baxter, G. (2004b). Management of harvesting debris in northern Alberta. *FERIC Advantage Reports, 5*(40).

Baxter, G. (2004c). Management of harvesting debris in west-central Alberta. *FERIC Advantage Reports, 5*(20).

Baxter, G. (2010). Costs and benefits of seven post-harvest debris treatments in Alberta's forests. *FERIC Advantage Reports, 11*(24).

Beauchemin, K., Kreuzer, M., O'Mara, F., & McAllister, T. (2008). Nutritional management for enteric methane abatement: a review. *Australian Journal of Experimental Agriculture, 48*, 21-27.

Bhatia, A., Sasmal, N., Jain, N., Pathak, H., Kumar, R., & Singh, A. (2010). Mitigating nitrous oxide emissions from soil under conventional and no-tillage in wheat using nitrification inhibitors. *Agriculture, Ecosystems & Environment, 136*(3-4), 247-253.

Biochar Protocol Development. (2010). Retrieved December 1, 2010, from Bringing Biochar to the Carbon Market: www.biocharprotocol.org

Blair, C. (2001). Evaluation of a tridem drive tractor with a long log B-train. *FERIC Advantage Reports, 2*(50).

Blue Source Canada. (2008). *Assessment of Greenhouse Gas Emission Reductions in Specific Agriculture Related Projects.* Alberta Agriculture and Rural Development.

Boadi, D., Cbenchaar, C., Chiquette, J., & Masse, D. (2004). Mitigation strategies to reduce enteric methane emissions from dairy cows: update review. *Canadian Journal of Animal Science, 84*, 319-335.

Bradley, A. (2003). Using optimized truck tire pressures to minimize damage to rural roads: summary of two trials in Saskatchewan. *FERIC Advantage Report, 4*(10).

Brick, S., & Wisonsin, M. (2010). *Biochar: Assessing the Promise and Risks to Guide U.S. Policy.* NRDC Issue Paper November 2011.

Burton, D., Li, X., & Grant, C. (2008). Influence of fertilizer nitrogen source and management practice on N_2O emissions from two Black Chernozemic soils. *Canadian Journal of Soil Science, 88*(2), 219-227.

Canada's Organic Industry at a Glance - 2009. (2009). Retrieved February, 27, 2012, from Agriculture and Agri-Food Canada: http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1276292934938&lang=eng

Canadian Carbon Program. (2011). *Ecosystems in flux: carbon, climate and disturbance in Canadian forests and peatlands - perspectives from the flux net-Canada and Canadian Carbon Program research networks (2001-2011).* (C. Coursolle, Ed.) Retrieved February 2012, from Canadian Carbon Program: http://ww.earth.uwaterloo.ca/~jcl/Publications/anglais_brochure_ccp_apr14.pdf

Caris, A., Macharis, C., & Janssens, G. (2008, June). Planning Problems in Intermodal Freight Transport: Accomplishments and Prospects. *Transportation Planning and Technology, 31*(3).

Carme, R. (2005). Evaluation of Allison's automatic transmission in a forestry context. *FERIC Advantage Report, 6*(14).

Cobbaert, D., Rochefort, L., & Price, J. (2004). Experimental restoration of a fen plant community after peat mining. *Applied Vegetation Science*(7), 209-220.

Cooper, C., Famakate, F., Reinhart, T., Kromer, M., & Wilson, R. R. (2009). *Reducing Heavy Duty Long Haul Combination Truck Fuel Consumption and CO_2 Emissions.* NESCCAF - Northeast States Center for a Clean Air Future.

Denef, K., Archebeque, S., & Paustian, K. (2011). *Greenhouse gas emissions from U.S. agriculture and forestry: A review of emission sources, controlling factors, and mitigation potential. Interim report to USDA under contract #GS-23F-8182H.*

Drury, C., Reynolds, W., Tan, C., Welacky, T., Calder, W., & McLaughlin, N. (2006). Emissions of nitrous oxide and carbon dioxide: influence of tillage type and nitrogen placement depth. *Soil Science Society of America Journal, 70*(2), 570-581.

Dyer, J. A., Verge, X., Desjardins, R., & Worth, D. (2008). Long-term trends in the GHG emissions from the Canadian dairy industry. *88*(5), 629-639.

Eagle, A. J., & Sifleet, S. D. (2011). *T-AGG Survey of Experts - Scientific Certainty Associated with GHG Mitigation Potential of Agricultural Land Management Practices.* Technical Working Group on Agricultural Greenhouse Gases, Nicholas Institute for Environmental Policy Solutions, Duke University.

Eagle, A. J., Henry, L. R., Olander, L. P., Haugen-Kozyra, K., Millar, N., & Robertson, G. P. (2011). *Greenhouse Gas Mitigation Potential of Agricultural Land Management in the United States: A Synthesis of the Literature Second Edition.* Technical Working Group on Agricultural Greenhouse Gases (T-AGG), Nicholas Institute for Environmental Policy Solutions, Duke University.

Eckford, R., & Gao, T. (2009). *Development of a preliminary database of digestate chemistry, heavy metal and pathogen content to assist in Alberta regulation compliance.*

Encana. (2011). *Encana expands natural gas infrastructure to Southern Alberta, opens new Strathmore CNG station .* Retrieved February 2012, from Encana Natural Gas: http://www.encana.com/news-stories/news-releases/details.html?release=615894

Environment Canada. (2010). *National Inventory Report 1990-2008: Greenhouse Gas Sources and Sinks in Canada.* Environment Canada.

Environment Canada. (2011). *Sulphur in Diesel Fuel Regulations.* Retrieved 2012, from Environment Canada: http://www.ec.gc.ca/energie-energy/default.asp?lang=En&n=7A8F92ED-1

Follett, R., Mooney, S., Morgan, J., Paustian, K., Allen, Jr., L. H., Archibeque, S., et al. (2011). *Carbon Sequestration and Greenhouse Gas Fluxes in Agriculture: Challenges and Opportunities Task Force Report.* Ames, Iowa, USA: Council for Agricultural Science and Technology.

Forrester, P. (2003). Recovering logging residues for hog fuel in northern Alberta. *FERIC Advantage Reports, 4*(9).

Fraser, G. (2002). Using constant reduced tire pressures on heavy trucks: a case study. *FERIC Advantage Reports, 3*(39).

Gill, R., & MacGregor, B. (2010). *GHG Abatement Cost Curves for the Agriculture Sector: Potential to Reduce Emissions.* Agriculture and Agri-Food Canada.

Government of Alberta. (2004). *Alberta Transportation and Trade Report.* Government of Alberta.

Government of Alberta. (2011). *Facts on Alberta - Living and doing Business in Alberta*. Retrieved February 2012, from http://www.albertacanada.com/document/SP-EH_facts_on_Alberta.pdf

Gregorich, E., Rochette, P., VandenBygaart, A., & Angers, D. (2005). Greenhouse gas contributions of agricultural soils and potential mitigation practices in Eastern Canada. *Soil and Tillage Research, 83*(1), 53-72.

Gulkis, A., & Clarke, A. (2010). Agricultural Energy Management Plans: Comception to implementation. *Journal of Soil and Water Conservation, 65*(1).

Halvorson, A., Del Grosso, S., & Reule, C. (2008). Nitrogen, tillage, and crop rotation effects on nitrous oxide emissions from irrigated cropping systems. *Journal of Environmental Quality*, 1337-1344.

Hao, X., Chang, C., Carefoot, J., Janzen, H., & Ellert, B. (2001). Nitrous oxide emissions from an irrigated soil as affected by fertilizer and straw management. *Nutrient Cycling in Agroecosystems, 60*(1), 1-8.

Haugen-Kozyra, K., Mihajlovich, M., Driver, K., & Li, X. (2010). *Enhancing Biological GHG Mitigation in Canada: Potentials, Priorities and Options.* Climate Change and Emissions Management Corporation.

Hawker, J., Comer, B., Corbett, J., Ghosh, A., Korfmacher, K., Lee, E., et al. (2010). An Integrated Model to Study Environmental, Economic, and Energy Trade-offs in Intermodal Freight Transportation. Ottawa, Ontario, Canada: International Environmental Modelling and Software Society (IEMSS), 2010 International Congress on Environmental Modelling and Software Modelling for Environment's Sake, Fifth Biennial Meeting.

Hegarty, R., Goopy, J., Herd, R., & McCorkell, B. (2007). Cattle selected for lower residual feed intake have reduced daily methane production. *Journal of Animal Science, 85*, 1479-1486.

Hultgreen, G., & Leduc, P. (2003). *The effect of nitrogen fertilizer placement, formulation, timing, and rate on greenhouse gas emissions and agronomic performance.* Swift Current, SK: Agriculture and Agr-Food Canada & Prairie Agricultural Machinery Institute.

ICF Consulting. (2005). *Determination of the Impact of Waste Management Activities on Greenhouse Gas Emissions: 2005 Update Final Report.* Contract No. K2216-04-0006.

Innovation Center for U.S. Dairy. (2012). Retrieved February 21, 2012, from http://www.usdairy.com/saveenergy/Pages/default.aspx

International Biochar Initiative. (2010). *International Biochar Initiative Response to November 2010 NRDC Report: Biochar-Assessing the Promise and Risks to Guide U.S. Policy.*

IPCC. (2006). *2006 IPCC Guidlines for National Greenhouse Gas Inventories, Volume 4, Agriculture, Forestry and Other Land Use, Prepared by the National Greenhouse Gas Inventories Programme.* (H. Eggleston, L. Buendia, K. Miwa, T. Ngara, & K. Tanabe, Eds.) Japan: IGES.

Jenson, & Li. (2003). *A technical feasibility study of coupling ethanol production with biogas production/utilization.* Report to Industry Research Assistant Program (IRAP) and Highland Feeders.

Johnson, C. (2010). *Business Case for Compressed Natural Gas in Municipal Fleets - Technical Report NREL/TP-7A2-47919.*

Johnson, K., & Johnson, D. (1995). Methane emissions from cattle. *Journal of Animal Science, 73*, 2483-2492.

Jones, F., Phillips, F., Naylor, T., & Mercer, N. (2011). Methane emission from grazing Angus cows selected for divergent residual feed intake. *Animal Feed Science and Technology, 166*, 302-307.

Kallenbach, C., Rolston, D., & Horwath, W. (2010). Cover cropping affects soil N_2O and CO_2 emissions differently depending on type of irrigation. *Agriculture, Ecosystems & Environment, 137*(3-4), 251-260.

Karhu, K., Mattila, T., Bergstrom, I., & Regina, K. (2011). Biochar addition to agricultural soil increased CH_4 uptake and water holding capacity - Results from a short-term pilot field study. *Agriculture, Ecosystems & Environment, 140*(1-2), 309-313.

Kebreab, E., Clark, K., Wagner-Riddle, C., & France, J. (2006). Methane and nitrous oxide emissions from Canadian animal agriculture: A review. *Canadian Journal of Animal Science, 86*(2), 135-158.

Kebreab, E., Johnson, K., Archibeque, S., & Pape, D. (2008). Model for estimating enteric methane emissions from United States dairy and feedlot cattle. *Journal of Animal Science, 86*(10), 2738-2748.

Kurkalova, L., Kling, C., & Zhao, J. (2004). Multiple benefits of carbon-friendly agricultural practices: Empirical assessment of conservation tillage. *Environmental Management, 33*, 519-527.

Kurkalova, L., Kling, C., & Zhao, J. (2006). Green subsidies in agriculture: estimating the adoption costs of conservation tillage from observed behavior. *Canadian Journal of Agricultural Economics, 54*, 247-267.

Lehmann, J., Czimczik, C., Laird, D., & Sohi, S. (2009). Stability of Biochar in Soil. In J. Lehmann, & S. Joseph (Eds.), *Biochar for Environmental Management - Science and Technology.*

Levelton (2006). *Levelton Report - Estimates based on Levelton and ST2 Consultant's Report: Bioenergy Opportunities for Alberta: Strategic Feasibility Study.* Alberta Government.

Li, X., Liebetrau, J., & Frank, K. (2008). *Anaerobic digestion of biowaste with high solid content (dry fermentation): feasibility study.*

Lindroos, O., Nilsson, B., & Sowlati, T. (2011). Costs, CO Emissions, and Energy Balances of Applying Nordic Slash Recovery Methods in British Columbia. *Western Journal of Applied Forestry, 26*(1), 30-36.

Liu, C., Zheng, X., Zhou, Z., Han, S., Wang, Y., Wang, K., et al. (2010). Nitrous oxide and nitric oxide emissions from an irrigated cotton field in Northern China. *Plant and Soil, 332*(1-2), 123-134.

Liu, X., Mosier, A., Halvorson, A., & Zhang, F. (2006). The impact of nitrogen placement and tillage on NO, N_2O, CH_4 and CO_2 fluxes from a clay loam soil. *Plant and Soil, 280*(1), 177-188.

Locky, D. (2011). Wetlands, Land Use and Policy: Alberta's Keystone Ecosystem at a Crossroads. *Green Paper Presented at the Annual Conference of the Alberta Institute of Agrologists.* Banff.

MacDonald, A. (2001). Energy balance, carbon emissions, and costs of sortyard debris disposal. *FERIC Advantage Report, 2*(38).

MacDonald, A. (2004). Drying of logs during storage in a logyard: effects on lumber recovery and value. *FERIC Advantage Reports, 5*(34).

MacGregor, B. (2010). GHG Abatement Cost Curve for the Agriculture Sector: Potential to Reduce Emissions.

Mariner, M., Clark, K., & Wagner-Riddel, C. (2004). *Improving Estimates of Methane Emissions Associated with Animal Waste Management Systems in Canada by Adopting an IPCC Tier-2 Methodology.* University of Guelph, Department of Land Resource Science, Guelph.

McGinn, S., Beauchemin, K., Coates, T., & Colombatto, D. (2004). Methane emissions from beef cattle: effects of monensin, sunflower oil, enzymes, yeast and fumaric acid. *Journal of Animal Science, 82*, 3346-3356.

McSwiney, C., & Robertson, G. (2005). Nonlinear response of N_2O flux to incremental fertilizer addition in a continuous maize (Zea mays L.) cropping system. *Global Change Biology, 11*(10), 1712-9.

McTaggart, I., Clayton, J., Parker, L., Swan, L., & Smith, K. (1997). Nitrous oxide emissions from grassland and spring barley, following N fertilizer application with and without nitrification inhibitors. *Biology and Fertility of Soils, 25*, 261-268.

Michaelson, J. (2007). *Trucking Solutions.* FERIC-Ontario.

Milbrandt, A., & Overend, R. (2009). *Assessment of biomass resources from marginal lands in APEC economies.* APEC #209-RE-01.4.

Moreira, A., Ribeiro, R., Declercq, E., Pereira, P., Schinas, O., Guerreiro, P., et al. (1998). Optimal location of intermodal terminals in Europe: an evaluation model. *Proceedings of the 6th European Congress on Intelligent Techniques and Soft Computing (EUFIT'98).* Aachen.

Mosier, A., Halvorson, A., Reule, C., & Liu, X. (2006). Net global warming potential and greenhouse gas intensity in irrigated cropping systems in northeastern Colorado. *Journal of Environmental Quality, 35*(4), 1584-1598.

Moss, A., Jouany, J., & Newbold, J. (2000). Methane production by ruminants: its contribution to global warming. *Ann.Zootech., 49*, 231-253.

Mui, S., Alson, J., Ellies, B., Ganss, D. 2007. A Wedge Analysis of the US Transportation Sector. US Environmental Protection Agency report EPA420-R-07-007. Retrieved February, 2012, from,http://www.epa.gov/otaq/climate/420r07007.pdf

Natural Resources Canada. (n.d.). *Fuel Efficiency Benchmarking in Canada's Trucking Industry.*

Novak, J. M., Lima, I., Xing, B., Gaskin, J. W., Steiner, C., Das, K., et al. (2009). Characterization of designer biochar produced at different temperatures and their effects on a loamy sand. *Annals of Environmental Science, 3*(2).

NRCS. (2012). *NRCS Feed Management Technical Note.* Washington, DC.

Ogle, S., Archibeque, S., Gurung, R., & Paustian, K. (2010). *Report on GHG Mitigation Literature Review for Agricultural Systems: Submitted to USDA Climate Change Office.*

Olander, L., Eagle, A., Baker, J., Haugen-Kozyra, K., Murray, B., Kravchenko, A., et al. (2012a). *Assessing greenhouse gas mitigation opportunities and implementation strategies for agricultural land management in the U.S.A.* Technical Working Group on Agricultural Greenhouse Gases (T-AGG), Nicolas Institute for Environmental Policy Solutions at Duke University.

Olander, L., Eagle, A., Baker, J., Haugen-Kozyra, K., Murray, B., Kravchenko, A., et al. (2012b). *Greenhouse Gas Mitigation Potential from Dairy, Beef and Swine Systems in the United States,.* Technical Working Group on Agricultural Greenhouse Gases (T-AGG), Nicolas Institute for Environmental Policy Solutions at Duke University.

Ominski, K., & Wittenberg, K. (2004). *Strategies for reducing enteric methane emissions in forage-based beef production systems. In "The Science of Changing Climates - Impact on Agriculture, Forestry and Wetlands".* University of Alberta, Canadian Society of Agronomy, Animal Science and Soil Science, Edmonton.

Osko, T. (2010). *A Gap Analysis of Knowledge and Practices for Reclaiming Disturbances Associated with In Situ Oil Sands and Conventional Oil & Gas Exploration on Wetlands in Northern Alberta.* Retrieved February 2012, from http://www.biology.ualberta.ca/faculty/stan_boutin/ilm/uploads/footprint/Gap%20Analysis%

Parker, S. (2002). Summary of tridem drive research in Alberta: 1995-2001. *FERIC Advantage Reports, 3*(32).

Pell, A. (1997). Manure and microbes: public and animal health problem? *Journal of Dairy Science, 80*, 2673-2681.

Robertson, G., & Vitousek, P. (2009). Nitrogen in agriculture: Balancing the cost of an essential resource. *Annual Review of Environment and Resources, 34*, 97-125.

Rochefort, L., Quinty, F., Campeau, S., Johnson, K., & Malterer, T. (2003). North American approach to the restoration of sphagnum dominated peatlands. *Wetlands Ecology and Management*(11), 3-20.

Rochette, P., Worth, D., Huffman, E., Brierley, J., McConkey, B., Yang, J., et al. (2008). Estimation of N_2O emissions from agricultural soils in Canada: 1990-2005 Inventory. *Canadian Journal of Soil Science, 88*(II), 655-669.

Sambo, S. (2002). Fuel consumption for ground-based harvesting systems in western Canada. *FERIC Advantage Reprots, 3*(29).

Scharf, P., & Lory, J. (2009). Calibrating reflectance measurements to predict optimal sidedress nitrogen rate for corn. *Agronomy Journal, 101*(3), 615-625.

Schmidt, J., Dellinger, A., & Beegle, D. (2009). Nitrogen recommendations for corn: an on-the-go sensor compared with current recommendation methods. *Agronomy Journal, 101*(9), 916-924.

Sehy, U., Ruser, R., & Munch, J. (2003). Nitrous oxide fluxes from maize fields: Relationship to yield, site-specific fertilization and soil conditions. *Agriculture, Ecosystems & Environment, 99*(1-3), 97-111.

Snyder, C., Bruulsema, T., & Jensen, T. (2007). *Greenhouse Gas Emissions from Cropping Systems and the Influence of Fertilizer Management - A Literature Review.* International Plan Nutrition Institute (IPNI).

Snyder, C., Bruulsema, T., Jensen, T., & Fixen, P. (2009). Review of greenhouse gas emissions from crop production systems and fertilizer management effects. *Agriculture, Ecosystems & Environment, 133*(3-4), 247-266.

Sokhansanj, J., & Fenton, J. (2006). *BIOCAP Research Integration Program Sysnthesis Paper: Cost benefit of biomass supply and pre-processing.* BIOCAP Research Integration Program.

Statistics Canada. (2010a). *Hog Statistics, Census of Agriculture.*

Statistics Canada. (2010b). *Statistics Canada 2010 Crop Statistics: Field Crop Reporting Series.* Retrieved December 1, 2010, from http://www.statcan.gc.ca/pub/21f0003g/2009000/crops-cultures-eng.htm

Statistics Canada. (2010c). *Cattle on farms - Alberta.*

Surcel, M. (2008a). Long term evaluation of heavy duty vehicles. *FERIC Advantage Report, 10*(6).

Surcel, M. (2008b). Track test evaluation of measures to reduce aerodynamic drag. *FERIC Advantage Report, 10*(5).

United Parcel Service. (2002). *DOE/NREL Truck Evaluation Project - CNG Truck Fleet: Final Results.*

United States Environmental Protection Agency. (2002). *United States Environmental Protection Agency.* Retrieved 2012, from Clean Alternative Fuels: Compressed Natural Gas: http://www.encana.com/news/newsreleases/2011/0928-open-strathmore-cng-station.html

United States Environmental Protection Agency. (2011). *SmartWay Technology Program.* Retrieved February 2012, from SmartWay: http://www.epa.gov/smartway/technology/index.htm

United States Environmental Protection Agency. (2012). *SmartWay Technology Program.* Retrieved February 2012, from Verified Low Rolling Resistance Tires: http://www.epa.gov/smartway/technology/tires.htm

United States Environmental Protection Agency. (2007). *An Analysis of the Cost-Effectiveness of Reducing Particulate Matter and Nitrogen Oxides Emissions from Heavy-Duty Non-road Diesel Engines through Retrofits.*

Vassallo, W. (Ed.). (2007). Freight Market Structure and Requirements for Intermodal Shifts. Project no. TREN/06/FP6TR/S07.60148FREIGHTWISE Management Framework for Intelligent Intermodal Transport.

Verge, X., Dyer, J., Desjardins, R., & Worth, D. (2008). Greenhouse gas emissions from the Canadian beef Industry. *Agricultural Systems, 98*(2), 126-134.

Verge, X., Dyer, J., Desjardins, R., & Worth, D. (2009). Greenhouse gas emissions from the Canadian pork industry. *Livestock Science, 121*(1), 92-101.

Verheijen, F., Jeffery, S., Bastos, A., Van der Velde, M., & Diafas, I. (2010). *Biochar Application to Soils: A Critical Scientific Review of Effects on Soil Properties, Processes and Functions.* European Commission, Joint Research Centre.

Vitt, D. (2006). Chapter 10 Peatlands: Canada's past and Future Carbon Legacy. In J. Bhatti, R. Lal, M. Apps, & M. Price (Eds.), *Climate Change and Managed Ecosystems* (pp. 201-216). Boca Raton, Florida: CRC Press.

Vitt, D., Halsey, L., Bauer, I., & Campbell, C. (2000). Spatial and Temporal Trends in Carbon Storage of Peatlands of Continental Western Canada through the Holocene. *Canadian Journal of Earth Science, 37*, 683-693.

Warnock, D., Lehmann, J., Kuyper, T., & Rillig, M. (2007). Mycorrhizal responses to biochar in soil - concepts and mechanisms. *Plant Soil, 300*, 9-20.

Webb, C. (2002). Log/chip B-train: a new concept in two-way hauling. *FERIC Advantage Reports, 3*(8).

Whalen, S., Reeburgh, W., & Sandbeck, K. (1990). Rapid methane oxidation in a landfill cover soil. *Applied Environmental Microbiology, 56*, 3405-3411.

Wood, S., & Cowie, A. (2004). *A review of greenhouse gas emission factors for fertilizer production.* Cooperative Research Centre for Greenhouse Accounting, for IEA Bioenergy Task 38.

Yang, H., Minuth, B., & Allen, D. (2002). Effects of nitrogen and oxygen on biofilter performance. *Journal of the Air and Waste Management Association, 52*(3), 279-86.

Zeiss, C. (2002). *Methane oxidation as an engineered greenhouse gas reduction method for solid waste landfills.* Ottawa: The Federation of Canadian Municipalities.

Zhao, X., Song, Z., Liu, H., Li, Z., Li, L., & Ma, C. (2010, September). Microwave pyrolysis of corn stalk bale: a promising method for direct utilization of large-sized biomass and syngas production. *Journal of Analytical and Applied Pyrolysis, 89*(1), 87-94.