Enhancing Biological GHG Mitigation in Canada: Potentials, Priorities and Options

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Executive Summary

This report explores the opportunity for significant emission reductions to be achieved from biological systems and management - particularly agriculture, forestry, waste to energy and landscape level/large scale integrated management. While much attention has tended towards the theoretical potentials from biological management, and not always taking into account those reductions that are additional, or beyond business as usual, this study applies common carbon accounting principles, and identifies “constrained” or “achievable” mitigation potentials from biological management. This analysis covers the range of activities, categorized as major wedges, and sub-wedges, summarized as follows:

Carbon Sequestration – Agriculture soils and forestry sub-wedge opportunities.

GHG Reductions – Direct reductions from livestock, nitrogen management and other sub-wedge opportunities.

Waste Management – Avoided methane emissions, methane capture and destruction, biogas, indirect reductions through electricity and heat capture sub-wedges.

Materials Switching – Substituting biological products such as biofertilizer, biocomposites and biomaterials.

Strategic Carbon Management – Landscape level or integrated large scale opportunities to reduce emissions.

For each of the sub-wedges, the opportunity is analyzed in full. The mechanisms and methodology for mitigation are detailed, and the theoretical mitigation potential is counted. This theoretical potential is then distilled to a constrained potential, acknowledging the technical, market and policy factors that will govern uptake. The mitigation potentials applied to each sub-wedge use the most reliable accounting methods. Further, for each sub-wedge the constraints to realizing the theoretical potentials are estimated, and critical requirements for operationalizing the sub-wedge are also identified. Accounting criteria like leakage, permanence, real, quantifiable are taken into account, unless otherwise specified.

The results of the analysis for each of the sub-wedges are further categorized by an assessment of key implementation considerations, and are summarized in Table 1. Ideally, those opportunities that rate at hi speed, high magnitude for reductions, are easily scaled and are at the market accumulation or diffusion stage are likely the most immediate opportunities.

Table 1 Explanation of categorical analysis for sub-wedge implementation.

Speed of Sub-Wedge Development to Reach Potential	Less than 6 years	5
	Between 6 and 10 years	3
	Greater than 10 years	1
Magnitude of Potential Emission Reductions for	Greater than 5 Mt CO_2e per year	5
	Between 1 and 5 Mt CO_2e per year	3

each Sub-Wedge	Less than 1 Mt CO_2e per year	1
Scalability of Emission Reductions from each Sub-Wedge	Contiguous and Scalable	5
	Patchy and Scalable with Difficulty	3
	Dispersed with Challenges for Scalability	1
Stage of Research and Development for activities in the Sub-Wedge	Diffusion	6
	Market Accumulation	5
	Commercialization	4
	Market Demonstration	3
	Product/Technology Design/Development	2
	Applied Research and Development	1

Results

The results of the analysis are summarized in the following tables and figures. Strategic carbon management is discussed in the report only in more broad terms. Table 2 below summarizes the theoretical and constrained mitigation potential for the major wedges and sub-wedge categories. The Canadian theoretical biological GHG mitigation potential is over 200 Mt CO_2 e /yr. Applying the constrained potential, the more achievable estimates range from 52.91 to 65.65 Mt CO_2 e /yr. In either case, over 53% of this potential is associated with waste management and utilization. The next largest is the carbon sequestration wedge with 20% of the total estimated mitigation potential. The GHG reduction and materials switching wedges share a similar potential of around 12%.

Table 2. Summary of Canadian biologically-based GHG capture and reduction opportunities.

Wedge	Sub-wedge	Protocol in Place	Theoretical Potential (Mt CO_2e/yr)	Constrained Potential (Mt CO_2e/yr)
Carbon Sequestration				
3.1.1	Afforestation/Reforestation	no	0.6	0.2
3.1.2	Generic Increases in Forest Productivity	no	~	0.29
3.1.3	Carbon Storage in Forest Soils	no	~	~
3.1.4	Improved Forest Management	no	0.075	0.075
3.1.5	Carbon Sequestration in Peatlands	no	<0.01	<0.01
3.1.6	Avoided Forest Conversion	no	~	~
3.1.7	Delayed Forest Harvesting*	no	7.2	2.4
3.1.8	Agriculture Soil Carbon Sequestration		11.38	3.6 to 6.1
3.1.9	Wetlands Sequestration	yes	10.14	2.0
3.1.10	Sludge Application to Agricultural lands	yes	0.76	0.41
3.1.11	Soil Amendments	no	5.3	2.7
SubTotal			**35.76**	**11.26 - 13.77**
GHG Reductions				
3.2.1	Soil Nitrogen Management	yes	2.72-4.54	0.25 - 1.36
3.2.2	Beef and Dairy Cattle - Reductions of CH_4 & N_2O	yes	6.82	2.0 - 2.27
3.2.3	Reductions from Hog, Poultry and some	yes	1.5	0.9 - 1.05

Wedge	Sub-wedge	Protocol in Place	Theoretical Potential (Mt CO_2e/yr)	Constrained Potential (Mt CO_2e/yr)
	Dairy			
3.2.4	Changes in Logging Slash Disposal	no	13.4	3.0
SubTotal			**24.4 - 26.26**	**6.15 - 7.68**
Waste Management				
3.3.1	Anaerobic digestion	yes	4.5-6.2	2.2 - 3.1
3.3.2	Management of Solid Wastes	yes	8.5-31.7	20
3.3.3	Biochar Production and Use	no	52 - 86.5	7.6 -9.0
3.3.4	Biomass Combustion	yes	5.1	1.5
SubTotal			**70.1 - 129.5**	**31.3 - 33.6**
Material Switching				
3.4.1	Biofertilizers	no	2.5	1.1
3.4.2	Building materials switching	no	4.42	1.5
3.4.3	Bio-based materials	no	79 - 88.0	1.6 - 8.0
SubTotal			**85.92 – 94.92**	**4.2 - 10.6**
Total			**216.18 - 224.42**	**52.91 - 65.65**

In the next series of figures the analysis for implement-ability of the wedges and sub-wedges is presented. Figure 1 illustrates that the carbon sequestration potentials of improved forest management and pulp paper sludge application are small but readily implemented. The carbon sequestration potential of agricultural soil and soil amendments is substantial and readily achieved. Afforestation – reforestation and delayed harvest have substantial carbon sequestration potentials but will require time and changes in paradigms to implement. Many of these sub-wedges have substantial environmental or social co-benefits that merit acknowledgement.

Figure 1 Summary of carbon sequestration wedge evaluation.

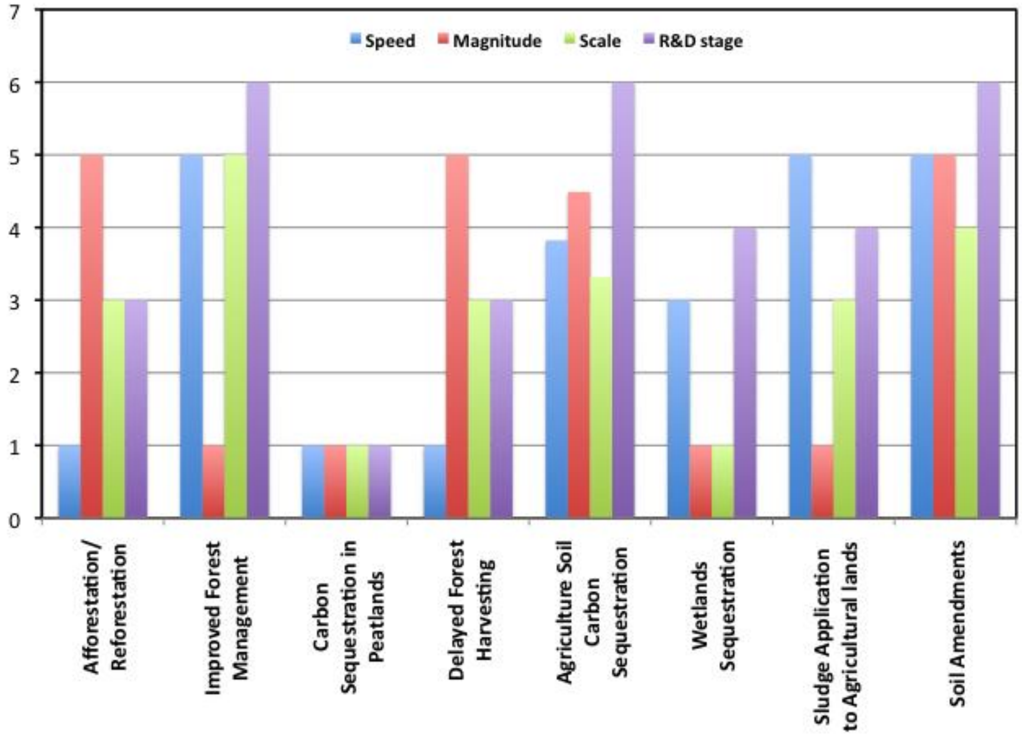


Figure 2 shows that the GHG reduction wedge has substantial potential to mitigate GHG emission but will likely be challenging to make operational, since scaling and complexity in measurement and accounting will be an issue.

Figure 2 Summary of GHG Reduction wedge evaluation.

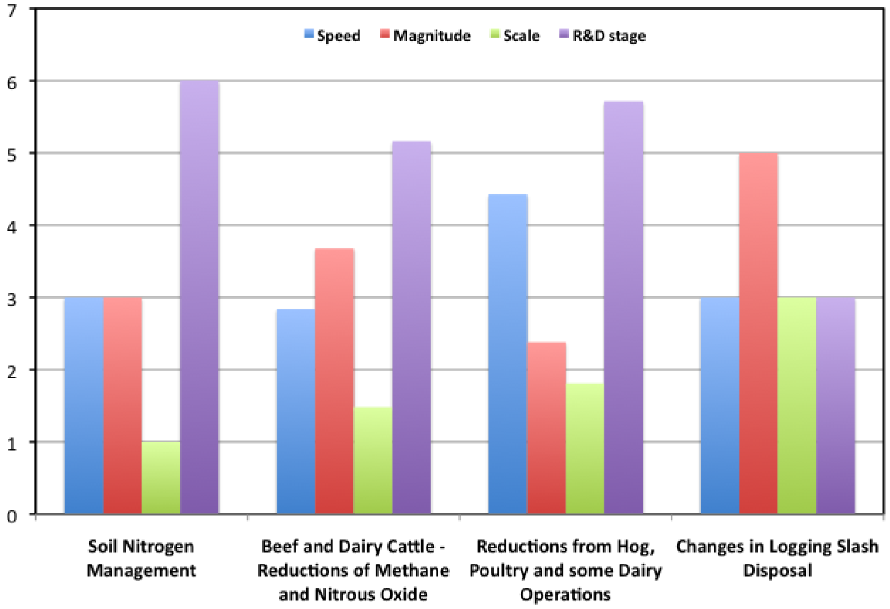
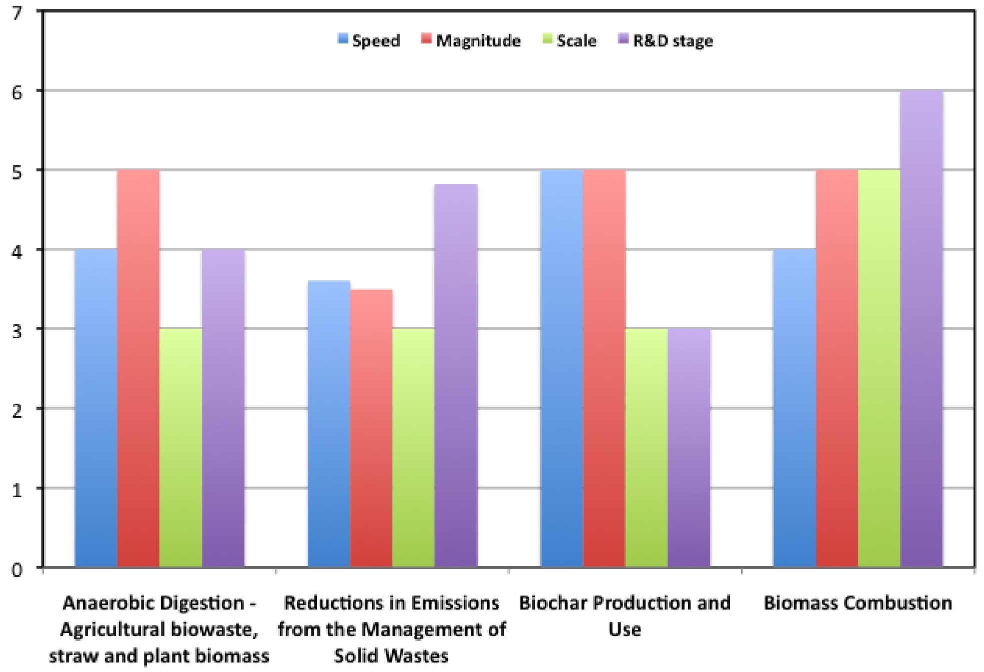


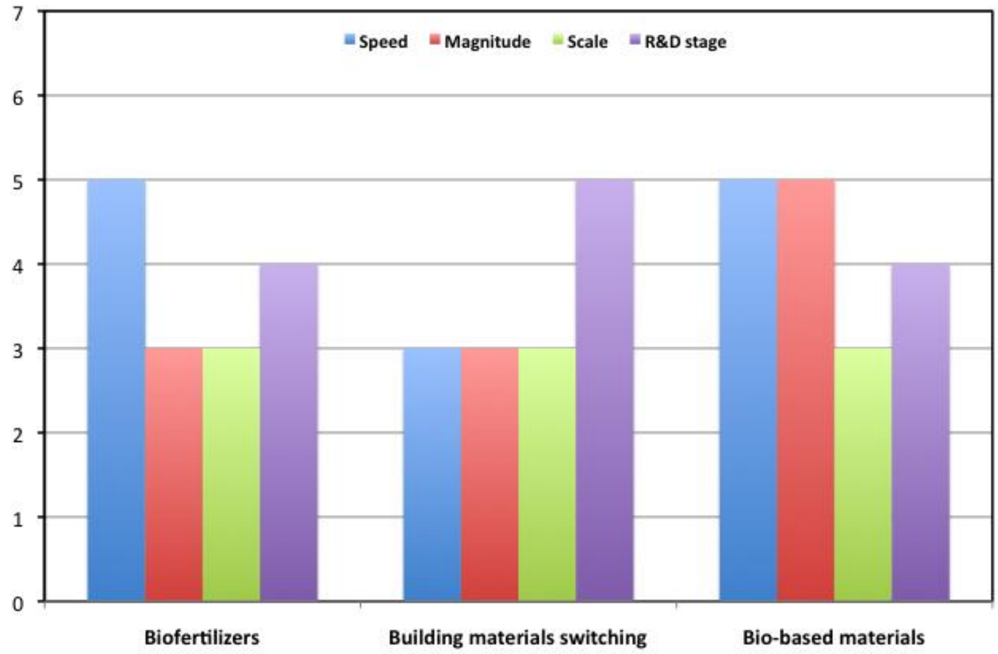
Figure 3 shows all waste management sub-wedges have great potential to mitigate GHG emissions; however, more R&D may be needed to render biochar operational. This wedge generally has substantial environmental and social co-benefits which merit consideration in deciding on operational deployment. Furthermore an integrated waste management approach maybe an attractive solution.

Figure 3 Summary of waste management wedge evaluation.



Material switching (Figure 4) shows great potential for GHG mitigation with slight to moderate challenges to operational implementation.

Figure 4 Summary evaluation of materials switching wedge



Observations and recommendations are provided to support operationalizing each of the activities. These vary across each of the sub-wedges, which may include policy, research and development, project development, and market development supports.

Final prescriptive measures were suggested to achieve the identified mitigation potentials through short- and long-term strategic plans that are both practical and measurable.

Key components of short-term strategic plans include addressing quantification tools and enabling policy for large-scale opportunities currently constrained by operational or quantification constraints. Furthermore a number of quantification protocols require revision or development to more effectively enable mitigation.

A need to focus on enabling large-scale opportunities was indicated as a key part of the long-term strategy. The enabling of large-scale opportunities requires significant changes to policy and/or infrastructure, and may call for considerable effort and collaboration. Reassessments and/or development of national biomass, bio-waste, and lifecycle analysis databases and inventories will enable ease of accountability and further project development. Initiating CCEMC-supported dialogue between project developers and land managers or policy developers would foster collaborative effort towards common goals of greenhouse gas mitigation which may otherwise be met with conflicts from established regulations. Finally, the CCEMC may wish to provide clear priorities on CCEMC perspectives to foster continued protocol development arising from the roadmap.

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1.0 Introduction

Conventional wisdom holds that biological sectors house great potential for achieving emissions reductions and sequestering greenhouse gases (GHG). These GHG reduction, removal and replacement opportunities[1] can be achieved alongside the provision of feed, food, fibre and renewable fuel for a growing global population. Through enhanced management of agricultural and forested ecosystems, the GHG mitigation potential of these and other land uses can far exceed the emissions contributions of these sectors around the world (Figure 5). In other words, in addition to cleaner energy and energy efficiency strategies, wiser and more sustainable use of our agricultural and forested ecosystems and waste streams have a critical role to play as necessary and expedient contributors to addressing climate change.

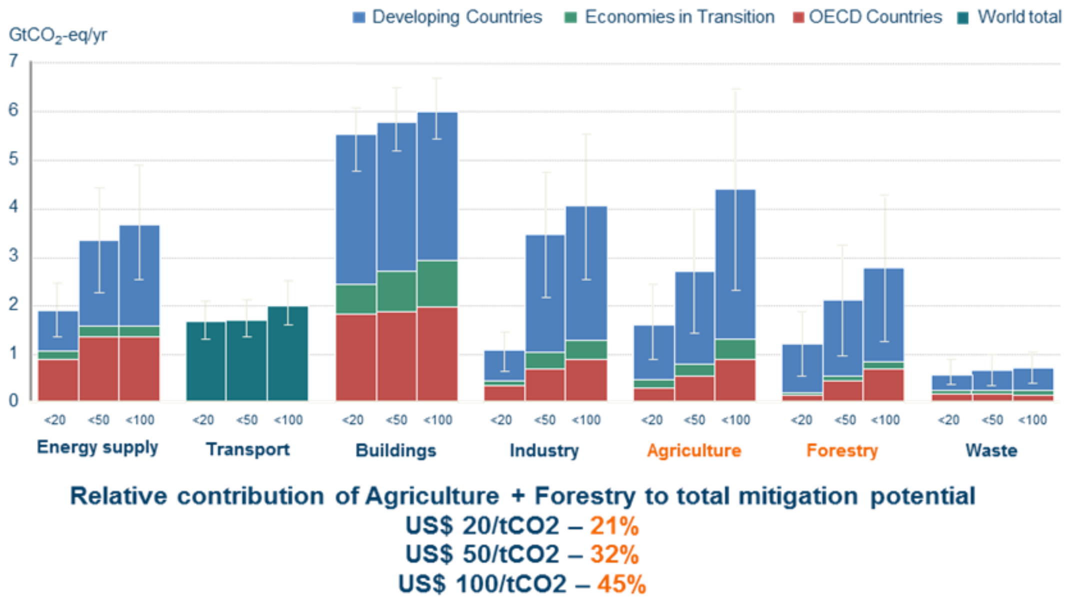

Figure 5 Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report: The economic potential of various sectors to contribute to climate change mitigation (estimated in USD market prices per metric ton of carbon dioxide equivalents; percentages reflect potential contribution of agriculture to offsetting the anthropogenic emissions at various market prices, (Smith et al. 2007)

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[1] Replacing means renewable energy, bio-based substitutes for more carbon intensive inputs in product supply chains, etc.

In addition to the 2007 IPCC report, other reports have been compiled over the last few years outlining the potential for emission reductions within these sectors, but the potential still remains largely untapped.

In Canada, most analyses of biological GHG mitigation potential have tended to be theoretical:

- Generic estimates made at a broad scale (e.g. National Greenhouse Gas Inventory level.)
- Unconstrained by policy considerations, these reviews:
    - Frequently ignore the impact of program start date requirements on slow to develop projects like afforestation or improved forest management
    - Do not fully address additionality when faced with general good management practice initiated in response to factors other than climate change (e.g. soil conservation, legally required sustainable forest management.)
    - Downplayed or ignored broader effects (e.g. changes in albedo, impact of climate change in contraindicating expected changes in GHG capture and storage.)

This paper explores both the theoretical and the “constrained” or “achievable” GHG mitigation potential of biological systems and management – particularly agriculture, forestry, waste to energy and landscape level management. It directly addresses factors limiting operational delivery of bio-capture and storage, including

1. Lack of enabling public policy or current public policy barriers (domestic and international);
2. Limited understanding of the range of practices and technologies, with a clear assessment of their potentials;
3. Lack of credible measurements of emission reductions associated with various practices and technologies;
4. Confusion among the types of Carbon accounting standards (i.e. Carbon Offsets, Life Cycle Assessments, Carbon Footprinting) for recognizing the environmental values created;
5. The lack of a coherent and coordinated approach to address biological potentials.

These circumstances highlight the importance of a coordinated national approach for Canada, since our country, and Alberta have been focused on resolving several of these concerns.

Canada has a ***natural advantage*** in mitigating its climate change impacts. Canada has 7% of the world’s land area, 10% of the world’s forests and approximately 68 M ha of agricultural land, with only 0.5% of the global population. According to BIOCAP (2006) every year, Canada’s biosphere takes up and releases 10 to 20 times the CO_2 produced by fossil fuel combustion. Managing these resources better and taking advantage of Canada's large natural ability to take sunlight and capture carbon dioxide and use that to reduce, remove and replace emissions, can enhance our biological potential to mitigate our impact and contribute to solutions. Canada is a leader in quantification science for these sectors both at a National Emissions Inventory level, and, for the last 6 or 7 years, in applying best practice guidance to codifying the science in offset quantification protocols that define the tangible benefits from these sectors.

In addition, Canada has a certain ***political advantage*** in its ability to enhance biological mitigation opportunities. The global consensus on policy approaches to better internalize and manage carbon, is to place a price on it so emission of carbon is no longer 'free' and has a value that can be incorporated into business, investment and corporate decisions. Canada is ahead of the curve on this through (1) Alberta's current and Saskatchewan's imminent GHG regulatory frameworks; (2) British Columbia's Pacific Carbon Trust, (3) Ontario and Quebec's commitment to and action on the Western Climate Initiative's cap and trade timelines and policies; and (4) New Brunswick and Nova Scotia's scoping of Voluntary Offset Fund initiatives. Most jurisdictions in Canada have or will have a pricing policy that, given certain direction and coordination, can also apply accompanying incentive and program measures that will enhance biological management opportunities. The critical aspect will be credible measurements of emission reductions, removals and replacements from these sectors in order to move forward.

To proceed, the Climate Change and Emissions Management Corporation (CCEMC)[2] recognizes there is a need for a summary document that broadly sketches the current potential of biological opportunities in Canada for the purpose of starting a dialogue to develop a coordinated national approach and associated Investment Road Map to address the above concerns.

But, more importantly, the CCEMC recognizes that in order to strategically invest in this priority area, they need to develop a deeper understanding to guide decisions to help ensure that CCEMC project funds, and hopefully other sources of funding are allocated to the most promising solutions to help Albertans and Canadians mitigate and adapt to climate change impacts, now and in the future. It is for this reason that the CCEMC is initiating a Knowledge Network on Biological GHG Management.

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[2] The Climate Change Emissions Management Corporation (CCEMC) is an independent Alberta-based not-for-profit corporation with a mandate to reduce greenhouse gas (GHG) emissions and adapt to climate change by supporting the discovery, development and deployment of clean technologies and biological GHG management.

2.0 Objectives and Structure of the Paper

This discussion paper is intended to provide a knowledge base of biological GHG mitigation opportunities for Canada, using the best science and information available. This effort is designed to be a precursor to the development of an Investment Road Map on how to efficiently engage the biological sector in achieving the available greenhouse gas reductions. It is anticipated that the Biological GHG Knowledge Network will coordinate ongoing work. This network will be discussed and formalized at the event planned for late 2010. The discussion paper will provide essential information to inform the development of the network, a roadmap and its future program focus.

2.1 Objectives and Structure of the Paper

This paper is essentially a snapshot of where Canada is in terms of biologically-based mitigation potential out to 2020, calculated on an annual emission reduction basis. The paper examines the theoretical potential using the most reliable accounting methods, examines a number of constraints for realizing that potential, and identifies what's standing in the way of progress, as well as that actions could be taken to enhance action and progress. Most of this information was be derived from literature searches and the authors' quantification estimates – but it should be acknowledged that some of the barriers and gaps may be preliminary and a more comprehensive assessment may need to be done by the Knowledge Network as they build the roadmap.

2.1.1 Structure and Scope

The structure and scope of the paper focuses on major categories or 'wedges' of biological mitigation. Some forms of biomass/waste to energy will be examined as they relate and contribute to some of the major wedges (e.g. byproducts of biochar production or biogas production)[3]. The CCEMC advised the authors to limit their focus on liquid biofuels, since this wedge seems to be well understood. Therefore, the major Wedge opportunities that structure this paper are:

1. **Carbon Sequestration** – includes agriculture soils and forestry sub-wedge opportunities;

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[3] Biofuel strategies and technologies will not be assessed as part of this study – this area has already been extensively studied.

2. **GHG Reductions** – includes direct reductions from livestock, nitrogen management and other sub-wedge opportunities;

3. **Waste Management** – includes avoided methane emissions, methane capture and destruction, biogas, indirect reductions through electricity and heat capture sub-wedges;

4. **Materials Switching** – includes substituting biological products such as biofertilizer, biocomposites and biomaterials for more intensive carbon inputs such as steel, concrete and conventional plastics and fibres;

5. **Strategic Carbon Management** – includes landscape level or integrated large-scale opportunities to reduce emissions.

Generally speaking, the quantification of GHG mitigation potential for the mitigation strategies presented in each wedge and sub-wedge opportunity use the standard accounting principles outlined in Best Practice Guidance by the IPCC (2006), ISO GHG accounting standards 14064:1, 2 and 3 (CSA Standards 2009); Canada's National Emissions Inventory Report 1990-2008 (Environment Canada 2010), as well as the World Resource Institute (WRI) - World Business Council for Sustainable Development (WBCSD) GHG Protocol standards (Daviet and Raganathan 2005). Where deviations exist from current UNFCCC/Kyoto standards, they will be mentioned in the report.

This means carbon policy criteria such as additionality, permanence, ensuring reductions are measurable and verifiable, dealing with potential leakage effects and uncertainty, are taken into account in the mitigation potentials. These factors will be addressed and discussed in the assessment of each wedge and sub-wedge opportunity in the paper. In all cases, the net impact of the major biological greenhouse gases – methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) is accounted for unless otherwise mentioned. The global warming potentials used in this report are consistent with the Kyoto Protocol 2008-2012 accounting period (CSA Standards 2009)[4].

2.2 Activities and Deliverables

For each Wedge, an attempt was made to categorize and classify the literature, supporting documentation and quantification methods for a baseline year that varied between 2006 and 2009. The availability of supporting data sources (Census, StatsCan surveys, and other relevant

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[4] GWP for nitrous oxide is 310, methane is 21 and carbon dioxide is 1.

reports) was more robust for this time frame, compared to earlier years. The data sources for baseline and the mitigation opportunities are indicated in each wedge section (Section 3.2). In most cases, the estimates for mitigation potential extend out to a consistent time frame (2020) and are annualized into Mt CO_2e/yr basis for comparison. In each Wedge section, the quantification basis is described.

2.2.1 Structured Analysis of each Wedge

Each wedge lists the various sub-wedge opportunities or mitigation strategies as well as a number of other systematic assessments. The format for each sub-wedge follows the following structure:

- **Introduction**
- **Mechanism and Methodology for Mitigation**
    - Description of mitigation mechanism for sub-wedge/supporting literature
    - Quantification approach being applied; basis for quantification approach
    - Discussion of the state of the science for carbon accounting/quantification in this area
- **Quantification: Theoretical Mitigation Potential**
    - Baseline Assumptions and Data Sources
    - Mitigation Assumptions and Activities
- **Constrained Potential: Market, Technical and Policy Overlay**
    - State of measurement, monitoring and verification
    - Reversal mechanisms for permanence
    - Assessment Matrix for Scale, Magnitude, Speed and R&D ranking
    - Re-assessment of the Mitigation Potential taking into account these constraints
    - Co-benefits/impacts
- **Operationalizing the Wedge**
    - Enabling tools – what would help operationalize – programs, policies, investments, related to the above subwedge
    - Recommendations on what to pursue or prioritize 1st, 2nd 3rd, etc.

2.2.2 Assessment Matrix for Scale, Magnitude and Research and Development (R&D) Ranking

To provide the reader with a relative understanding of some of the constraints around implementing the Wedge or sub-wedge opportunity, the following assessment matrix is applied (Table 3):

Table 3. Categorical assessment for speed, scale, magnitude and R&D.

Speed -Score	Magnitude - Score	Scalability - Score	R&D stage
< 6 yrs - 5	>5 Mt/yr - 5	Contiguous/ scalable - 5	See below
6-10 yrs -3	1-5 Mt/yr - 3	Patchy/scalable w/difficulty - 3	
> 10 yrs - 1	< 1 Mt/yr - 1	Dispersed/ challenges to scalability - 1	

If the opportunity/strategy can be implemented relatively quickly, it rates a score of 5 on the Speed scale. If the mitigation potential is relatively high, within the Wedge category, it rates a higher number on the Magnitude scale. If it can be scaled relatively easy then it rates a higher score on the Scalability category. The R&D stage is also included and is identified according to the CCEMC R&D chart, categorized by the following numeric categories (Figure 7).

R&D Stage: 1 2 3 4 5 6

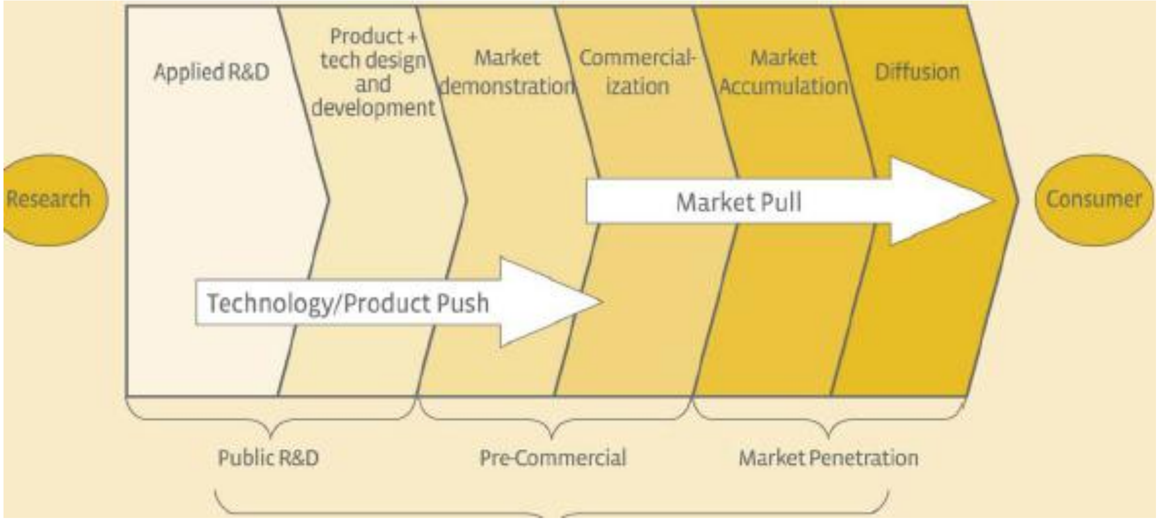


Figure 6: R&D Stages

This assessment sets the stage for the final category for each Sub-Wedge opportunity – Operationalizing the Wedge.

3.0 Wedge Mitigation Potentials and Analysis

The following sections are organized according to major Wedge opportunities as outlined in Section 2.1.1 above. Each Wedge is broken down into a series of sub-wedges based on the most promising and quantitative estimates available. For some of these opportunities, case studies are presented rather than Canada-wide coverage of mitigation potentials. The case study approach is typically applied when a lack of consistent datasets across Canada exist (e.g. Improved Forest Management estimates are based on Alberta's quantitative yield-based timber prediction system), or the wedge is a demand-driven and dependent on many market and penetration factors (e.g. biomaterials).

3.1 Carbon Sequestration

Carbon sequestration by trees is the most intuitive and most challenging component of the complex relationship between forests and climate change. Canada contains approximately 1/3 of the circumpolar boreal forest; which, in turn, constitutes 77 percent of Canada's forest area and 35 percent of Canada's land area (Natural Resources Canada 2009). Boreal forest productivity of native upland forest types ranges from approximately 1 m^3/ha/yr (in NL, northern ON, PQ, MB and SK) to approximately 3 m^3/ha/yr in the central interior of British Columbia (National Forestry Database 2010).

Forest carbon is stored in trees (and other woody plants), soil, peat, and dead woody material. Each of these pools is considered and addressed in the Carbon Budget Model – Canadian Forest Sector (CBM-CFS 3). Durability of storage depends on multiple factors, including the size and nature of the storage medium, location (soil, air, standing, etc.) of the storage medium, and local or regional climatic regime. To more completely address forest carbon capture and storage a number of carbon capture and storage opportunities will be addressed individually; these include afforestation/reforestation, generic increases in forest productivity mediated by climate change, improved forest management, and storage in mineral soil and peatlands.

Early estimates of carbon capture and storage by forests were optimistic that forests would handily meet Canada's need for GHG emission mitigation; for example van Kooten *et al* (2009) comment that "the Kyoto Protocol rules permit the use of forestry activities that create carbon offset credits. These could obviate the need for lifestyle-changing reductions in fossil fuel use." Similarly, Brown *et al* (2002) found carbon sequestration in forests was likely the least costly way for tropical countries to meet GHG mitigation objectives. Unfortunately, these potentials were generalized into overly optimistic expectations.

3.1.1 Afforestation/Reforestation

Afforestation and reforestation, as defined under IPCC rules, offer a substantial opportunity for carbon capture and storage. Afforestation can take a number of forms including:

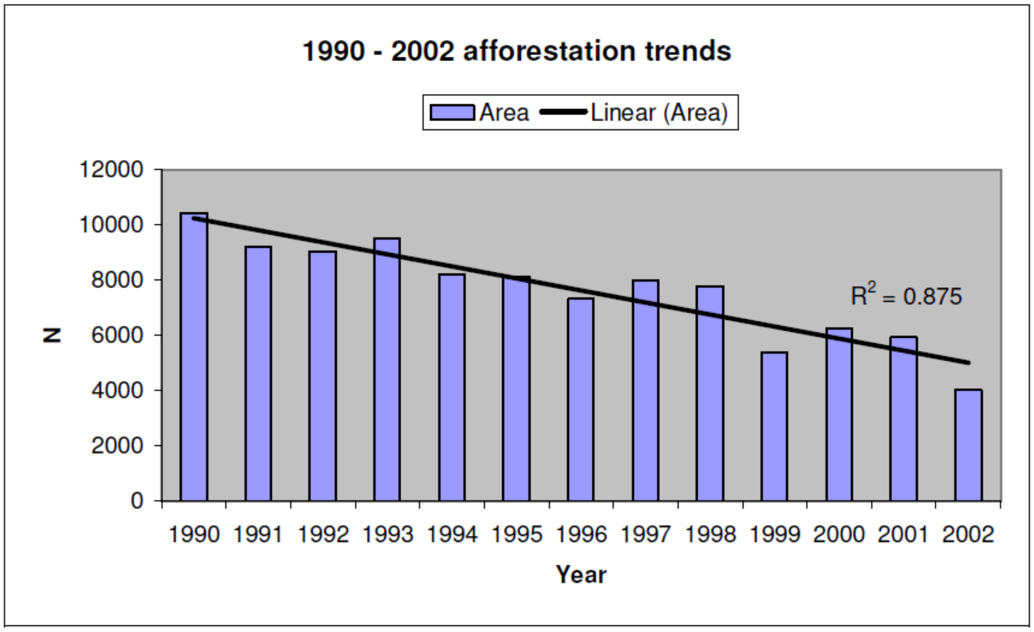
- Agro-forestry where trees are planted across a functioning agricultural landscape – this form of afforestation is frequently integrated with pastoral agriculture;
- Shelterbelt plantings where trees or shrubs are planted as buffers along agricultural fields – this form of afforestation has been used extensively for soil conservation purposes on the Canadian prairies;
- Amenity plantings where trees and shrubs are planted for recreational, ornamental or landscape purposes;
- Production afforestation where afforestation is used to supply mill furnish to a wood processing facility;
- Short rotation intensive culture (SRIC) afforestation is a subset of production afforestation, where highly productive woody crops are managed intensively to produce extremely high yields of fibre on short time horizons. SRIC afforestation is particularly useful when using higher value land for afforestation purposes.

Forest 2020

Natural Resources Canada (NRCAN) conducted a pilot project (Forest 2020) in 2005 – 2006 to examine the potential of afforestation across Canada. This project provided an opportunity to evaluate afforestation techniques, to predict yield of afforestation projects, to engage landowners in afforestation, and to address a number of topical issues around afforestation. NRCAN maintains a website where many of the Forest 2020 outcomes are available – much of the data used in developing this section of the report were drawn from that website (Natural Resources Canada 2008).

Forest 2020 quantified afforestation activity in Canada for the period 1990 through 2002; Figure 7 taken from the Forest 2020 website shows the trend in afforestation activity in Canada during this period.

Figure 7. National Trends in Afforestation Plantings 1990 - 2002.



Mean annual area afforested in Canada during the period was approximately 6000 ha per year. Area afforested in Alberta between 1995 and 2009 totals approximately 14000 ha or approximately 1000 ha per year (Alberta Pacific Forest Industries data, personal data of author, AAFRD data). Thus, at present rates of afforestation Alberta represents approximately 1/6 of Canada's afforestation activity.

Mechanism and Methodology for Mitigation

A case study approach was used to quantify afforestation potential in Alberta. This approach allowed a fairly precise estimate of potential that was then scaled to a national estimate for Canada by using proportional application of the Forest 2020 quantification of afforestation.

The case study was based on an annual afforestation value of 2800 ha was used (1200 ha Alberta Pacific Forest Industries (doubled assuming adoption by one other large, kraft pulpmill) and 400 ha agricultural amenity planting) as base analysis. It was projected to the rest of Canada using a factor of 6 based on Forest 2020 during the 1994 to 2002 assessment period. All afforestation was treated as being additional for purposes of this analysis as it meets all IPCC and ISO-14064: 2 requirements for additionality, and the analysis assumes quantification of projects developed subsequent to 2010.

Forest 2020 did not provide yield estimates; however, potential yields on afforested areas in Alberta range from 1.5 m^3/ha/yr (in amenity plantings) to approximately 8 m^3/ha/yr (in SRIC hybrid poplar plantings). For this evaluation a SRIC yield of 7.5 m^3/ha/yr was used for hardwood plantings (Anderson and Luckert 2007); for agricultural amenity plantings a yield of 1.5 m^3/ha/yr softwood yield and a 4 m^3/ha/yr hardwood yield were used (author, unpublished data). By definition, afforestation has a *de facto* baseline of 0, as there is no forest present prior to afforestation.

Table 4 Alberta case study of annual afforestation GHG mitigation potential.

Cultural Practice	Area (ha)	Yield (m^3/ha/yr)	Total Yield (m^3)	Density (kg/m^3)	Wood to Carbon Conversion	Expansion Factor (from CBMCFS-3)	Root to Shoot Ratio (from CBMCFS-3)	Above Ground CO_2e (MT)	Below Ground CO_2e (MT)	Total CO_2e (MT)
SRIC Poplar	2800	7.5	21000	0.36	0.5	1.11	0.14	0.015	0.002	
Amenity Hardwood	200	4	800	0.36	0.5	1.11	0.14	0.001	0.000	
Amenity Softwood	200	1.5	300	0.4	0.5	0.09	0.12	0.000	0.000	0.018

For Canada, this translates into an annual carbon dioxide capture and storage rate of approximately 0.1 Mt CO_2e (multiplying the Alberta afforestation result by 6 to estimate national potential – the multiplier (6) is based on the Forest 2020 afforestation census). Thus over a decade afforestation could result in approximately 0.6 Mt of CO_2e mitigation potential – presuming a consistent rate of afforestation.

Post-Disturbance Reforestation

At present, Canadian forest management policy does not require reforestation of “natural” disturbances – wildfire, insect-induced mortality and climatic mediated mortality. The usual response to disturbance is to recalculate allowable harvest levels unless the forest company actively reforests the disturbed area. While there is a dearth of data on disturbance reforestation, a review of company and provincial forest management plans suggests that reforestation of disturbed areas generally occurs on an *ad hoc* basis. To assure conservatism in estimation, a factor of ½ of all naturally disturbed areas within the managed forest area was assumed to be eligible for reforestation quantification.

Criteria for eligibility include:

- No legislative requirement for reforestation, as disturbed areas are treated as if they are regenerating on “natural stand” yield curves.
- No incentive funding is available to reforest disturbed areas.
- Only disturbed areas within the “managed” forest area as described by the Canadian Council of Forest Ministers are eligible for quantification.

Table 5 makes a coarse estimate of post-disturbance reforestation potential based on conservative estimates of both native and managed stand growth[5]. Estimated GHG mitigation potential is the difference attributable to reforestation, i.e. the difference between managed stand and native stand yield expectations.

Table 5 GHG mitigation potential arising from reforestation of natural disturbances.

Disturbance	***Potential Reforestation Area (ha/yr)[1]***	***Native Stand Annual Growth (m^3/ha)[2]***	***Managed Stand Annual Growth (m^3/ha)[3]***	***Increase Over "BAU" (m^3/ha)***	***Increase over "BAU" (m^3)***	***CO_2e (t)***	
Wildfire	1060000	1.5	1.75	0.25	265000	53000	
Spruce Budworm[4]	400000	1.5	1.75	0.25	100000	20000	
Mountain Pine Beetle	2650000	2.5	2.9	0.4	1060000	212000	
Jackpine Budworm[4]	2500	1.5	1.75	0.25	625	125	
Total (Mt)							**0.29**

Footnotes:
1. Average annual disturbed area 1990 - 2008.
2. Weighted estimate of cross-boreal MAI figures for conifer and conifer leading yield groups.
3. Esitmated managed stand increase in MAI of 15%.
4. Imputed mortality of 10% of defoliated area.

Constrained Potential: Policy, Market and Technical Overlay

Forest 2020 conducted a series of rural landowner focus groups, which identified several barriers to scaling up afforestation efforts, which include:

- Cost: benefit ratio of afforestation is relatively high, requiring that landowners undertake afforestation on a cost-shared basis with likely consumers of wood fibre –

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[5] Data used to generate the table were taken from the National Forest Database: http://nfdp.ccfm.org/dynamic_report/dynamic_report_ui_e.php

this is, in fact, the model used for SRIC hybrid poplar production in Alberta. Where a cost-shared approach is not available landowners are unlikely to undertake afforestation.

- Opportunity costs are high. Afforestation effectively locks up land, preventing production of high value annual crops. Landowners are reluctant to undertake afforestation as it might prevent their capitalizing on a significant opportunity should one arise.

- Value of hybrid poplar varies with distance to mill and who harvests the trees, but is likely to net landowners on the order of \$10 per m^3. Given a yield of 145 m^3/ha landowners will realize revenue of \$1450 per ha over 20 years. Should they grow hay on the same land for 20 years their revenue stream would likely be approximately \$150/ha/yr. This would give a future value of approximately \$4500, which is substantially greater than the revenue arising from afforestation while providing interim income.

- Landowners feel the technical skills and support needed to successfully implement afforestation is lacking; to quote: “A wide variety of information needs were expressed, and generally these have to do with growing, establishing, maintaining, and harvesting trees. Infrastructure support would come in the form of appropriate technology sourcing and leasing or renting of machinery through delivery agents.”

- Landowners felt that to grow “good” trees there was a need to practice afforestation on “good” land, upping the opportunity cost and need for interim financing substantially, as growers are unlikely to be able to wait for harvest to receive income on high quality sites.

- Forest 2020 identified a break-even carbon price of \$15-18 per tonne as being necessary for afforestation investment to make economic sense in Alberta; this included an average standing timber value of \$10 per tonne or \$7-8 per m^3.

Disturbance reforestation requires empirical evaluation and quantification as wide-ranging assumptions were used to make the estimate given. These include:

- Empirical quantification of area reforested under subsidy or legal requirement for each disturbance type.
- More precise determination of growth potential as the estimates used are a simple average across the boreal forest.

- A quantitative assessment of reforestation costs in both monetary and GHG terms to better estimate both practicality and mitigation potential.

At present, the only active afforestation program in Canada is found in Alberta. Therefore for purposes of estimating the constrained potential current afforestation activity in Alberta was treated as representing the constrained potential for afforestation. Disturbance reforestation is episodic but it appears that reforestation of some of the mountain pine beetle denuded forest lands is likely occur providing another 0.7 Mt of mitigation potential.

Table 6. Categorical evaluation of the afforestation-based mitigation opportunity

	Afforestation	*Explanation/Deviation from criteria outlined in section 2.2.2*
Speed	1	Time required to overcome economic barriers, then stimulate landowner adoption
Magnitude	3	Realized outcome (approx 6Mt)
Scale	3	Many locations, contractors, suppliers therefore verification will be challenging
R&D Stage	3	Know this will work, required significant economic incentives and support
Total (of 21)	**10**	

Operationalizing the Sub-Wedge

- Changes to Canadian personal and corporate tax structures to facilitate investment in afforestation.
- Economic incentives to offset the opportunity cost of afforestation to farm income.
- Technical support and training to facilitate adoption of afforestation as an operational farming practice, building on Woodlot Extension programs and shelterbelt programs across the country.
- Clarity around ownership of increased **standing** wood volume on public lands that arises from private initiatives.
- Development of prioritization and planning tools to guide reforestation efforts to disturbed areas with the greatest economic mitigation potential.

3.1.2 Generic Increases in Forest Productivity

There has been considerable investigation of the potential for increased atmospheric CO_2 levels to act as a “fertilizer” resulting in a passive enhancement in tree growth. In general, older studies have tended toward greater optimism on the response of forests to increasing levels of atmospheric CO_2. For example, Pastor and Post (1988) suggested increases in forest growth were a likely response to increased atmospheric CO_2; while Calef (2010) contends: “Although green-up and thus growing season seem to be starting earlier in the boreal forest (Hicke *et al* 2002), most studies conclude that net photosynthetic activity (carbon uptake by plants for growth) is decreasing, which was termed ‘browning’ (Bunn and Goetz 2006; Bunn *et al* 2007; Goetz *et al* 2005; Verbyla 2008). This browning is most pronounced in the warm and dry areas of interior Alaska (Verbyla 2008) in July and August; it has been detected in the entire circumpolar boreal forest and is in stark contrast to the greening observed in the tundra (Bunn and Goetz 2006; Bunn *et al* 2007; Goetz *et al* 2005; Verbyla 2008) and has caused a stir in the science community which had been in the belief that the vegetation at high latitudes was getting greener with warming based on a landmark paper (Myneni *et al* 1997).”

Clearly, then, improvements in monitoring and modeling techniques suggest the boreal forest is unlikely to respond to increasing levels of atmospheric CO_2 as if it were an involuntary fertilization effect.

3.1.3 Carbon Storage in Forest Soils

Soils, including forest soils, are large reservoirs of carbon; however, soil may function as a sink or source of carbon depending on land management, agricultural practice, or forest management system. Goodale *et al* (2002) contend soil organic carbon is the largest active sink in Canadian forests, capturing approximately 0.08 Mt of carbon between 1990 and 1994. Trumper *et al* (2009) consider boreal forest soil a substantial carbon reservoir: “Because of the low temperatures, decomposition in boreal forests is slow. This leads, as in the tundra, to large accumulations of carbon in the soil pool (116-343 t C per ha, Mahli *et al*, 1999; Amundson 2001)[…] though recent studies suggest that these old-growth forests may indeed be carbon sinks (Luyssaert *et al* 2008).” Bhatti *et al* (2002) compared empirical estimates of carbon storage in boreal forest soils with two modeling approaches – storage values ranged from 10.2 to 14.6 kg/m^2. Taking the most conservative value (10.2 kg/m^2) gives a storage value of 102 t C per ha in upland boreal forest soils in Canada.

Hendrickson (2003) suggests changes in forest soil organic carbon (SOC) in response to climate change will likely be variable depending on changes in precipitation regime, and somewhat stochastic at a finer scale depending on severe weather instigated disturbance. He speculates that overall boreal forest SOC stock is likely to increase provided reforestation of cutover areas is prompt and that minimal soil disruption occurs during the forest harvesting and renewal cycle. Fleming *et al* (2006) found harvesting had little effect on SOC provided soil disturbance was avoided during the harvest operation. In particular, Hendrickson singled out mechanical site preparation for reforestation as a practice likely to induce negative flux in SOC. Kurz *et al* 2007 suggest that boreal SOC stocks may decline (i.e. function as net carbon sources) for several decades due to temperature increase-mediated increases in soil aerobic respiration and increased soil disturbance. Jones *et al* 2005 found that SOC levels in upland boreal soils are likely to increase in the face of climate change. Euskirchen *et al* (2010) suggest climate change will alter forest renewal and will likely result in increased carbon storage in upland forest soils.

Mechanism and Methodology for Mitigation

While there is not a consensus, the bulk of the literature suggests SOC will increase; however, there is a dearth of information on the potential scale of this increase. In fact, there is little information on the rate of carbon sequestration in boreal forest soils in Canada. In contrast, Yurova and Landkriejer (2007) predict upland boreal forest soils in Sweden will sequester carbon at 0.0103 kg/m^2/yr. Similarly, there is little information on the extent of upland soils in the Canadian boreal forest.

Given the size of the boreal forest upland SOC reservoir and our present inability to quantify upland forest SOC stocks or fluxes it would be prudent to manage SOC to minimize loss. This suggests minimizing anthropogenic soil disturbance at both the operational and landscape levels.

For example, at the operational level forest mechanical site preparation is critical to successful reforestation of many boreal site types, as it provides trees a measure of buffer from cold wet soils. Unfortunately, mechanical site preparation results in negative SOC flux. In following disturbance minimization strategy reforestation prescriptions would more accurately define the bounds of cold, wet soils and then apply a more targeted mechanical site preparation treatment. Recent advances in light detection and ranging (LiDAR) technology – specifically Wet Areas Mapping (WAM) (Chicoine and Mihajlovich (2010)) provides the ability to identify areas where mechanical site preparation is critical and more importantly to identify areas where it is not required. Further, once these areas have been identified, targeted site preparation techniques such as making individual planting micro-sites (mounding) will result in far less soil disturbance and efflux of SOC.

At the landscape level, efforts like the on-going regional planning initiative in Alberta will result in less cumulative footprint arising from industrial infrastructure and therefore less disturbance and SOC efflux.

Operationalizing the Sub-Wedge

- A clear and easily applied definition of upland boreal soils.
- Determine the extent of upland soils in Canada’s boreal forest.
- Use a previous soil or soil organic carbon inventory to set a baseline.
- Develop an on-going SOC inventory to quantify changes.

3.1.4 Improved Forest Management

Forest management in Canada occurs primarily on public lands and is undertaken primarily by private enterprises. Reforestation of lands harvested to supply forest products is generally a legal requirement of forest tenure; i.e. forest products enterprises are required to reforest lands they harvest as part of their tenure obligation. Thus most reforestation activity is not “additional” in terms of GHG capture and storage. Furthermore, forest tenure takes two forms: volume-based allocations of forest fibre and land-based tenure. Forest enterprises holding land-based tenure are required to develop forest management plans that effectively define reforestation expectations – in effect, defining “business as usual” (BAU) for purposes of determining additionality for GHG quantification.

Forest management plans generally expect and plan for additional fibre volume over that found in native forests. These “managed stand” expectations are generally predicated on:

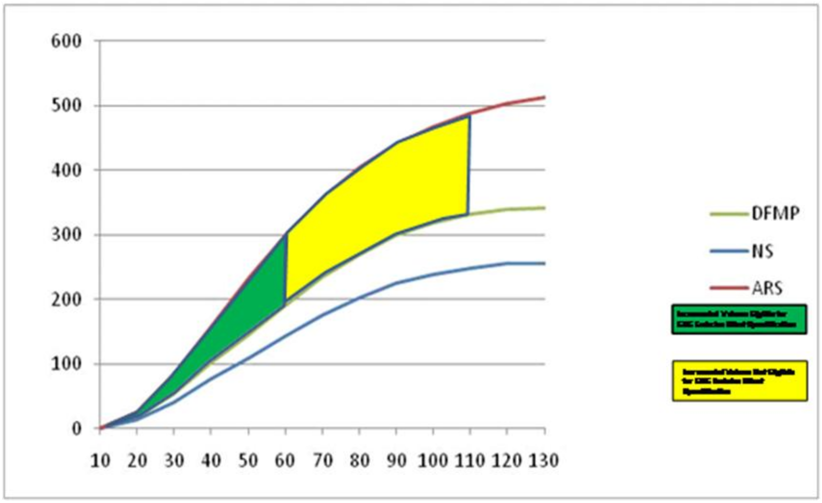
- Reducing (or eliminating) delays in reforestation – native forest stands are presumed to have taken a period of time to establish. This “reforestation lag” is generally assumed to be reduced or eliminated in managed forests.

- Reforestation activities frequently utilize technologies or techniques, which are expected to increase forest productivity. These include genetically improved planting stock, physiologically conditioned seedlings, mechanical site preparation and competition control or tending of planted trees.

- Density management and uniform site occupancy are expected to result in more uniform and more consistently rapid forest growth.

Thus managed stands generally show better growth than native forests –these managed stand growth expectations must underpin any definition of additionality. Figure 9 is a “real world” illustration of both managed stands expectations and growth that is additional to managed stands expectations. In this illustration “NS” refers to native (fire origin) stand growth expectations, “DFMP” refers to detailed forest management plan expectations, and “ARS” refers to regeneration survey outcomes.

Figure 8. Illustration of managed stand expectations and additional fibre volume.



The area shaded green and yellow between the DFMP and ARS curves is truly additional; while the area between the NS and DFMP curves shows substantial increases in volume, these are not additional because the DFMP is effectively BAU for purposes of defining additionality. For the area between ARS and DFMP to remain completely additional harvest levels must not be increased to capture the additional volume. If the increase in volume production is added to the harvest queue it must be discounted by a factor that represents storage in harvested wood products.

Mechanism and Methodology for Mitigation

A case study approach using recent (2008 and 2009) provincial regeneration assessment outcomes was used to broadly quantify the potential for improved forest management to mitigate greenhouse gas emissions. Alberta is unique in having a regeneration assessment method that links reforestation outcomes quantitatively to management planning expectations – effectively, a built-in test for additionality. Thus, an empirical assessment of the mitigation potential of improved forest management in Alberta could be undertaken easily.

Table 7 uses average results of both years' regeneration assessments to evaluate increase in carbon dioxide capture attributable to improved forest management.

Table 7 Annual increase in carbon dioxide sequestration from improved forest management.

Species	***Average Area Planted (ha/yr)*** [1]	***Expected Annual Growth (m^3/ha)*** [2]	***Realized Annual Growth (m^3/ha)*** [3]	***Increase Over "BAU" (m^3/ha)***	***Increase over "BAU" (m^3)***	***CO$_2$e (t)***	
Lodgepole pine	29000	2.3	2.5	0.2	5800	4300	
White spruce	35000	2.1	2.4	0.3	10500	7700	
Total (Mt of *CO$_2$e*)							**0.012**

Footnotes:
1. Average annual planting area 2004 - 2009
2. Average MAI figures for conifer and conifer leading yield groups from ARS manual
3. Average MAI figures from 2008 and 2009 ARS results

Scaling the case study to a national estimate requires a number of estimates:

- Growth gains arising from improved forest management are likely most commonly found in New Brunswick, Nova Scotia, Ontario, Alberta and British Columbia. These jurisdictions incent improved forest management through volume assignment strategies and do not constrain access to the tools necessary to achieve improved forest management. Thus the Alberta case study represents approximately 16% of the Canadian opportunity[6].
- These gains are most easily quantified in Alberta due to the quantitative growth-based approach to regeneration assessment recently implemented in Alberta.

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[6] http://nfdp.ccfm.org/dynamic_report/dynamic_report_ui_e.php

- Forest growth varies widely across Canada; from a low of ~1 m^3/ha/yr in NL, ON and QC to a high of more than 10 m^3/ha/yr in intensively managed coastal forests. Quantification at a level of resolution that addressed these growth differences and their responses to improved forest management was beyond the scope of this document. In the interest of conservatism the Alberta numbers were simply scaled up to an area proportion basis.

Thus a conservative national estimate of the potential for improved forest management to mitigate GHG emissions is 0.012 Mt X 100/16 or 0.075 Mt CO_2e per year.

Constrained Potential: Policy, Market and Technical Overlay

For improved forest management to provide GHG capture and sequestration a number of critical changes to forest management expectations must be made:

- Forest management planning must recognize carbon dioxide capture and storage as a forest product. Effectively, this means management plans must recognize that increased volume production may be assigned to either conventional forest products **or** GHG capture and storage but not to both.

- Silvicultural practices must be prescribed and deployed to attain both fibre and carbon production objectives. While similar these objectives are not always the same – for example, carbon management objectives might suggest longer rotation ages than fibre management objectives.

- Better quantification of GHG emissions associated with forest management and particularly reforestation must occur. In particular, any differences in GHG emission profile between what is needed to attain DFMP and ARS must be quantified and netted from the ARS quantification. This must include fluxes in forest sinks as well as direct project emissions.

- Ownership of carbon (particularly “additional” carbon) stored in trees on public lands must be re-examined. At present, carbon stored in trees on public lands is deemed to be property of the Crown until such time as the tree is severed (Alberta Sustainable Resource Development, 2010) effectively preventing forest managers from realizing any gain from GHG sequestration for decades.

- Alberta is the only province, at present, with a forest regeneration assessment system that determine growth trajectory of young stands and contrasts these results with management expectations. Other provinces would require development of a suite of tools including juvenile growth models, baseline determination and sampling/verification methods to adequately quantify carbon dioxide sequestration attributable to improved forest management.

- Substantial funding is required to implement improved forest management and at present there is no financial benefit that accrues to increased carbon storage in standing forests.

Table 8. Categorical evaluation of mitigation potential of Improved Forest Management

	Improved Forest Management	***Explanation/Deviation from criteria outlined in section 2.2.2***
Speed	5	Activity in place until approx 2008, quantification method already exists
Magnitude	1	Realized outcome (<1Mt)
Scale	3	Quantification outside AB must be developed
R&D Stage	6	Current operational practice
Total (of 21)	**14**	

Operationalizing the Sub-Wedge

- Include carbon dioxide capture and storage in the forest products mix when developing detailed forest management plans.

- Apply silvicultural treatments to increase carbon density at the cutblock or reforestation project level.

- Develop a more targeted approach to reforestation, including:
  - Focused, site specific mechanical site preparation treatments.
  - Use models and empirical assessment of older plantations to assess the role of planting density from a carbon management perspective.

    - Include “emission costs” in selection criteria for silvicultural treatments.

- Extend use of CBM-CFS 3 to assist silviculturists in developing silviculture processes and prescriptions.

- Develop and include *ex poste* GHG quantification tools in silviculture assessment processes.

3.1.5 Carbon Sequestration in Peatlands

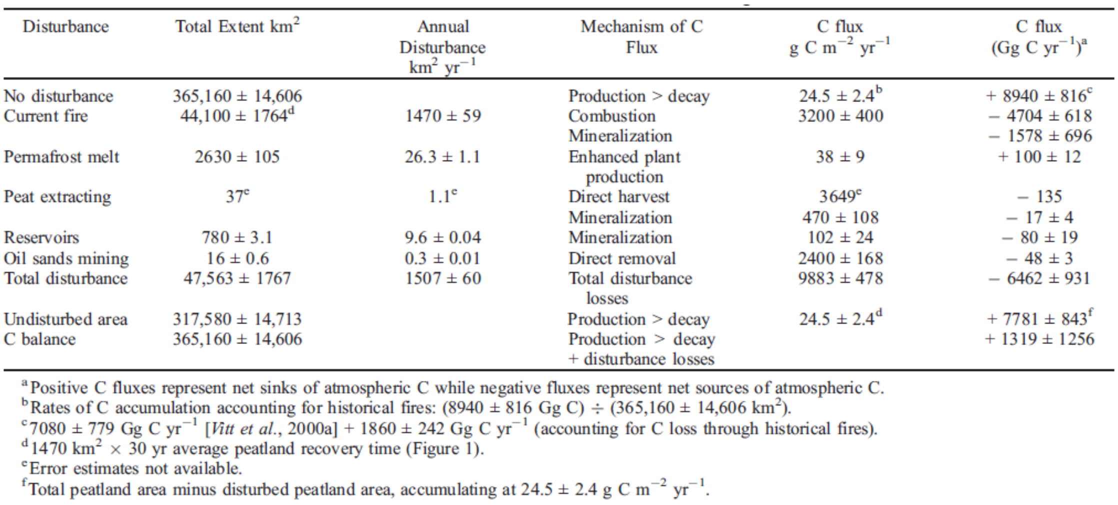
Peat accumulating lowlands (peatlands) are recognized as large reservoirs of carbon storage in the ecosystem. Peatlands cover approximately 3% of the Earth’s land surface and store approximately one third of the world’s soil carbon (Vitt, 2006). Canada’s peatlands have been estimated to contain up to 170,000 Mt of carbon (Vitt *ibid*). In Alberta up to 70% of soil carbon is stored in peatlands (13,500 Mt in peatlands, 2300 Mt in lakes, 2700 Mt in forests, and 800 Mt in grasslands).

Mechanism and Methodology for Mitigation

Despite the enormous scale of organic carbon storage in peatlands, they are recognized as large reservoirs but only weak sinks due to variations in greenhouse gas emissions with variation in water level. As peatlands dry they move from capturing carbon in plant material found below the water surface, to emitting methane from semi-decomposed plant material exposed by the retreating water (Vitt 2006). Furthermore, peatlands tend to accumulate carbon at relatively low rates, which are driven by both slow growth rates of plants found in peatlands and recurring fire disturbance of peatlands. For example, pristine peatlands in western Canada sequester 194 kg/ha/yr of carbon in the absence of land management practices, however this increases to 245 kg/ha/yr under present management regimes that exclude wildfire (Vitt 2006).

Turetsky *et al* (2002) conducted a regional cumulative effects analysis that encompasses wildfire, anthropogenic disturbance, harvest and climate change impacts on peatland carbon fluxes. They found a net increase in carbon storage in peatlands across western Canada of 4.8 Mt CO_2e. Most erosion of peatland carbon storage was driven by fire and natural mineralization processes; however, approximately 0.7 Mt/yr of loss were attributable to harvesting of peat and to industrial development on peatlands. This analysis did not consider dispersed disturbance of peatlands for forest harvesting and mineral/petroleum exploration purposes. Table 9 taken from Turetsky *et al* 2002 provides regional peatland carbon flux baseline.

Table 9. Peatland carbon fluxes-Western Canada (from Turetsky et al.)



Disturbance	Total Extent km^2	Annual Disturbance km^2 yr^{-1}	Mechanism of C Flux	C flux g C m^{-2} yr^{-1}	C flux (Gg C yr^{-1})[a]
No disturbance	365,160 ± 14,606		Production > decay	24.5 ± 2.4[b]	+ 8940 ± 816[c]
Current fire	44,100 ± 1764[d]	1470 ± 59	Combustion	3200 ± 400	− 4704 ± 618
			Mineralization		− 1578 ± 696
Permafrost melt	2630 ± 105	26.3 ± 1.1	Enhanced plant production	38 ± 9	+ 100 ± 12
Peat extracting	37[e]	1.1[e]	Direct harvest	3649[e]	− 135
			Mineralization	470 ± 108	− 17 ± 4
Reservoirs	780 ± 3.1	9.6 ± 0.04	Mineralization	102 ± 24	− 80 ± 19
Oil sands mining	16 ± 0.6	0.3 ± 0.01	Direct removal	2400 ± 168	− 48 ± 3
Total disturbance	47,563 ± 1767	1507 ± 60	Total disturbance losses	9883 ± 478	− 6462 ± 931
Undisturbed area	317,580 ± 14,713		Production > decay	24.5 ± 2.4[d]	+ 7781 ± 843[f]
C balance	365,160 ± 14,606		Production > decay + disturbance losses		+ 1319 ± 1256

[a] Positive C fluxes represent net sinks of atmospheric C while negative fluxes represent net sources of atmospheric C.
[b] Rates of C accumulation accounting for historical fires: (8940 ± 816 Gg C) ÷ (365,160 ± 14,606 km^2).
[c] 7080 ± 779 Gg C yr^{-1} [*Vitt et al.*, 2000a] + 1860 ± 242 Gg C yr^{-1} (accounting for C loss through historical fires).
[d] 1470 km^2 × 30 yr average peatland recovery time (Figure 1).
[e] Error estimates not available.
[f] Total peatland area minus disturbed peatland area, accumulating at 24.5 ± 2.4 g C m^{-2} yr^{-1}.

The scientific consensus around carbon storage in peatlands is that carbon storage is likely to be adversely affected by climate mediated disturbance. Unfortunately, once disturbed, peatlands take centuries to recover the pre-disturbance carbon storage levels, and peatlands are likely to become net sources due to release of CH_4 following disturbance. Vitt 2006 suggests it takes approximately 500 years for peatlands to return to being weak sinks following disturbance. The Oilsands Wetlands Working Group (2000) states that peatlands cannot be replaced by reclamation efforts following disturbance as there are no techniques available, at present, to replace bogs and fens on post-disturbance landscapes.

Constrained Potential: Policy, Market and Technical Overlay

In summary peatlands might best be viewed as vast carbon reservoirs at significant risk of alteration through climate change or anthropogenic effects on the forest and tundra landscapes. In particular disturbance may result in significant methane emissions as peatlands become warmer – resulting in more rapid decomposition of organic materials currently “stored” in peatlands. If this view is taken it would be prudent to manage peatlands and their associated landscapes to minimize disturbance of peatlands and attempt to buffer them from the effects of climate change. Turetsky *et al* 2002 shows the value of anthropogenic protection in maintaining intact peatlands in the face of wildfire.

Operationalizing the Sub-Wedge

Vitt 2006 offers an array of guidelines for mitigating climatic and anthropogenic impacts on the ability of peatlands to continue to function as a carbon sink. They are:

- "Develop a long-range plan of corridors and reserves that includes predicted future occurrences of peatlands. Since our future peatlands may only exist in a fully functional condition north of 60° N latitude, we should begin now to incorporate a reserve system that examines these northern sites.

- "Restoration of wetlands after oil sands extraction may only be possible by examining wetlands that currently exist under our future predicted climatic regime. Examination of how these wetlands have initiated and continue to exist may provide valuable insights into our wetland environments. For example, a key indicator species of rich fens is *Meesia triquetra*. Examination of herbarium specimens and distribution maps of the occurrence of *M. triquetra* in southern Saskatchewan and the Midwestern states may be useful in developing landscapes for rich fen development under future climatic regimes.

- "Maintain our peatlands in as pristine condition as possible. Use of peatlands for agriculture increases GWP (global warming potential) of fens and bogs substantially. Whereas the GWP of pristine bogs is negative and of fens is only slightly positive (less than 100 kg CO_2e ha^{-1} yr^{-1}), when peatlands are drained for pasture or tilled the GWP increases to 4000 to 5000 kg CO_2e equiv. ha^{-1} yr^{-1} for the former and more than 10,000 for the latter for fens.

- "Mitigation for indirect effects can be as follows:
  Do not remove the actively growing top few centimeters of the ground layer when grading access lines.
  Keep the time from the end of peat harvesting activity to revegetation as short as possible. In western Canada, develop a clear management plan for restoration of cut over bogs back to fens.
  Avoid nutrient inputs to peatlands during construction activities; these include keeping to a minimum the introduction of mineral soil to peatland areas.
  Adequate buffer zones should be maintained around peatland complexes.
  Higher water tables from increased upland runoff after forest harvest or wildfire increase nutrients and decrease acrotelms resulting in complete successional turnover of keystone species and this may be as devastating for peatlands as lowered water tables due to climate change. Buffer zones should be designed

> relative to peatland size, runoff amount, and watershed extent in order to protect small, sensitive peatlands as well as larger, less sensitive peatland complexes.
> Road construction engineering should endeavor to understand peatland hydrology in order to avoid changes in water levels."

Table 10. Categorical Assessment of Peatland Management Mitigation Opportunity.

	Peatland Management	***Explanation/Deviation from criteria outlined in section 2.2.2***
Speed	1	Indirect, preventative measures are the only methods available
Magnitude	1	Realized outcome (<1Mt)
Scale	1	Large area but highly variable and difficult to quantify
R&D Stage	1	Basic Science only
Total (of 21)	**4**	

3.1.6 Avoided Forest Conversion

Avoided forest conversion is commonly used to reduce GHG emissions from burning of tropical forests in preparation for agricultural exploitation. This option is less commonly considered in the Canadian context. In Alberta, forest tenure holders are expected to manage and harvest the forest for commercial production; if they do not, their holdings are subject to being reallocation by the Crown: "Alberta will cancel forestry tenure in areas outside protected areas where forestry tenure holders have suspended timber harvesting solely to earn offset credits" (Alberta Sustainable Resource Development 2010).

3.1.7 Delayed Forest Harvesting

Conversely, delayed harvesting is a sound carbon management strategy that is gaining considerable support (Brown *et al, op cit*; Meng *et al*, 2003; Li *et* al, 2006; Hines *et al*, 2009; Ryan *et al, op* cit; and (locally) Price *et al*, 1997), and that is likely to win regulatory acceptance.

Mechanism and Methodology for Mitigation

Effectively, delayed harvesting is analogous to improved forest management; harvest levels are reduced by lengthening the rotation age. This has the effect of retaining carbon storage in older trees, resulting in less erosion of carbon stocks when managing old forests. Li *et al, op cit* found delayed harvesting a viable strategy for maintaining forest carbon stocks – which, as they point out, is a critical consideration in IPCC-based forest carbon quantification. Price *et al op cit* found that extended rotation age in combination with effective forest protection resulted in substantial increases in carbon stocks, compared to natural disturbance dynamics or harvesting to emulate natural disturbance ("business as usual").

Delayed harvest has a number of appealing attributes:

- It is primarily passive in nature, that is, benefit accrues to doing less and thus there is less need to quantify a balance between carbon gain and carbon expenditures necessary to achieve the outcome;

- "Carbon benefits" accrue immediately similar to direct reduction of emissions as one is protecting carbon stocks rather than increasing carbon scavenging from the atmosphere;

- Delayed harvesting is likely to increase species and structural diversity of forests, albeit at the cost of potential leakage (Ryan *et al, op cit*).

- Forest management planning has an impressive array of inventory and accounting tools that would render quantification and verification of delayed harvest relatively straightforward.

- As with afforestation, delayed harvest has a substantial suite of environmental co-benefits associated with it; including increased biodiversity, maintenance of habitat for old growth dependent species, and public perception of conservation.

A case study approach was used to illustrate the potential of delayed forest harvesting as tool for GHG mitigation. It illustrates the effect of delaying harvest 10, 20 or 30 years across an area representing approximately 10% of Alberta's forest landbase (Table 11). The table is drawn from a detailed forest management plan but does not represent a revision of the timber supply analysis. Thus it should be considered as an indication of the potential of delayed harvest rather than a quantitative analysis.

Table 11. Effect of delaying harvest on carbon dioxide capture and storage by forests.

Deciduous - 80 year rotation, Conifer - 110 year rotation							
		AAC with Δ Rotation (yrs)			***AAC Reduction (m^3) with Δ Rotation (yrs)***		
	Current AAC	***10***	***20***	***30***	***10***	***20***	***30***
Deciduous	2500000	2187500	1640625	1025391	312500	859375	1474609
Coniferous	1500000	1363636	1115702	811420	136364	384298	688580
Annual CO_2 (Mt)							
Deciduous		0.210	0.580	1.000			
Coniferous		0.100	0.290	0.510			
Total		***0.310***	***0.870***	***1.510***			

Assumptions:

Based on 21000 km^2 (10% of productive provincial forest land base.)
Deciduous density = 0.367
Coniferous density = 0.410
Carbon content in wood = 0.500

Canada has total productive forest area[7] of 3,973,000 km^2; thus the case study represents approximately 05% of the total productive forestland base. It is not possible to readily scale the case study to a national scale at a level of resolution similar to the case study. However, delayed softwood harvest can be scaled at a generic level. (Hardwood harvest is less easy to quantify, as there are substantial differences in managing aspen and other hardwood species.)

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[7] http://foretscanada.rncan.gc.ca/statsprofile/keyfacts/ca

Table 12 National estimate of impact of delaying conifer harvest

Nominal Conifer - 100 year rotation							
		AAC with Δ Rotation (yrs)			AAC Reduction (m^3) with Δ Rotation (yrs)		
	Current AAC	10	20	30	10	20	30
Coniferous	126000000	113400000	90720000	63504000	12600000	35280000	62496000
Annual CO_2 (Mt)		***2.6***	***7.2***	***12.8***			

Assumptions:
Coniferous density = 0.410
Carbon content in wood = 0.500
Delayed harvest results in all unharvested volume accruing to standing carbon stock.
Generic rotation age of 100 used for all conifer species.

Constrained Potential: Policy, Market and Technical Overlay

There are several barriers to implementing delayed harvesting:

- Forest resource users generally have capital investments that are predicated on a specific wood supply and are likely to seek wood elsewhere to maintain manufacturing, resulting in leakage.
- With few exceptions, forest management planning focuses on optimizing fibre flow and harvest costs, treating other forest values or ecological services as constraints not opportunities.
- Alberta Sustainable Resource Development's interpretation of forest carbon ownership challenges the ability of forest management actors to realize benefits from delayed harvest.
- Forest products manufacturers would face a substantial cost of rationalizing production capacity. The cost estimate in Table 12 ignores leakage – it simply projects a cost of mill furnish replacement using wood values to landowner taken from Alberta Agriculture Food and Rural Development (2003) data (\$3/m^3 hardwood, and \$30/m^3 softwood).
- The analysis in Tables 11 and 12 also ignore the multiplier effect of reduced employment for loggers and mill workers arising from reduced harvest levels.

- The national estimate is broadly generic and requires substantial effort to be made truly quantitative. A regional approach using real rotation ages and including both softwood and hardwood harvest levels is recommended.

Table 13. Cost per tonne of CO_2e mitigation derived from delay harvest, AB case study.

	AAC Reduction (m^3) and Cost ($) with Δ Rotation					
	10 years		***20 years***		***30 years***	
Deciduous	312500	$937,500	859375	$2,578,125	1474609	$4,423,828
Coniferous	136364	$4,090,909	384298	$11,528,926	688580	$20,657,400
Total Cost		$5,028,409		$14,107,051		$25,081,229
Mt CO_2e		0.3		0.9		1.5
Cost/Mt	$16,761,364		$15,674,501		$16,720,819	
Cost/t	***$16.76***		***$15.67***		***$16.72***	

Table 14. Categorical assessment of GHG mitigation potential of delayed harvesting.

	Delayed Forest Harvest	***Explanation/Deviation from criteria outlined in section 2.2.2***
Speed	1	Change would require considerable adjustment to industrial infrastructure
Magnitude	5	Realized outcome (0.5 - 1.5 Mt)
Scale	5	Large area but quantification tools and models are in place
R&D Stage	5	Science and tools are in place, downstream costs need to be quantified
Total (of 21)	**16**	

The constrained potential of approximately 1/3 of theoretical potential represents delayed harvesting arising from not re-starting facilities idled by the current downturn in forest products exports. This potential is presently being realized without quantification and could be sustained without occasioning the economic challenges associated with dislocation of workers or replacement of mill furnish associated with achieving the full theoretical potential.

Operationalizing the Sub-Wedge

- Forest industry investment in wood processing facilities would need to be rationalized – likely requiring financial support.

- Ownership of carbon "stored" standing trees would have to accrue to the holders of harvesting rights not the Crown.

- Forest management planning would need to be re-tooled to include carbon on an equal footing with production of mill furnish.

- Disruption of forest industry workers, suppliers and towns would need to be addressed.

Comparison of Opportunities

Figure 9 compares building material switching, afforestation, improved forest management, and delayed harvest based on the categorical assessments done individually. Clearly realizing greenhouse gas mitigation from forest-based activities will require time to incent changes in landowner behavior (afforestation) or forest industry expectations (improved forest management or delayed harvest). Given the potential magnitude of mitigation associated with these options, more thought should be expended on how to realize their potential while managing the potential of delayed harvesting to perturb the forest industrial base. Integrating these by using afforestation to replace mill furnish lost to delayed harvest is an example of how these opportunities might be better realized through integration.

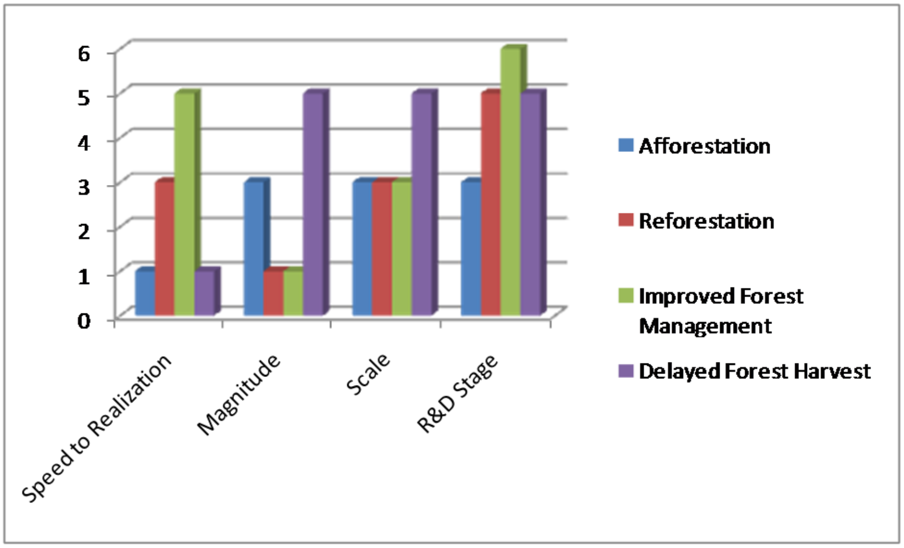

Figure 9. Comparison of categorical evaluations of forest based GHG mitigation opportunities.

3.1.8 Agriculture Soil Carbon Sequestration

In 2008, the Agricultural sector in Canada was responsible for emissions of 62 Mt of CO$_2$e (8.4% of Canada's anthropogenic emissions). Of this, 32 Mt of CO$_2$e were emitted from agricultural soils across Canada, with 17 Mt from direct emission sources, 3.8 Mt from pasture, range and paddocks, and 10 Mt from indirect sources. Cropland covers approximately 48 million hectares of the Canadian agricultural region. Cultivated agricultural land in Canada includes areas of field crops, summerfallow, hayland and tame or seeded pasture. About 83% of Canada's cropland is in the interior plains of western Canada, made up of the Semiarid and Subhumid Prairies and the Boreal Plains zones. There are roughly 2 dozen crops grown across Canada on over 100,000 farms. Crops like corn, wheat, barley and canola require more fertilizers to sustain their production.

From a management perspective, 13 Mt were emitted from soils due to synthetic N fertilizer application, 9.1 Mt from crop residue decomposition (related to yields) and 0.17 Mt from a variety of other cropping management practices (summerfallow, conservation tillage, Irrigation and cultivation of organic soils) (Environment Canada 2010). These emissions were partly offset by the mitigating effects of increased soil carbon sequestration. In 1990, the management of mineral soils amounted to a net CO$_2$ removal of about 2 Mt. This net sink steadily increased to about 12 Mt in 2008, through changes in management over time.

As stated in Lindwall and Sontaag (2010), the adoption trends of conservation tillage and other closely associated practices show:

- The rate of no-till seeding has increased from < 15% in all eco-zones in 1991, to 61% in the brown and dark brown soil zones of the prairies, about 45% for black soils, 40% for gray soils, and 26% in the mixed wood plains (southern Ontario /Quebec) as of 2006;

- Similarly, the use of chemical fallow has increased from <5% to 13, 24, 41, and 52% in the gray, black, dark brown, and brown soil zones, respectively, over the same time period.

- The practice of reduced till, which is a transition between conventional tillage and no-till, has remained fairly constant around 30% since 1991.

The amount of organic carbon sequestered in the mineral soils of Canada is a function of yield (residue inputs) and decomposition rate of soil organic carbon (SOC). Cultivation and different management practices can lead to either an increase or decrease in the rate of decomposition and hence, organic carbon stocks in soils. This change in SOC results in either a CO_2 emission or removal in the atmosphere. Reducing fallow and switching to more continuous cropping results in lower decomposition rates and increased residue inputs. Minimizing tillage to the point where the seed is placed directly into the ground, preferably with concomitant fertilizer placement beside the seedbed, decreases the rate of soil decomposition compared to higher soil disturbance practices. Finally, perennial cropping is one of the best means of enhancing GHG removals from the atmosphere and increasing soil carbon storage. This is due to the longer growing season; deeper and more fibrous rooting systems that increase each year; reduced soil disturbance; and higher plant biomass inputs per unit area of soil.

Mechanism and Methodology for Mitigation

The primary strategies with high confidence for sequestering more carbon in Canada's soils through altered management are:

- Increasing the adoption of no-till and reduced till across Canadian farming regions
- Converting more acres of summer and chem-fallowed land to continuous cropping
- Converting more acres of marginal crop land to land under perennial forage.

Some studies have identified diversifying crop rotations as a means to increase soil carbon sequestration. This is not included in this study since the science remains incomplete in this area. Further, the measuring, monitoring and verification requirements are difficult to implement given that choices of crops depend on annual decisions by growers, as influenced by market, anticipated seasonal conditions, and other management and economic factors.

The quantification approaches used in the calculations in this sub-wedge are based on the Alberta GHG quantification protocols for tillage system management, draft summerfallow management and proposed conversion to perennial forage (Climate Change Central 2009). GHG emissions are calculated using IPCC best practice guidance (IPCC 2006) and Canadian-based Tier 2 emission factors as set out in the National Emissions Inventory methodology (IPCC 2000, IPCC 2006)). In addition, analysis undertaken by Agriculture and Agri-food Canada's Strategic Policy Branch is also included in the quantification estimates (Gill and MacGregor 2010).

These protocols have been developed through a comprehensive scientific and technical review, including both the federal and provincial governments, Canada's leading academic experts in soils, cropping and agronomic science as well as scientists from abroad (United States and overseas experts). The science and quantification represented in these strategies is robust and highly confident. Note that in adapting this quantification to Canada-wide mitigation estimates, certain assumptions need to be made. These are listed in the next section.

Quantification: Theoretical Mitigation Potential

Baseline Assumptions and Data Sources – Soil Carbon Sequestering Practices:

According to the NIR, the size of Canada's accumulated net agricultural soil sink from 1990-2008, is approximately 12 Mt CO_2e. This is the most comprehensive accounting for emissions in Canada. Any incremental gains in soil organic carbon through the strategies mentioned above would need to be based on the year to date acreage uptakes of these practices that lead to this accumulated amount. The most recent and comprehensive statistics on tillage practice adoption is the 2006 Statistics Canada survey. These adoption rates will be used as the basis for carbon gains going forward - above and beyond current rates in the 2007-2020 time period.

Adoption rates and current acres of summerfallow and tillage practices in Canada for census reporting periods 1991 – 2006 are shown below (Table 15) (Statistics Canada 2009 and Statistics Canada 2008a). For summerfallow, Statistics Canada also publishes estimated summerfallow acres annually since 1990.

Table 15. Tillage Practices Used to Prepare Land for Seeding and Summerfallow areas from Statistics Canada, 1991-2006.

Land Base/Practice	1991	1996	2001	2006
Total Land Prepared for Seeding (ha)	29,028,766	28,692,831	29,733,424	29,048,749
Full Till[a] –				
Area under Full Till (ha)	19,986,611	15,334,293	12,039,711	8,140,025
Percentage of Total Land Seeded (%)	68.9	53.4	40.5	28.0
Reduced Till[b]				
Area under Reduced Till (ha)	7,091,001	8,766,760	8,870,230	7,427,910
Percentage of Total Land Seeded (%)	24.4	30.6	29.8	25.6
No Till[c]				
Area under No Till (ha)	1,951,154	4,591,779	8,823,482	13,480,814
Percentage of Total Land Seeded	6.7	16.0	29.7	46.4

(%)				
Summerfallow Area				
Area under Summerfallow (ha)	7,781,000	6,192,000	4,675,000	3,462,000[e]
Percentage of Total Cropped Land (%)[d]	23	18	13	10

a – defined as tillage with most of the residues incorporated into the soil
b – defined as tillage with most crop residues remaining on the soil
c – defined as no-till seeding or zero tillage
d – includes all cropped land in Canada; field crops, summerfallow, hayland and tame or seeded pasture – 1991 – 33,507,780 ha; 1996 – 34,918,733 ha; 2001-36,395,150 ha; 2006 - 35,912,247 ha; http://www40.statcan.ca/l01/cst01/agrc25a-eng.htm
e – note, estimated land in summerfallow for 2010 jumped to 4,868,000 ha due to flooded acres in Canada.

Mitigation Assumptions and Activities – Soil Carbon Sequestering Practices

To estimate the amount of carbon sequestered from conservation tillage practices, the calculation methods adapted from Canada's IPCC Tier 2 accounting for the NIR, and rolled up to reporting units, breaks agricultural lands into regional areas based on common C sequestering outcomes (Table 16). This report uses the calculation methods based on the integration of the NIR methodology into the protocol accounting procedures for Alberta, and originally designed under a National effort in 2006 (Haak 2006). The carbon gain coefficients are adjusted on a proportional basis, according to the level of adoption rates of continuous No-Till (NT), Reduced Till (RT) and Full Till (FT) for a given region in the baseline year – essentially setting the baseline to zero, and rewarding only new carbon sequestered going forward. This is known as proportional additionality. Thus, using percent adoption rates for the different tillage management systems in the 2006 Census, the theoretical potentials are shown in Table 19. The calculations assume that all areas of in NT would sell carbon offsets, all areas of FT would change to NT and all areas of RT would change to NT to arrive at the theoretical potential of stored carbon.

Table 16. Coefficients, acreages and Potential Tonnes of Carbon Sequestered across Canada from Conservation Tillage Practices on an annual basis (2006 Census).

Region[a]	Coefficient t/ac/yr	Total Acres	Eligible Acreage		Mt CO_2e/yr	Total Mt CO_2e/yr
Net No-Till Coefficient						
			NT acres	**FT acres**		
East	0.13	507054	34,733	392,967	0.06	5.28
East Central	0.14	9,460,500	1,929,942	5,009,335	1.00	
Parkland	0.12	35,469,051	15,283,614	10,193,805	3.02	

Dry Prairie	0.06	25,855,124	13,954,010	5,535,582	1.17	
West	0.09	290434	93673	268758	0.03	
Net Reduced-Till Coefficient						
			RT Acres			
East	0.09	507054	79,100		0.01	0.09
East Central	0.03	9,460,500	2,525,954		0.08	
Parkland	0.00	35,469,051	9,988,085		0.00	
Dry Prairie	0.00	25,855,124	7,668,630		0.00	
West	0.00	290434	128,003		0.00	

a- East (Newfoundland, Prince Edward Island, Nova Scotia, New Brunswick); East Central (Ontario, Quebec; Parkland AB, SK, MB – black, grey and dark grey soil zones; Dry Prairie, AB and SK Brown and Dk. Brown soil zones; West, BC)

Based on the above estimates, the Theoretical Mitigation Potential for storing atmospheric carbon in eligible agricultural soils through tillage system management systems is as high as **5.29 Mt CO_2e/yr**.

To estimate the amount of carbon sequestered from conversion of summer or chem.- fallow to more continuous cropping, the calculation methods adapted from Canada's IPCC Tier 2 accounting for the NIR, integrated into the protocol accounting procedures for Alberta are used. Acres under summerfallow according to the 2006 census, was 3, 462,000 hectares. It was assumed the majority of these hectares reside in the Dry Prairie region of Alberta and Saskatchewan (Brown and Dark Brown soil zones) where this practice is still used to conserve moisture during drier years. Further, it is assumed that 100% of these hectares were converted to continuous cropping until 2020.

Applying the summerfallow conversion net coefficient of 1.31 tCO_2e/ha/yr (C. Rice Pers. Comm)[8], the total mitigation potential could be up to **4.54 t CO_2e/yr**.

Estimating the amount of carbon that could be stored from converting annually cropped land to perennial forage are more difficult to obtain and less confident. The calculation methods adapted from Canada's IPCC Tier 2 accounting for the NIR, is only beginning to be integrated into the protocol accounting procedures for a draft protocol in Alberta.

Further, the extensive grazing systems and the net GHG emissions from these systems is a

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[8] The net coefficient addresses permanence through a discount of 20% from the C sequestration rates, based on the interannual flux of producers moving in and out of summerfallow practices in the Dry Prairie Region.

major focus for improving Canada's inventory methodology at this time. Thus, the net coefficients at this stage are estimated on average at 2.0 t CO_2e/ha /yr – but this would apply to lands where forage is being produced for hay, without grazing animals (the science is still developing on the livestock-pasture GHG interface). The land must be secured under a 20 year contract that will guarantee it remains in perennial cover for the credit duration period (in part addressing permanence – but a discount and buffer reserve will also be applied based on historical program dropout rates). Further, the lands that can be targeted are those lands being annually cropped that are on Class 4, 5, 6 and 7. This narrows the applicability of the eligible acres even further. Taking this into account, the maximum area where this activity could take place is likely only 1 million hectares across Canada (less than 3% of the annual seeded acres in2006[9]. Applying the yet to be vetted net coefficient less a 10% discount for future reversals post 20 year contract expiration, is approximately **1.8 Mt CO_2e annually**.

Taken collectively, the theoretical potential of carbon storage from soil sequestering practices can be up to **11.62 Mt CO_2e/yr** out to 2020. However, the reality of achieving these numbers will be discussed in the next section.

Constrained Potential: Market, Policy and Technical Overlay

Obviously the maximum theoretical potential estimated above is reflective of what could be achievable with widespread adoption of the practices. However, in reality there are numerous constraints to achieving these potentials. Despite the rapid adoption rate of conservation tillage, Lindwall and Sontaag (2010) point out that a number of constraints to adoption in some regions and specific cropping systems are still present – these are related to social barriers, cost and risk in areas with higher moisture conditions, specific soil constraints, and interactions with other practices such as the need to incorporate manure on a regular basis, or specialty crops that need higher disturbance preparation of the seed bed (i.e. potatoes, beans, etc). In a recent analysis prepared by Agriculture and Agri-Food Canada's Strategic Policy Branch, feasible adoption rates of no till on remaining full till acres were decided by a group of experts, given the current constraints to adoption (Table 17). Adjusting the total numbers calculated above for conservation tillage (theoretical of 5.29 Mt CO_2e/yr) by these constraints, gives a more realistic range of **2.5 to 3.3 Mt CO_2e/yr**.

Table 17. Feasible adoption rates of No-Till on remaining eligible acres in Canada.

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[9] Based on extrapolation of estimates in Alberta to the rest of Canada.

Scenario	AL	SA	MB	ON	QU
Baseline (2006)	48%	60%	22%	32%	10%
Low Adoption	50%	65%	25%	35%	12%
Medium Adoption	60%	70%	30%	40%	18%
High Adoption	65%	75%	40%	45%	30%

Reductions in the area of fallowed land have occurred over the years because of the economic need to keep arable land productive, along with diversified and extended crop rotations, improved seeding and tilling methods which conserve moisture and proper use of herbicides. However, it's unrealistic to assume that 100% of this cultural practice will disappear on the prairies, particularly with increasing droughts during growing seasons looming on the horizon. The use of summer or chem fallowing stubbornly fluctuates between 10 to 20% of the acreage, based on the cyclic nature of drier and moister cycles that seem to oscillate every 4 to 5 years.

Again, AAFC's study estimated, based on expert judgment, that summerfallow would decline out to 2017 by 17% (low adoption), 35% (medium adoption) and up to 54% (high adoption) due to changing technologies on farm. This more realistic assessment adjusts the theoretical potential of up to 4.54 tCO_2e/yr to ranges of between **0.77 and 2.45 Mt of CO_2e** for the Dry Prairie region of Canada.

Conversion to Perennial cover has a number of economic and technical constraints in play. Due to a lack of complete scientific information on extensive grazing systems resulting in increased GHG accounting complexity of methane emissions from the rumen dependent on varying forage quality, and nitrous oxide (N_2O) emissions from dung and urine patches in pastures, animals are excluded in the eligibility of this type of land use conversion. Thus, eligible conversions are those that convert land use from annual cropland to perennial crops for the purposes of producing forage, hay or forage seed crops for sale or other uses. As a result, estimated adoption rates for this land use change is not large since only a few farmers and ranchers would be willing to commit to converting land to perennial crop uses where grazing is not permitted. Further, having to sign a 20-year agreement for the land to remain in permanent cover represents another level of constraint on the potential.

Based on past permanent cover programs run by the federal government over the last 20 to 25 years, only 20% of the program uptake dedicates acres to hay production – the rest of the acreage is grazed. Therefore, a more realistic potential for this land use conversion changes from the theoretical 1.81 to **0.36 Mt CO_2e/yr**.

Taking these more realistic numbers into account, the constrained potential for agricultural soil carbon sequestration is likely in the range of **3.6 to 6.1 Mt CO_2e/yr.**

The measuring, monitoring and verification (MMV) procedures for these kinds of mitigation activities are clearly laid out in the Alberta protocols. The data gathering to support mitigation that is real, measurable and verifiable for these kinds of activities for the No-Till potential is more streamlined and scalable, and has been demonstrated with over 4 Mt of no-till offsets serialized to date in Alberta. However, the MMV for summerfallow, perennial forages and NERP require establishment of project-level baselines, which are an average of data over 3 years and requires more evidence and justification to the verifier. It can be done but will require significantly more data gathering, and justification to have viable reductions.

Table 18. Categorical assessment of GHG mitigation potential of soil carbon sequestration practices.

	No- Till	***Reduced Summerfallow***	***Perennial Cover***	***Explanation/Deviation from criteria outlined in section 2.2.2***
Speed	5	3	3	Easily adopted
Magnitude	5	5	3	Big on large scale
Scale	5	3	1	Many sources, small tonnes
R&D Stage	6	6	6	
Total *(of 21)*	***21***	***17***	***13***	

Conservation tillage is closely linked with a number of other beneficial crop and soil management practices such as diverse crop rotations, reduced fallow, and more effective weed, nutrient, moisture and crop residue management. A number of specific economic benefits for growers associated with conservation tillage include reduced labor, reduced energy consumption, improved crop yields, improved soil productivity, and higher fertilizer efficiency – but these depend on the region and the cropping system. Environmental benefits associated with conservation tillage include reduced soil erosion; reduced GHG emissions through increased soil organic matter, and in some cases increased biodiversity and improved water quality.

Challenges still remain – Canadian soils still have a large capacity for storing atmospheric carbon on a go forward basis as a result of carbon sequestering management practices. Saturation of soil sinks occurs slowly and over long periods of time (20 to 25 years), and emerging research shows that sequestered carbon can move down the soil profile to be stored in the layers below the A horizon (Chuck Rice, Kansas State University, personal communication[10]), perhaps increasing carbon storage beyond previously modeled soil organic carbon saturation curves. Further investigations into the science for carbon storage potential and enhanced nitrous oxide reduction potentials can result in increased mitigation potentials from this sector.

Operationalizing the Sub-Wedge

- Extend carbon pricing policies at a national level so carbon offset markets can help fund more sequestration activities
- Invest research dollars into the livestock-pasture interface to measure the net GHG impacts associated with extensive grazing systems
- Develop further carbon sequestration mitigation options through applied research
- Invest in developing independent, publicly housed land use monitoring and verification GIS and remote sensing systems to reduce transaction costs of GHG projects

3.1.9 Wetlands Sequestration

The Canadian Prairie Pothole region covers 54 185 611 ha across Manitoba, Saskatchewan and Alberta; of which 5.8% or 3 120 260 ha are wetlands. This wetland area is assumed to represent half of the original wetlands that extend across the Prairie Pothole region (Badiou pers. comm.). The original wetland extent consisted of 6 240 520 ha, with an estimated loss of up to 70% (NRTEE 2002). Wetland drainage often is a result of agricultural conversion of land (Watmough et al. 2002). Calculations made by Badiou (pers. comm.), and Badiou et al. (submitted) indicate that wetland drainage leads to carbon dioxide emission rates of 326 t CO_2e /ha of wetland drained per year. The restoration of wetlands increases primary plant productivity and CH_4 emissions while decreasing overall decomposition rates, and N_2O emissions, resulting in a net CO_2 sequestration rate of 3.25 t CO_2e /ha/yr (Badiou et al, submitted).

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[10] Dr. Charles Rice, Kansas State University.

Wetland loss through drainage and agricultural conversion has been experienced in the United States, which has had larger magnitudes of wetland loss to be reported to be at least 50% loss since the 1700's (Mitch and Gosselink 2000). Some areas in the United States have reported losses of upwards of 80% of their wetlands. The global trend of wetland loss is a result of human development. Organizations such as Ducks Unlimited, the Nature Conservancy Canada and the Ramsar Convention on Wetlands have developed best practices and agreements aimed at conserving wetlands through 'wise use', sustainable practices and, in some cases, restoration and reclamation. Drained wetlands have been noted as sources of greenhouse gases in numerous countries such as, Estonia (Kimmel et al. 2010), and the United States and Canada as noted by Mitch and Gosselink (2000). Wetland restoration has also been noted to be a source of soil carbon sequestration under flooded conditions in areas such as the mangrove wetlands (Matsui et al. 2010), deltaic marshes (Miller and Fujii 2010), and papyrus wetlands (Saunders et al. 2007). Freshwater mineral soil wetlands have consistently demonstrated the properties of carbon sinks (Gleason et al. 2005, Beard-Haughn et al. (2006), Euliss et al. (2006), and as such may act as a potential source of greenhouse gas mitigation.

Mechanisms and Methodology for Mitigation

Freshwater mineral soil wetlands have consistently been assessed as carbon sinks, there are approximately 20 million ponds in North America, (Euliss et al. (2006)) of which the Prairie Pothole wetlands have not been identified for their GHG sequestration potential. Recent studies have begun to quantify fluctuations in greenhouse gases from these wetland systems Pennock et al. (2010), and the draft Alberta Offset System protocol includes CO_2, N_2O and CH_4 in its emission sequestration assessment, based off this literature (Alberta Environment 2010b). Following the scientific literature and an intensive study of gas fluctuation within Prairie Pothole wetlands, the Prairie Pothole region of Alberta was determined to have a net sequestration rate of 3.25 t CO_2e/ha/yr (Badiou et al. submitted), and it is this value with which emission sequestration is to be calculated.

The Alberta Offset System draft quantification protocol for wetlands restoration (Alberta Environment 2010b, Climate Check and Ducks Unlimited 2010) indicates that emissions mitigation measures will be achieved through the restoration and re-creation of wetlands within the Prairie Pothole region of Alberta. The protocol is not designed with the intention of reducing emissions within a process, but instead creating an opportunity for carbon sequestration through the restoration of wetlands. The accounting process stipulates that **Prairie Pothole wetlands reconstruction is restricted to the restoration of closed basin, internally drained wetlands, and thus is geographically and ecologically restricted in its applicability.**

Wetland restoration to re-establish GHG mitigation potential will occur through the construction of ‘earth plugs’ or dams, and ongoing basin, margin and associated upland delineation, monitoring and management will be used to ensure that no burning, cultivation or clearing occurs along the margins of the wetland, affecting nutrient cycles. Wetland restoration in this form is considered a land use change with a net carbon sequestration gain. Wetland restoration projects will achieve changed and sustained land use change through integration with various actions and requirements that have been established by the policies under the Alberta Water Act (similar policies may exist in other provinces).

Quantification: Theoretical Mitigation Potential

Baseline Assumptions and Data Sources – Wetlands Restoration:
The baseline assumption follows the current status of wetlands within the Prairie Pothole region of Alberta. Carbon sequestration will be gained through the practice of restoring wetlands that do not currently exist due to prior drainage. Wetland restoration will follow historical imagery of peak hydrological periods and archival aerial photography records for interpreting wetland features and presence on the landscape. As this protocol has been created to restore degraded and drained wetlands, the procedures assume a zero-value as baseline and quantify carbon sequestration with each wetland that is restored.

Mitigation Assumptions and Activities – Restoring Wetlands
The restoration of wetlands in the prairie pothole region, particularly in Alberta, has primarily been the responsibility of Ducks Unlimited, with some involvement from Nature Conservancy Canada and other habitat and conservation groups. Wetlands converted from agricultural lands back to wetlands through this process will be credited as part of a 30 year conservation, restoration or set-aside agreement and/or through a permanent conservation easement. These sorts of agreements ensure that adequate wetland conversion and development activities are performed, and that appropriate post-conversion management practices are conducted to ensure the maintenance of these restored wetlands. Such management activities will restrict the cultivation, clearing and burning of adjacent associated uplands and wetland margins to ensure proper nutrient cycling within the wetlands.

Restoration of drained freshwater mineral wetlands in the Prairie Pothole region addresses management changes to the wetland margin and basin areas of closed basins forming internally drained areas that under normal conditions, were isolated from natural external drainage systems. Wetland restoration will include addressing management of the margin and upland areas to maintain consistent soil nutrient flux within the wetland basin. Within the wetland itself, restoration will include the installation of an 'earth plug' designed to recreate the original hydrological dynamics of the area, and encourage the natural water-collecting properties through mitigation of anthropogenically-introduced drainage.

Within Alberta alone, there is great potential for offset crediting through this wetland conversion protocol. Following the initial assumptions of Badiou (pers. comm.), half the originally existing wetlands within the prairie pothole region have been drained or otherwise converted into agricultural lands. With the implementation of this protocol, that half of total original wetlands could conceivably be restored, resulting in a potential wetlands conversion of up to 1 039 460 ha for the province of Alberta, and up to 3 120 260 ha across Manitoba, Saskatchewan and Alberta. This wetland conversion potential provides the opportunity for upwards of **10.14 Mt CO_2e/yr** of sequestration, using Badiou et al's (submitted) net rate of 3.25 t/ha/yr of CO_2e sequestration quoted in the draft wetland protocol.

Constrained Potential: Policy, Market and Technical Overlay

Given that wetlands continue to be drained or altered within the Prairie Pothole region, it would be unrealistic to assume that 100% of the lost wetlands will be restored. The PHJV (Prairie Habitat Joint Venture) has been conducting a wetland restoration and preservation program for the purpose of sustaining waterfowl populations. The PHJV has developed a wetland restoration target that they are seeking to achieve through such efforts as those described in this document. This more practical approach is seeking to prevent further wetland loss to preserve habitat, and focus on small basin wetland reclamation and restore 300,000 hectares of wetlands in each province of Manitoba, Saskatchewan and Alberta by 2026 (PHJV 2008). This compared against the total number of lost or degraded wetlands in the Prairie Provinces: 3 120 260 ha. A more realistic and achievable potential would take into account the habitat acreage of the PHJV, and double that amount for those landowners who would undertake projects for carbon. As a result, a more realistic carbon sequestration potential for the wetland restoration efforts in the prairies would be **1.95 CO_2e/yr.**

Canadian Prairie Pothole wetlands are potential carbon sinks upon restoration. This has been established as a result of a Benchmark study undertaken for the last 5 years in the Prairie Pothole Region. This comprehensive Canadian study, is also part of the Great Plains CO_2 Partnership initiative coordinated by the US-based National Energy Technology Lab (NETL, Department of Energy). The results of this study have been used to develop a series of procedures for measurement, monitoring and verification for the submitted Alberta Offset System quantification protocol for wetland restoration. The assessments of nutrient fluctuation that exists in agricultural systems and for other types of wetlands, have been codified to meet the requirements of the Draft Alberta Wetland protocol.

Upon provisions of accreditation and land tenure, wetland restoration proposals must indicate a former wetland class (pre-drainage or -degradation) ranging from 3: seasonal ponds and lakes, to 4: semi-permanent ponds and lakes, to 5: permanent ponds and lakes, and develop and implement a plan to restore both the wetland and the surrounding margin and upland areas. Measurement, monitoring and verification of wetland restoration and the resulting GHG sequestration must follow Alberta Offset System and appropriate reclamation monitoring techniques (e.g. those of Ducks Unlimited). Within those terms, emission reduction quantification must be assessed on a per-hectare-of-restored-wetland basis.

Where challenges lie for development of this type of sequestration activity are in the reversal of stored carbon through changes in weather patterns. Wetlands across the Prairie Provinces are historically known for climate-related fluctuations of water levels and resulting changes in nutrient flux dynamics. Prairie Pothole region wetlands, particularly those that are ephemeral in nature, as in classes 3 and 4 will respond to changes in climatic patterns, drying out in periods of drought, or draining, to much-reduced water levels. These changes will undoubtedly have similar results to those of the anthropogenic drainage of wetlands for cultivation, producing net carbon sources due to the increased rate of decomposition that results when aquatic organic matter deposits become exposed to the atmosphere through drying.

Further risks of reversal from changes in land tenures may exist in the nature and permanence of land tenures under 30-year conservation/restoration set-asides. Depending on the intentions of the Alberta Offset System, or other similar carbon market registries, 30 years may not be an acceptably long period of time for carbon offset registration. The protocol will likely have to include a buffer reserve of credits to cover off future liabilities. Alternatively, the risk of reversals from land tenures can be alleviated through the use of longer-term, or more permanent land tenure structures such as conservation easements, which provide a legal framework for land management tenures, and may more effectively prevent land conversion of reclaimed wetlands in the future.

The development of wetlands has many environmental co-benefits associated with the alterations of land use patterns and hydrological regime. The re-introduction of wetlands to the agricultural landscape provides an important source of habitat in an otherwise marginal land-use type. Since there has been a steady decline in the capacity of agricultural landscapes to support wildlife over the past 20 years (from 1990), largely due to the increase of intense agricultural activity and the loss of natural and semi-natural land cover types, like wetlands

(Canada 2010). In addition to the wildlife habitat benefits, increases in local water tables due to wetland presence could enable farm operations to better-withstand periods of drought (Schuyt 2005), and avoid costly installation of irrigation infrastructure across large areas of farmland.

Operationalizing the SubWedge

- Social perceptions - there is a large challenge in introducing wetland restoration and management to agricultural practices due to the reduction in agriculturally productive land that results from wetland restoration. Groups such as Ducks Unlimited have made great headway in creating a positive public perception to wetlands rehabilitation. There is still friction, however, around lands conversion and conservation easement creation;

- Scalability - challenge of extending this idea to other forms of wetlands beyond the closed basin Prairie Pothole wetlands of Manitoba, Saskatchewan and Alberta, because nutrient cycling and hydrological regimes are not going to be the same;

- Science - It has been recognized that more research is needed on the carbon sequestration rates and potential within Prairie Pothole wetlands, specifically, as most research has been occurring on other wetlands outside of the Prairies;

- Enabling tools - the Alberta Offset System is currently reviewing a draft protocol by Ducks Unlimited for wetland reclamation that would facilitate greater carbon sequestration accounting through wetland restoration. Ducks Unlimited and similar land and resource conservation groups like Nature Conservancy Canada have become more prevalent in recent years in their reclamation and conservation efforts

- Challenges In harmonizing with current regulations/policy for wetland conservation/preservation may come into effect in certain provinces.

Table 19. Categorical Assessment of Wetlands

	Wetland Restoration	***Explanation/Deviation from criteria outlined in section 2.2.2***
Speed	3	Often multi year construction process that requires land tenure exchanges and regulatory approvals
Magnitude	1	Potential sequestration of 1 Mt CO_2e/yr
Scale	1	Prairie pothole wetlands are very small and isolated. Credit on reclamation applies only to specific wetland

		types (wetland classes, lentic water)
R&D Stage	4	Research is needed on the Prairie Pothole Wetland restoration, but restoration is undergoing practical application
Total (of 21)	**10**	

3.1.10 Sludge Application to Agricultural lands

Pulp mill sludge is a common waste by-product of pulp and paper production. Bleached chemi-thermomechanical pulp is one of many forms of pulp produced in the Canadian paper industry. Historically, waste pulp mill sludge has commonly been dried, incinerated and landfilled or composted as a means of waste management. The use of beehive burners has mostly been curtailed within Canada, as their use contributed to air pollution increases both in greenhouse gases and particulate matter. Many jurisdictions have developed regulations to prohibit the use of beehive burners, such as the British Columbia Air Action Plan (British Columbia Environment 2010) in an effort to promote more efficient and environmentally sound mill waste management approaches, such as waste to energy conversion, which produce lower levels of air pollution, and result in mill or community energy benefits.

Given the costly nature of incinerator conversion, combined with a goal to reduce environmental impacts, and economic costs while enhancing agricultural productivity, a number of Alberta pulp mills begun to develop standards and guidelines for the land application of mechanical pulp mill sludge to agricultural land (Alberta Research Council 2008c). These standards and guidelines were approved in 1999, at which point, mill operators began to apply portions of their mill sludge to local agricultural lands. Initially, a larger portion of Alberta’s pulp mill sludge was being incinerated and landfilled rather than being spread on agricultural lands, however, by 2003, 90% of mill sludge produced by three of the larger pulp mills was being land spread in Alberta, and by 2008 those three mills had fully switched to spreading 100% of their mill sludge (Alberta Research Council 2008c).

This trend was not continued through the rest of Canada. National practice trends have turned to energy production from pulp mill sludge, instead. Canada-wide, landspreading of mill sludge had a 33% use rate in 2007, and a 21% use rate in 2007, with less than half of all pulp mills in Canada employing some level of landspreading practice (Alberta Innovates – Technology Futures 2010). Energy production, however, changed from 8% in 2003, to 44% in 2007 (Alberta

Research Council 2008c, AITF 2010). Landfilling, although still being used, had dropped from 29% in 2003 to 22% in 2007 (Alberta Research Council 2008c, AITF 2010). Landspreading is often accompanied by extra costs, compared to alternative waste treatment practices like biomass to energy or landfilling, due to the extra transportation and materials handling required to achieve the end use. These costs may prove prohibitive to the average mill, as compared to the comparatively inexpensive waste management alternatives like biomass to energy, incineration and landfilling.

Landspreading of mechanical pulp sludge is a more environmentally responsible alternative to sludge incineration and landfilling. The application of mill sludge provides soil benefits through added nutrients and organic matter, as well as improving soil structure and water holding capacity, increasing the initial below ground soil carbon reservoir, which thus increases the above ground carbon reservoirs in crop growth (Technical Protocol Plan).

Worldwide, pulp mill sludge has been used and assessed for its fertilizer effects, and the cross-benefit of waste management. A study in Chile indicated that pulp mill sludge from wastewater treatment may have potential to act as a beneficial soil amendment for improving the biological properties of volcanic soils (Gallardo et al. 2010). Studies in the USA have assessed the influence of sludge application on tree plantations (e.g. Goodwin and Burrows 2006), identifying positive effects on height growth, however also recognizing the prohibitive costs of pulp sludge transportation and application. A greenhouse study in Iran (Torkashvand et al. 2010) further indicated the fertilizer and plant growth-enhancement effects of mill sludge on acidic soils, noting improved shoot growth and nutrient uptake with sludge application.

Mechanisms and Methodology for Mitigation

Mill sludge application, as proposed by the Alberta Research Council (2008a) in the draft quantification protocol submitted to the Alberta Offset System, seeks to decrease GHG emissions through creating an alternative end-use for pulp mill sludge. Instead of being incinerated or placed in a landfill, the application of pulp sludge to agricultural land increases the above and below ground carbon reservoir and significantly increases crop yields and residues on agricultural lands. While incineration and landfilling result in GHG off-gassing, soil carbon reservoirs store and accumulate carbon rather than releasing greenhouse gases to the atmosphere. Mill sludge application has the combined impact of improving soil carbon reservoirs and reducing the need for fertilizer application, thus reducing the associated emissions from fertilizer production, transportation and application.

The protocol takes a comparison approach to the measurement of mitigation effects, by using actual measurements of control and treatment groups for comparisons, and to recognize an increase in the soil carbon reservoir though the addition of mill sludge. Because soil type, cropping practices, farm management and climatic conditions will all vary from farm to farm, the baseline business as usual conditions must be measured specifically for each farm quantifying emission reductions as a result of applying mill sludge. Project developers establish a baseline condition through the maintenance of a control group that represents business as usual factors in order to assess the efficacy of mill sludge application. Baseline measurements will be collected prior to sludge application, and throughout the sludge treatment by using a control group. Both CO_2 and N_2O are measured through this quantification approach, in an effort to address soil carbon flux and changes to fertilizer use and application rates.

The protocol is intended to apply to all agricultural soils within Alberta, however more research may be needed to quantify the effects of mill sludge application on soils where crop types other than forage and grain crops have been planted. Research on land applications of mill sludge is difficult to find within the scientific literature, suggesting that it is an under-studied area within forest and agricultural practices.

Quantification: Theoretical Mitigation Potential

As previously mentioned, baselines are calculated through the use of both a pre-treatment control and during-treatment samples of both the control and the treatment soils for changes in soil carbon fluctuations. Since measuring soil organic carbon is challenging, and pre-treatment soil conditions will vary with each practitioner, a discounting factor of 50% was applied to the carbon values produced during quantification. Discount factors may be decreased with the use of appropriate historical data and documentation could provide further clarification on soil bulk density and soil carbon content variability within the treatment area(s).

Within Alberta, the 100% participation of three major mills: Alberta Newsprint Company, Slave Lake Pulp and Millar Western will skew the baseline assessments. This challenge will not be faced by the majority mills outside Alberta as practice uptake has declined from 2003 to 2007 (Alberta Research Council 2008c). Baseline quantifications will vary between jurisdiction not only by current uptake of the landspreading practice, but also by current practice, as landfilling and biomass to energy conversion etc. all have different cost and greenhouse gas production values.

Landspreading of mechanical pulp mill sludge acts as an abatement technique, preventing the loss of carbon to the atmosphere through the disposal of mill sludge in landfills. It further acts as a sequestering activity by promoting improved soil carbon sequestration and retention both through initial increases in soil carbon stocks, but also through the fertilizer effect of improved plant and root growth. According to Alberta Innovates Technology Futures (2010), approximately 0.267 t CO_2e is released per tonne of sludge released from landfills every year. Over the course of a six year crediting period, one tonne of landfilled sludge will release 1.6 t CO_2e. Had that sludge been used in a landspreading application on agricultural soils**, 1.28 t CO_2e/ tonne sludge would be sequestered.**

Constrained Potential: Market, Policy and Technical Overlay

Measurement, monitoring and verification of the increase in soil carbon reserves must be conducted with the utmost care by trained and skilled soil professionals, as sampling plans in ongoing research projects, and the chemical analysis required to effectively determine soil carbon content require a particular level of understanding of soil science. The protocol proposed by the Alberta Research Council (2008a) lays out a rigorous series of assessment requirements, and will call for responsible reporting to ensure appropriate measurements have occurred.

The risk of reversal must be addressed within any treatment involving landspreading for carbon sequestration. Project proponents must acknowledge and address potential risks that could result in the release of carbon associated with the applied mill sludge. Assumptions about soil carbon volatilization suggest that losses will be of the same magnitude as the carbon sequestration value of the practice change (McConkey et al. 2007). These assumptions then require not only accounting for the impact of failing to store any new carbon from the current year, but also the impact of losing carbon previously sequestered in the soil, likely due to a change in management practice (Alberta Research Council 2008c). As a result of this assumption, the risk of reversal for mill sludge landspreading is similar to the risk of reversal of switching from No-Till practices to Full-Till (Alberta Research Council 2008c).

It must be acknowledged that the Alberta Offset System protocol, and all assessments of mill sludge land applications reflect only mechanical pulp sludge. The majority of pulping processes produce sludge, which is not suitable for land application due to high B, Na, metal compounds or chlorinated compounds (Technical Protocol Plan). As a result of this, landspreading is limited to a very specific subsection of pulp sludge, and testing will likely be required to assure landowners of the safety of the sludge, and that landspreading will be beneficial to their farming practices. As recognized by Gallardo et al. (2010), alternative mill sludge sources beyond mechanical pulp (e.g. Kraft) contain metals and other compounds that could have potentially hazardous phyto-toxicological effects.

Balancing the risks of chemical contamination and potential reversal, appropriate use and management of mill sludge application can also have positive co benefits. As discussed, soil productivity and soil quality can be improved through mill sludge application (Gallardo et al. 2010, Torkashvand et al. 2010), and plant growth can also be improved (Goodwin and Burrow 2006, Torkashvand et al. 2010). Increases in plant productivity thus reduce the need for fertilizer inputs, reducing a further stream of greenhouse gas emissions and agricultural costs.

Table 20. Categorical Assessment of Mill Sludge Application to Agricultural Lands.

	Mill Sludge Application	*Explanation/Deviation from criteria outlined in section 2.2.2*
Speed	5	Currently used as approximately 1/4 of all pulp management practices across Canada
Magnitude	*1	At current agricultural landspreading rate, of 415 694t CO_2e/yr is sequestered
Scale	3	Likely be developed on a per-farm basis that is in close proximity to mills. Transportation costs are greatest limitation for practical implementation.
R&D Stage	4	Already a current practice at some mills in Alberta. Development dependent on practical uptake and diffusion
Total (of 21)	**10**	

*Following Alberta Research Council (2008c) indications of 324 761t mill sludge applied to agricultural lands in 2003

Operationalizing the Wedge

- Barriers to this kind of sequestration activity is transportation and application costs to agricultural land; incentives through the carbon markets or other means would assist uptake in the practice
- Research into the possibilities of using other types of sludges (e.g. Kraft) through chemical scavenging
- Trials for application to reclaimed sites

3.1.11 Soil Amendments

Many field studies have demonstrated that application of organic amendments can increase soil organic matter (Jenson 1990, Feng and Li 2001). Long-term experimental findings from Rothamsted, in the United Kingdom, and the Breton plots (North-Central Alberta), which are typical of these findings, are shown in Figures 10 and 11. In both cases, manure additions increased soil organic carbon content (SOC) while SOC remained constant under inorganic fertilizer treatment and control. Particularly, in the case of Rothamsted, SOC under inorganic fertilizer showed little difference compared to the control despite considerably higher crop yields and higher rate of organic carbon addition to the soils from plant roots and residues (Jenkinson 1990). Higher resistance to decomposition of manure makes it nearly twice as effective at increasing SOC content as plant residues (Feng and Li 2001).

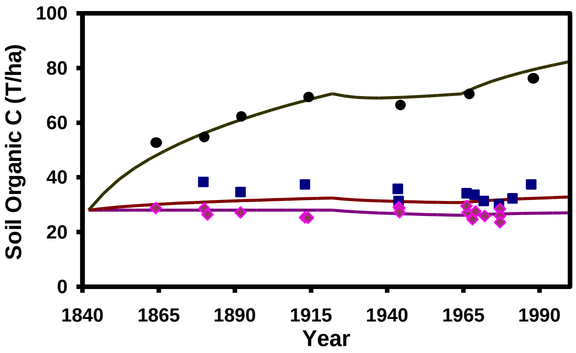

Figure 10. SOC change with manure application at Rothamsted (adapted from Fend and Li (2001))

Treatments are: annual addition of manure at 3 t carbon/ha, yr (●); annual addition of fertilizer at 144 kg N, 35 kg P, 90 kg K and 12 kg Mg/ha (■); control (♦). Solid lines are from the model perditions. Experimental data are from Jenkinson (1990), Rothamsted, is the oldest research site in the world.

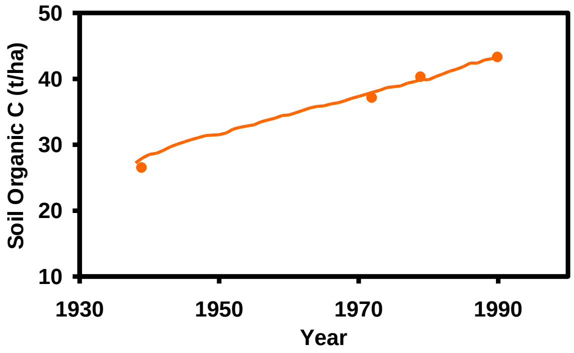

Figure 11. SOC change with manure application at Bretton (adapted from Feng and Li (2002)).

Solid line is from the model prediction and (•) is measured data. Experimental data is generated from Breton classical plot of the manure treatment of the 5-year Wheat-oats-barley-hey-hey rotation. Average manure input at 2.1 t carbon/ha/yr.

This section assesses the potential of using soil organic amendments to increase soil carbon sequestration.

Mechanism and Methodology for Mitigation

SOC content is determined by the balance between organic carbon addition by plant residues and their subsequent decomposition, transformation and stabilization in the soil. Increasing the rate of addition or decreasing the rate of decomposition both lead to increases in SOC content. At any given moment, total SOC in a soil is the cumulative result of organic carbon additions and decomposition in its past. After a change in either the rate of addition, such as application of organic amendment, or rate of decomposition, such as initiation or cessation of cultivation, SOC content changes over time towards a new equilibrium dictated by the new set of conditions (Feng 2009). Such changes can last for centuries or even longer, as shown by experiments (Figures 11 and 12) and by the fact that stable fractions of SOC are found to have remained in soils for millennia (Gaudinski et al. 2000, Trumbore 2000, Paul et al. 2001). However, the rate of change decreases over time (Figure 11), often become nearly un-detectable after several decades (Christensen and Johnston 1997, West and Post 2002, VandenBygaart et al. 2003). Increasing carbon input to soils can be achieved by managing the soils to achieve higher yields, reducing the removal of plant residues, or by addition of organic amendments to the soil (Paustian 1997, Feng 2009).

Changes in SOC after a change in soil management are transient. As such, assessment of soil carbon sequestration must contend with several questions that arise.

What is the time frame at which such assessment is made? If the same amount of amendment is applied each year, SOC will increase continuously at ever slowing rates over time (Figure 11). The slope of a line drawn from the starting point to any given point on the SOC curve is the average rate of SOC sequestration per year. Whilst the total amount of SOC stored increases, the average rate of SOC sequestration decreases continuously with time. This factor has contributed significantly to highly variable, and in many cases unreasonably high, values of annual rate of carbon sequestration reported in the literature (West and Post 2002). As an assessment parameter, it can be argued that the large, short-term annual carbon sequestration rates cannot be used to represent the potential for long-term carbon storage. Equilibrium values of SOC, on the other hand, are nearly impossible to measure experimentally and therefore, as an assessment parameter, are not verifiable. Even if one adopts a reasonable operational compromise of 50 years, experimental validation can only be done against findings in a few established long-term experimental sites. The only feasible assessment tool is using SOC models

How will the ‘sequestered’ SOC be maintained? Continued addition of amendments is necessary to maintain SOC at or above a level at which amount of carbon sequestration is assessed. For example, consider the case shown in Figure 11. If carbon sequestration is assessed after 50 years of continuous manure addition, SOC had increased to 62 t/ha from the initial 28 t/ha, with a net carbon storage of 34 t/ha. The rate of manure application that is required to maintain SOC at or above this level is considerably less than the 3 t/ha-yr of C used in the first 50 years because continued application at this rate lead to much higher SOC levels. In this particular case, it can be estimated that an application rate of 1.5 t/ha-yr of C would be sufficient to maintain SOC at 62 t/ha after 50 years.

How penalties or credits should be assessed if the practice, which leads to SOC sequestration, were reversed, discontinued, or changed? Figure 13 shows that SOC had reached 70 t/ha, sequestering 42 t/ha of carbon after 75 years of continuous manure application and cropping. A 1 in 5 year fallow, during which no manure was applied, caused a stop of SOC increase but maintained SOC at the 70 t/ha level. At the same site, Figure 12 shows that SOC decreased when manure application stopped after 25 years, but at a slower rate than the initial SOC increase. SOC remained 15 t/ha higher than control after more than a century, maintained in part by higher productivity and crop residue input. Theoretically, SOC will continue to decrease towards the equilibrium value—assumed to be that of the control. The process, however, could take millennia. If improved soil management is adopted, SOC could be maintained above a higher equilibrium.

Fortunately, these complex long-term changes in SOC can be predicted with reasonable reliability with models that have been validated against existing long-term experimental studies, the longest of which, the Rothamsted, has been maintained for more than 150 years. The models, however, may differ in their predictions for time periods longer than that of the available validation data sets, particularly in their predictions of equilibrium values.

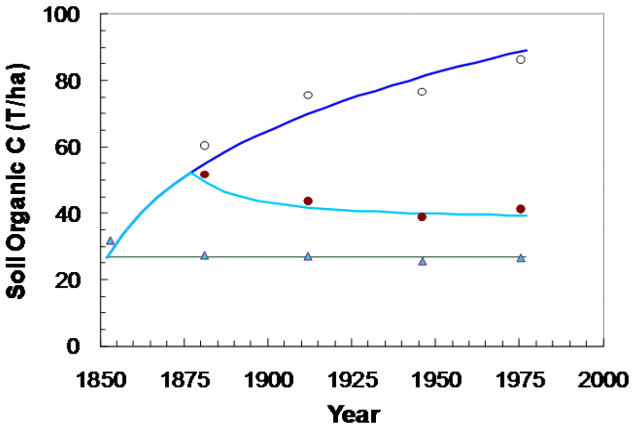

Figure 12. SOC change with manure application at Rothamsted (adapted from Feng and Li (2001)).

Treatments are: annual addition of manure at 3 t carbon/ha- yr (o); continued manure application for 25 years (•); control (Δ). Solid lines are K-model Predictions. Experimental data are from Jenkinson (1990).

Quantification: Theoretical Mitigation Potential

Collectable animal manure and legume biomass that can be produced on marginal lands of Canada could be used as sources of soil amendments.

Manure:

Table 21 illustrates the total collectable manure from the Canadian livestock sector is 14 million tonnes annually.

Table 21. Manure generated in the Canadian livestock industry that can be collected.

Animal	Total animal[1]	Dry manure[2,3]	Total manure
year 2010	X 1000 head	kg/head, day	t/yr
Beef cow	7,359	3.5	9,401,250
Dairy cow	980	8.2	2,933,140
Hog	11,850	0.33	1,427,333
Poultry/egg	49,650	0.027	293,830
Total			14,055,553

[1] Statistic Canada 2010 census; [2]ASAE 2005; [3] average of 3% N content in manure was used (Alberta biowaste inventory, to be published in 2011).

Biomass from alfalfa:

Canada has over 37 million hectares of marginal land (Milbrandt and Ocerend, 2009 with a potential biomass yield of ≈2.6 t/ha. If one assumes that 15% of these lands can be used to grow legumes (represented by alfalfa), it can produce 15 Mt of biomass annually.

Thus, materials potentially available as soil organic amendments annually in Canada may include, as dry mass:

1. Manure: 14.1 Mt/yr
2. Alfalfa: 14.8 Mt/yr

Total: 28.9 Mt/yr with an average of 45% carbon content.

The theoretical mitigation potential assessment is based the following assumptions and activities (Table 22) associated with the baseline and proposed practice.

Table 22. Summary of Assumptions and activities for the proposed practice baseline scenario

Baseline (no organic amendment addition)	
Assumptions	**GHG emission/mitigation potential**
Soil organic carbon remains constant with normal practices	N/A
Mitigation Practice -Organic amendments	
1. Materials (manure and legume biomass) go through anaerobic digestion 2. Carbon content in both materials = 45% 3. For every unit C input it results in 0.22 unit C in soil in a 50 period 4. Energy requirement of producing biofertilizer pellets will be included in AD 5. Energy requirements of growing, harvesting, transporting legume biomass will be included in AD 6. Distribution of bio-fertilizer on land is only activity resulting in GHG emissions	1. Manure offset: 2.7 CO_2e Mt/yr 2. Alfalfa offset: 2.6 CO_2e Mt/yr 3. Transportation emission: 0.028 Mt/yr
Total	***5.3CO_2 e Mt/yr***

After the anaerobic digestion (AD) process, 50% of carbon and its related biomass will be turned into biogas. Therefore, the total available biomass after AD will be 14.4 Mt/yr with 45% carbon content.

Soil carbon sequestration is assessed at 50 years. Based on Jenkinson (1990) and Feng (2009), if manure is applied at a constant rate over 50 years, then for every 1 unit of carbon added to the soil, 0.22 unit will remain as increased SOC. Manure is nearly twice as effective at increasing SOC as plant residue (Feng and Li 2001, Feng 2009a). The K-model predicts that digestate resulting from treating plant biomass with AD is similar to animal manure with regard to soil carbon sequestration. Digestate from treating manure with AD is 35% more effective than manure with regard to soil carbon sequestration. However, unlike manure, stabilization efficiency of digestate in soils lacks support from extensive experimental data. For simplicity, digestates from manure and plant biomass are assumed to behave in a similar fashion as manure. This is a conservative assumption for assessing soil carbon sequestration potential from these materials.

For a total C input of 13 Mt/yr of AD processed organic materials to the soil, a total of 143 Mt will be in the soil at 50 years, resulting in an **average annual carbon sequestration rate of 1.4 Mt/yr of C, or 5.3 Mt CO_2e/yr.**

Under the proposed practice, carbon emission is 1.95 kg CO_2e/t (Jesse and Neael, 2005) if AD processed bio-fertilizer is distributed within a 100 km radius. This is 0.5% of the carbon sequestration potential.

Constrained Potential: Market, Policy and Technical Overlay

Crop producers gradually recognize the value of organic amendments, but economics of applying these amendments limit its application. A particular impediment is the fact that unprocessed manure is generally wet, bulky, heavy, and with low nutrient concentration. There are some issues that need to be resolved in assessing carbon sequestration with organic amendments, particularly whether or not adding manure to soils is truly additional and beyond business as usual. It may be argued that since the organic carbon in manure is fixed by plants and is already primarily applied to land, the difference, at most, is where this carbon ends up and there should be no net credit assigned to it – it's simply a matter of moving the carbon around on the landscape. To quantify the true mitigation potential of the activity, one would need to take into account the carbon that is not being accrued in the soils that are no longer receiving the manure – the difference would be the true incremental mitigation. The counter argument is that, while it is true that sequestration potentials should only be assigned to "net additional storage" of organic carbon, the current practice is to re-apply the manures within an economic hauling distance of the livestock operation – this concentrates manure on land that is saturated, with a greater rate of decomposition and little capacity for additional SOC sequestration. However, research shows that degraded soils low in soil organic carbon have higher potential for carbon sequestration than soils with high organic carbon contents (Nyborg et al. 1998, Moulin et al. 2002). Thus, there could be substantial net carbon sequestration if organic amendments are encouraged to be applied to low organic matter soils rather than continuously being piled on soils already saturated with organic carbon and nutrients.

Table 23. Categorical Assessment of Amendments to Soils

	Amendments	***Explanation/Deviation from criteria described in section 2.2.2***
Speed	5	If a standard protocol is in place it can be quickly implemented
Magnitude	5	It has a 5.4 Mt/yr potential
Scale	4	More education is required; proper government policy will accelerate the market uptake
R&D Stage	6	At Market penetration stage
Total *(of 21)*	***20***	

Co-benefits: The value of organic amendments will be considered along with bio-fertilizer. Once these practices are recognized, it will promote the development for more comprehensive products that will have balanced nutrient contents for targeted crop productions while enhance nutrient use efficiency, particularly for nitrogen and soil carbon sequestration.

The major risk for this practice is that realization of the potentials will depend on the availability of the materials. Further, there is a particular challenge for no-till practices – most nutrient management regulations require incorporation of manure within 24 to 48 hours to minimize odour. This practice conflicts with the no-till agriculture and may limit manure application to marginal soils. Raw manure can have a similar impact but transportation cost will be a major limiting factor since raw manure contains significant amount of water. In addition, weed seeds and pathogen contamination will be a concern. Much of these risk factors can be addressed by producing bio-fertilizer from AD processed materials. High capital costs of AD and bio-fertilizer systems can be a significant challenge.

The estimation under the constrained condition is based on the assumptions of:

1) most collectable manure is available for this practice, once the quantification protocol is in place, the market is ready;
2) growing biomass from marginal land may take time; and

3) the constrained potential is 50% of the theoretical potential, which is based on collectable manure and biomass from marginal land only.

Operationalizing the Sub-Wedge

- Requires incentive for applying organic amendments.
- Invest in the development of a comprehensive dataset for manure application history and current soil organic carbon levels in the province.
- Develop a comprehensive, flexible, farm scale decision support model or tool that evaluates economic and environmental benefits and risks of specific production systems ranging from single crop production to integrated operations that may include soil management and crop production, livestock production, biowaste management, bioenergy and biofertilizer production. In particular, the this tool will be able to evaluate soil carbon sequestration and reduction in greenhouse gas emissions from integrated soil management, crop production, livestock production, and application of available biowaste management/utilization technologies, e.g., bioenergy and bio-fertilizer production technologies.
- Calculate regional nutrient budgets to identify manure sending and receiving zones for balanced manure applications to land.
- Need to develop a comprehensive quantification protocol.

3.2 GHG Reductions

3.2.1 Soil Nitrogen Management

From a management perspective, the National Emissions Inventory reports that 13 Mt were emitted from soils due to synthetic N fertilizer application, 9.1 Mt from crop residue decomposition (related to yields) and 0.17 Mt from a variety of other cropping management practices (summerfallow, conservation tillage, Irrigation and cultivation of organic soils) in 2008 (Environment Canada 2010). These emissions were partly offset by the mitigating effects of increased soil carbon sequestration. In 1990, the management of mineral soils amounted to a net CO_2 removal of about 2 Mt. This net sink steadily increased to about 12 Mt in 2008, through changes in management over time.

In the environment, fertilizer-derived N, like any form of mineral N[11] (or 'free' or 'soluble' N), is subject to emission as N_2O from nitrification or denitrification, subject to indirect losses through leaching of nitrate, and/or volatilization of ammonia from the system, and 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 emission of GHGs. That is, because mineral N tends to be mobile and subject to many loss pathways (particularly when N is in the NO_3^- form in the soil), N application rate alone may not be the best indicator of GHG emission reduction potential.

Using a comprehensive approach to N management, the likelihood of conditions that would lead to both (1) excessive losses of fertilizer N through direct and indirect means, and (2) improved N use efficiency, can be achieved, so that more than just rate reduction is the focus of the mitigation activity. Further, since the dynamics of N_2O from soils are typically characterized by pulses of emissions, both when soil conditions are favorable, and at certain places in farmers fields where moisture and dissolved carbon/nutrients collect, they are highly variable in both space and time. Managing N_2O emissions becomes a probability game, so mitigating the likelihood of those conditions occurring is the best approach to reducing emissions.

Mechanism and Methodology for Mitigation

In the case of managing N_2O emissions from Canadian soils, the primary strategies take into account fertilizer practices that not only decrease the rate of fertilizer added, but also manage the applied N to:

- Optimize the crop response per unit of added N; and,
- Minimize the opportunity for nitrate N to accumulate or persist in the soil where it is potentially denitrified, and/or emitted directly or indirectly as N_2O or lost to the system through leaching.

These strategies have been bundled into a suite of precision-management practices[12] that apply the right source, at the right time, in the right place at the right rate (so called 4R's). To be effective, the practices across the 4R's are designed to manage all sources of applied N to minimize the opportunity for nitrate to accumulate and supply N at the time and rate that suits the particular crop's needs given tested residual soil N levels.

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

[12] Precision management in this context means varying degrees of temporal and spatial management of nitrogen according to soil tests, topographic position, crops grown and other circumstances (see reference document for more explanation).

The quantification approaches used in the calculations in this sub-wedge are based on the Alberta GHG quantification protocol for nitrous oxide management. GHG emissions are calculated using IPCC best practice guidance (Climate Change Central 2009, IPCC 2006) and Canadian-based Tier 2 emission factors as set out in the National Emissions Inventory methodology. In addition, analysis undertaken by Agriculture and Agri-food Canada's Strategic Policy Branch is also included in the quantification estimates (Gill and MacGregor 2010).

These protocols have been developed through a comprehensive scientific and technical review, by both the federal and provincial governments, as well as the Canadian Fertilizer Institute. Canada's leading experts in soils, cropping and agronomic science as well as scientists from abroad (United States and overseas experts) were consulted. The science and quantification represented in these strategies is robust and highly confident. Note that in adapting this quantification to Canada-wide mitigation estimates, certain assumptions need to be made. These are listed in the next section.

Quantification: Theoretical Mitigation Potential

Baseline Assumptions and Data Sources – Soil Nitrogen Management:
To calculate the baseline acres and production levels, the 2009 crop reporting statistics from Statistics Canada were used. To streamline the calculations, the 5 major crops, capturing 61% of the production across the country were used in the analysis (Spring Wheat, Barley, Canola, Corn and Soybeans; see attached reference material for more detail). It was assumed that these productivity levels were held constant out to 2020. The 2009 year was used because of less catastrophic events such as flooding or drought.

To calculate the amount of N_2O emitted in the baseline year (2008 census), the NIR emission factors were used (Figure 14). These factors, applied for the average tillage, texture, topographic and irrigation adjustments per ecodistrict were used to calculate the baseline GHG emission intensity (N_2O emissions/per crop yield), including direct and indirect emissions, for each of the 5 major crops listed above. The calculation method of the NIR takes into account all forms of N inputs to the soil (fertilizer N, crop residue N, any organic N inputs, etc). So for each ecodistrict, for each major crop, the NIR values for fertilizer application and 2009 crop areas and yield data were used to calculate the emissions intensity and then averaged for each province (see supporting reference materials for a summary of the analysis). This makes it very consistent with the emissions inventory methodology.

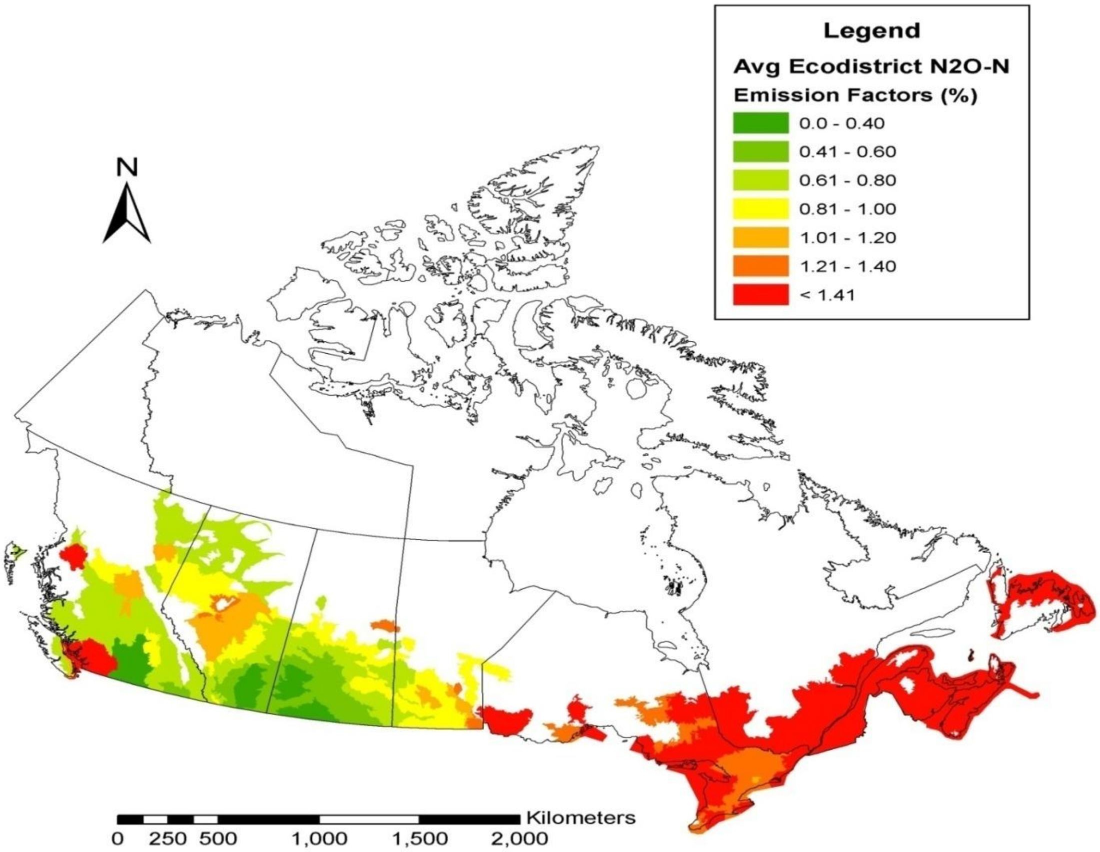

Figure 13. NIR Emission Factor

<u>Mitigation Assumptions and Activities – Soil Nitrogen Management:</u>

To estimate the amount of nitrous oxide that could be reduced from adoption of precision-management practices, the reduction modifiers established in the Nitrous Oxide Emissions Reduction (NERP) protocol in Alberta were used (Table 24 and 25). The reduction modifiers were scientifically developed (based on the last 40 years of research of soil N balance and soil nitrous oxide studies across Canada for individual practices) and vetted with experts from the US and Canada as to the potential reductions conservatively achievable as a result of implementing the suite of practices across the 4 performance areas (source, rate, time, place)[13].

Table 24. Management Practices and Reduction Coefficients for the 3 Performance Levels of the NERP Drier Soils of Canada.

Performance Level	Right Source	Right Rate	Right Time	Right Place	Reduction Modifier

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[13] See http://environment.gov.ab.ca/info/library/8294.pdf for the Nitrous Oxide Emissions Reduction protocol.

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
Intermediate	• Ammonium-based formulation; and/or • 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
Advanced	• Ammonium-based formulation; and/or • 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.

Table 25. Management Practices and Reduction Coefficients for the 3 Performance Levels of the NERP Moister Soils in Canada.

Performance Level	Right Source	Right Rate	Right Time	Right Place	Reduction Modifier
Basic	• Ammonium-based formulation;	• Apply N according to recommendation of 4R N	• Apply fertilizer in spring only; or • Split apply.	Apply in bands / Injection	0.85

		stewardship plan*, using annual soil testing** and/or N balance to determine application rate.	• Apply liquid or solid manure in spring; or • After soil cools in fall		
Intermediate	• Ammonium-based formulation	• Apply N according to 4R N stewardship plan*, modified by qualitative estimates of field variability (landscape position, soil variability)	• Apply fertilizer or liquid manure in spring only; or • Split apply. • Apply solid manure in spring; or • Apply after soil cools in fall	Apply in bands / Injection	0.75
Advanced	• Ammonium-based formulation ; and/or • Use slow/ controlled release fertilizers; or • Inhibitors; or • Stabilized nitrogen.	• Apply N according to 4R N stewardship plan*, modified by quantified field variability (e.g. digitized soil maps, grid sampling, satellite imagery, real time crop sensors.), and complemented by in season crop monitoring	• Apply controlled release fertilizer or inhibitor/ stabilized nitrogen fertilizer; or • Apply liquid manure in spring; or • Split apply; • Apply solid manure in spring; or • Apply after soil cools in fall.	Apply in bands/ Injection	0.75***

*4R Plan 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 reduction of fertilizer rate as a result of implementing a ‘Basic’ or ‘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 in this paper will just apply the reduction modifier, since assumptions about rate reductions of N application as a result of implementing the performance levels would be prone to error. The results for the two levels of potential emission reductions for the 5 major crops are shown below (Table 26 and 27). It was assumed that the NERP was applied across the entire acreage where the 5 major crops are grown. It was also assumed that the 2009 reduction potential is consistent out to 2020[14].

Table 26. Reductions for 2009 Year by Crop Basic NERP Mt CO_2e.

	Reductions for 2009 Year By Crop - Basic NERP Mt CO_2e					
Province	**Barley**	**Canola**	**Corn**	**Spring Wheat**	**Soybeans**	**Total Reductions in 2009 Mt CO_2e**
NF	0.00	0.00	0.00	0.00	0.00	**0.00**
PE	0.01	0.00	0.00	0.00	0.00	**0.01**
NS	0.00	0.00	0.00	0.00	0.00	**0.00**
NB	0.00	0.00	0.00	0.00	0.00	**0.00**
PQ	0.03	0.00	0.17	0.01	0.01	**0.23**
ON	0.02	0.01	0.29	0.01	0.06	**0.38**
MB	0.06	0.12	0.01	0.18	0.00	**0.37**
SK	0.10	0.21	0.00	0.22	0.00	**0.53**
AB	0.17	0.19	0.00	0.22	0.00	**0.58**
BC	0.00	0.00	0.00	0.00	0.00	**0.01**
Canada	**0.51**	**0.81**	**0.30**	**1.05**	**0.05**	**2.72**

Table 27. Reductions for 2009 Year Crop by Intermediate/Advanced NERP Mt CO_2e.

	Reductions for 2009 Year By Crop – Intermediate/Advanced NERP Mt CO_2e					
Provinc	**Barley**	**Canola**	**Corn**	**Spring Wheat**	**Soybeans**	**Total Reductions in 2009 Mt CO_2e**

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[14] To calculate one year of baseline data emissions is a laborious undertaking and assumptions would need to be made regarding the increase or decrease in fertilizers, yields etc. For this reason the 2009 results are assumed to be indicative of the theoretical potential in this paper.

e						
NF	0.00	0.00	0.00	0.00	0.00	**0.00**
PE	0.01	0.00	0.00	0.00	0.00	**0.02**
NS	0.00	0.00	0.00	0.00	0.00	**0.00**
NB	0.00	0.00	0.00	0.00	0.00	**0.01**
PQ	0.05	0.00	0.29	0.02	0.02	**0.38**
ON	0.03	0.01	0.48	0.01	0.10	**0.64**
MB	0.10	0.21	0.02	0.29	0.00	**0.61**
SK	0.16	0.34	0.00	0.37	0.00	**0.88**
AB	0.29	0.32	0.00	0.36	0.00	**0.97**
BC	0.01	0.01	0.00	0.00	0.00	**0.02**
Canada	**0.85**	**1.34**	**0.51**	**1.75**	**0.09**	**4.54**

In total, for 61% of the crops grown in Canada, the potential for nitrous oxide reductions through changes in precision management practices varies from between **2.72 to 4.54 Mt CO_2e/yr**. This could be even more if rates of fertilizer reduction decrease per hectare as a result of more variable application considerations.

Constrained Potential: Policy, Market and Technical Overlay

In the case of Soil Nitrogen Management practices, adoption of variable rate technologies (GPS based precision application) is not mainstream in cropping systems today. While most growers have monitors on their equipment for real-time yield detection during harvesting and other productivity indices, the adoption to in-field GPS application of fertilizer applications is lagging behind. The cost-benefit productivity ratios need to be demonstrated to growers, and this technology will likely need to be provided in 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.

Part of the evolution in this space is that private sector companies are filling the void left by government agencies who provided traditional extension. The benefits will need to be reliably and consistently demonstrated by the private sector agencies because this technology is expensive. However, the level of implementation is flexible enough that the precision GPS based application is an option. Thus, at the Basic level of implementation, field variability is not the over-riding factor so adoption rates could be as high as 50%. For Intermediate level of application, qualitative assessments for field variability are allowed, so this could be as high as 50% also. To move to the highest level of precision application, a significant cost hurdle is encountered –this is the full-on GPS and variable rate technologies for fertilizer application. and Agriculture and Agri-Food Canada, through expert judgment, assessed that Low, Medium and High Adoption rates for Canada are in the order of 5% (low); 11% (medium) and 20%.

Applying these constraints, the more realistic estimates are:

- Basic Level Implementation – **1.36 Mt CO_2e/yr**
- Intermediate– **1.36 Mt CO_2e/yr (non-additive)**
- Advanced - ranges from **0.23 to 1 Mt CO_2e/yr,**

The measuring, monitoring and verification (MMV) procedures for these kinds of mitigation activities are clearly laid out in the Alberta protocols. The data gathering to support mitigation that is real, measurable and verifiable for these kinds of activities for the NERP require establishment of project-level baselines, which are an average of data over 3 years and requires more evidence and justification to the verifier. It can be done but will require significantly more data gathering, and justification to support viable and verifiable reductions.

Table 28. Categorical Assessment of NERP Implementation.

	Basic Level	***Intermediate/ Advanced Level***	***Explanation/Deviation from Criteria described in Section 2.2.2***
Speed	3	1	Basic easilty adpoted
Magnitude	3	3	Big on large scale
Scale	1	1	Many sources, small tonnes
R&D Stage	6	6	Technology Available
Total *(of 21)*	***13***	***11***	

Numerous co-benefits are realized from managing N inputs more sustainably. Optimizing N applications according to the right source at the right rate, time and place means less volatilization of ammonia gas, and less leaching of nitrates through the soil profile. Further, run-off events have minimal impact with incorporated fertilizers. Improved water and soil quality result in the lowland and upland areas, leading to better agro-ecosystem health overall.

Operationalizing the Sub-Wedge

- Invest in research to measure integrated BMP impacts on GHGs through the 4R management system, across a variety of soils-cropping systems

- Invest in research to measure performance of 'next generation' fertilizers like time-release coated fertilizers (e.g Environmentally Smart Nitrogen, Thiofertilizers)
- Invest in demonstration of variable rate technologies on-farm; precision application of fertilizers, pesticides
- Invest in research to measure net GHG impacts from precision application systems in various soils-cropping systems
- Invest in building the measurement tools of tomorrow - integrated measuring, monitoring and verification systems through the use of remote sensing, optical satellite sensors, GIS databases and biogeochemical process models for direct farm measurement

3.2.2 Beef and Dairy Cattle - Reductions of Methane and Nitrous Oxide

In 2008, the Agricultural sector in Canada was responsible for emissions of 62 Mt of CO_2e (8.4% of Canada's anthropogenic emissions), with enteric methane emissions from ruminant livestock making up roughly 22 Mt of CO_2e annually (approximately 19 Mt from beef cattle and 3 Mt from dairy (IPCC 2000, IPCC 2006, Atlantic Dairy and Forage Institute 2008, Environment Canada 2010)). Numerous studies have demonstrated that enteric methane reductions in cattle can be achieved through the use of various nutritional and genetic /cattle management strategies. There are approximately 83,000 beef producers across Canada, managing over 13 million head, with dairy operators managing 982,000 head (Gill and MacGregor 2010). Therefore small reductions in emissions associated with each animal can lead to significant reductions overall. Many of the strategies designed to reduce enteric fermentation also reduce manure production, leading to further reduction potentials in GHGs. From the period of 1981 to 2006, GHG emissions /kg head has decreased from 16.4 to 10.4 kg CO_2e in the beef sector – a clear trend towards increased efficiency in management (Statistics Canada 2010a).

Dairy cattle emissions in 2008 were approximately 3 Mt from enteric fermentation and an additional 1.5 Mt from manure-based emissions. Dairy cattle are supply-side managed in Canada through a dairy-quota system. Trends in dairy populations over the inventory accounting period declined by 28% (1990-2008), causing a decline in emissions overall. 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.

In Australia, agriculture accounts for 16% of that country's total GHG emissions, with livestock (mainly ruminants) accounting for two-thirds of agriculture emissions, whereas in New Zealand agriculture represents 49.4% of all New Zealand's emissions with CH_4 (66.4%) and N_2O (33.6%) making up the majority of the emissions. Thus many governments throughout the world are actively researching and implementing strategies to reduce GHG emissions from ruminants. Canada is blessed with some of the world's best experts in ruminant nutrition and management (especially in Alberta), as well as a sizeable beef and dairy herd with which to make improvements.

Mechanism and Methodology for Mitigation

The primary strategies with high confidence for reducing enteric methane emissions, and associated manure emissions from beef cattle are:

- Adding specified edible oils to the diet (providing alternate electron acceptors, or suppressing methanogenic rumen microbes);
- Modifying the diet with additives that suppress methanogenic rumen microbes (adding halogenated methane analogues, beta-antagonists or ionophores) causing cattle to convert more of their feed into meat or milk;
- Selecting for more genetically efficient cattle (based on markers for low residual feed intake (RFI) - a technology that emerged in Canada first);
- Managing the production chain to shorten cattle lifespans – reducing maintenance diets in their feeding stages where animals idle on roughage, producing unnecessary methane and manure (with associated CH_4 and N_2O emissions).

The basis for emission reductions in the dairy sector, with high confidence, include the following strategies:

- Increasing milk productivity through better genetics or husbandry to achieve equal milk with less feed
- Modifying the diet with higher quality feed or supplements (edible oils, ionophores or distillers grains) to decrease enteric methane per unit feed
- Increasing heifer replacement rate so there are fewer non-productive cows
- Season of spreading — avoid storing manure in warm months where methane emissions can be higher

The quantification approaches used in the calculations in this sub-wedge are based on the Alberta GHG quantification protocols for beef and dairy management (Dyer et al. 2008, Vergé et al. 2008). GHG emissions are calculated within cattle category and feeding period (e.g., nursing calves, calves grazing summer, fall and stockpiled pasture, calves on backgrounding diet in the feedlot, yearling grazing pasture, yearlings on a finishing diet; lactating cattle, etc) using

IPCC best practice guidance (IPCC 2006) and Canadian-based Tier 2 emission factors (Basarab et al., 2009).

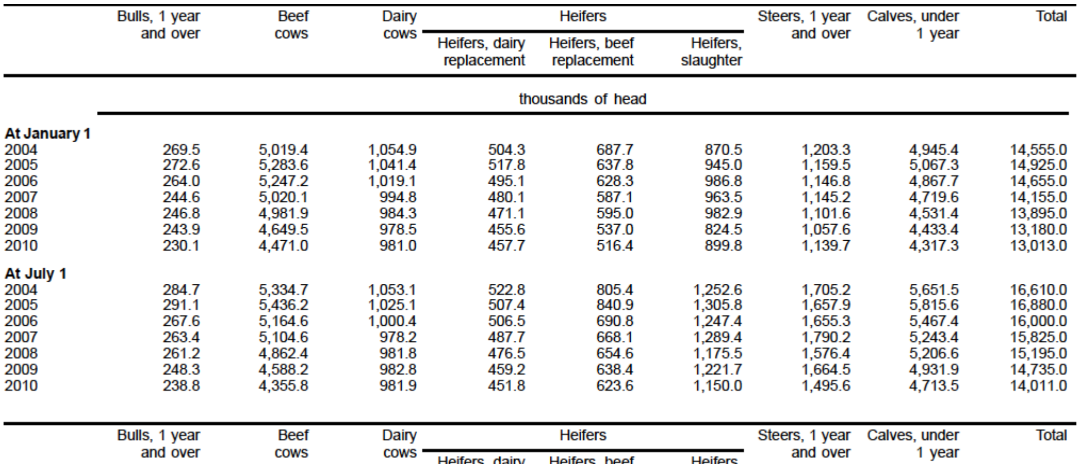
These protocols have been developed through a comprehensive scientific and technical review that engaged Canada's leading experts in beef and dairy cattle science as well as scientists from abroad (United States and overseas experts). The science and quantification represented in these strategies is robust and highly confident. It should be noted that in adapting this quantification to Canada-wide mitigation estimates, certain assumptions need to be made. These are listed in the next section.

Quantification: Theoretical Mitigation Potential

<u>Baseline Assumptions and Data Sources: Beef and Dairy Cattle</u>

Canada's NIR Tier 2 accounting method estimates the 2008 enteric methane emissions from beef cattle as 19 Mt CO_2e annually, and 30 Mt if manure emissions are included. This is the most comprehensive accounting for emissions in Canada. Beef cattle populations expanded by 29% over the inventory accounting period (1990-2008) due to increasing demand for beef, causing an increase in emissions from enteric fermentation. However, the beef herd in Canada has contacted over the last few years due to high feed grain costs and rising commodity prices for grains/oilseeds (Table 29).

Table 29. Cattle Types on Farms-Canada (Statistics Canada 2010b)



	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	269.5	5,019.4	1,054.9	504.3	687.7	870.5	1,203.3	4,945.4	14,555.0
2005	272.6	5,283.6	1,041.4	517.8	637.8	945.0	1,159.5	5,067.3	14,925.0
2006	264.0	5,247.2	1,019.1	495.1	628.3	986.8	1,146.8	4,867.7	14,655.0
2007	244.6	5,020.1	994.8	480.1	587.1	963.5	1,145.2	4,719.6	14,155.0
2008	246.8	4,981.9	984.3	471.1	595.0	982.9	1,101.6	4,531.4	13,895.0
2009	243.9	4,649.5	978.5	455.6	537.0	824.5	1,057.6	4,433.4	13,180.0
2010	230.1	4,471.0	981.0	457.7	516.4	899.8	1,139.7	4,317.3	13,013.0
At July 1									
2004	284.7	5,334.7	1,053.1	522.8	805.4	1,252.6	1,705.2	5,651.5	16,610.0
2005	291.1	5,436.2	1,025.1	507.4	840.9	1,305.8	1,657.9	5,815.6	16,880.0
2006	267.6	5,164.6	1,000.4	506.5	690.8	1,247.4	1,655.3	5,467.4	16,000.0
2007	263.4	5,104.6	978.2	487.7	668.1	1,289.4	1,790.2	5,243.4	15,825.0
2008	261.2	4,862.4	981.8	476.5	654.6	1,175.5	1,576.4	5,206.6	15,195.0
2009	248.3	4,588.2	982.8	459.2	638.4	1,221.7	1,664.5	4,931.9	14,735.0
2010	238.8	4,355.8	981.9	451.8	623.6	1,150.0	1,495.6	4,713.5	14,011.0
	Bulls, 1 year and over	Beef cows	Dairy cows	Heifers			Steers, 1 year and over	Calves, under 1 year	Total

Continuing downward trends in the cattle population is predicted to continue with 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. A conservative assumption is made in this report that the baseline number of beef cattle, across all cattle types, will hold relatively constant over the estimation period of 2007 to 2020, at 14 million head.

For the purposes of this report, it is safe to assume that supply-side managed dairy cattle populations will not increase and conservative to assume that they remain constant at approximately 980,000 head from 2007 to 2020.

Mitigation Assumptions and Activities: Beef and Dairy Cattle

Most of the mitigation strategies listed above are efficiency gains in meat or milk production, expressed on emissions level per product output basis (with the exception of emissions from manure management). 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 beef or fat corrected milk. Thus, a consideration for calculating the theoretical mitigation potential in absolute terms, across the entire beef/dairy herd will depend on whether or not animal populations increase. We are assuming the herds do not increase from now until 2020 based on previous justifications. Note that in Table 30 below, efforts have been made to quantify the mitigation potential for those cattle types that apply to the mitigation strategy.

Table 30. Mitigation Potential of Beef Dairy Strategies.

Mitigation Activity[a]	**Enteric Fermentation Mitigation Potential**	**Nitrous Oxide/Manure Methane Potential**
Adding Edible Oils in range of 4 to 6% of DM in the feedlot diet[b]	Up to a 20% decrease in methane per head; Up to 0.59 Mt CO_2e annually	-
Reducing Age at Harvest[c]	Reducing lifecycle by 3 months results in up to 0.7 tonnes CO_2e/head; up to 3.71 Mt CO_2e reduced annually	Less manure excretion results in up to 0.25 tonnes CO_2e /head; up to 1 Mt reduced annually
Selecting for Improved Feed Utilization Efficiency (RFI markers)[d]	Less methane 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 mgmt ↑ Heifer replacement	Up to 1.5 tonnes CO_2e/head; up to 1.49 Mt annually	

rate	
Total:	**Up to 6.82 Mt CO_2e/yr**

a - Quantification based on methodologies within Alberta-based protocols

b – Based on feeding edible oils in confined operations; number of head based on July 1 2010 slaughter heifers and Steers 1 year and over in Table X.

c – Based on number of head on July 1, 2010, Table X – slaughter steers (over 1 year); slaughter heifers and 50% of the Calves under 1 year could be harvested 3 months earlier.

d – Based on a case study where 4 low RFI bulls on 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.

Based on the above estimates, the Theoretical Mitigation Potential for reducing emissions from beef and dairy Cattle **could be as high as 6.82 Mt CO_2e** annually across Canada.

Constrained Potential: Market, Policy and Technical Overlay

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 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 methane 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 methane 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 relatively high demand of oils and oilseeds for other purposes.

In dairy, Dyer *et al.* (2008) reported that efficiency gains made in the dairy sector are stabilizing, and further activities to increase milk production efficiency will have increasing marginal costs of adoption. The dairy cattle population in Canada from 1981 to 2001 dropped by 57%, made possible by increasing milk per cow, resulting in a 49% decrease in GHGs per litre of milk in that period. 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 gathering to support mitigation that is real, measurable and verifiable for these kinds of activities is not insignificant, requiring tracking of diets and rations fed to each class of cattle, by pen in a feedlot – signed off by the nutritionist/veterinarian consulting to the feedlot, certification of genetic breeding stock by qualified testing facilities, 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. Can be applied anywhere in Canada.

Table 31. Categorical Assessment of Beef and Dairy Cattle Reduction Strategies.

	Edible Oils	***Genetic Selection***	***Earlier Harvest***	***Dairy Practices***	***Explanation/ Deviation from Criteria described in Section 2.2.2***
Speed	1	1	5	3	Hi oil cost; slow head turnover; genetic technologies coming
Magnitude	3	3	5	3	Significant if implemented widely
Scale	1	3	1	1	Small dispersed farms/ranches; will require aggregation costs
R&D Stage	4	5	6	5	
***Total** (of 21)*	***9***	***12***	***17***	***7***	

Taking these constraining factors into consideration, conservative estimates of adoption rates for 2020, would be in the 30 to 40% range, resulting in a potential **2 to 2.7 Mt CO_2e/yr**.

There are multiple and synergistic co-benefits arising from these sub-wedge opportunities, including higher efficiencies of production for ranchers and dairy operators. For example, shortening the age to harvest saves production costs of up to $23 CAD/head to the feedlot/backgrounder operation. Feeding edible oils to cattle can enhance the profile of Omega3 Beef, a nascent market opportunity. And, selecting for low RFI cattle, in the case for the 100 head cow-calf herd, can save the operation up to $2200 in production costs (Atlantic Dairy and Forage Institute 2008). In addition, savings in manure production means lower impact of other nutrients on the environment. As noted by (Basarab et al. 2009), multiple co-benefits exist to these practices – (1) identify management to improve the efficiency of feed and energy utilization without adversely affecting production and profitability; (2) reduce the environmental impacts of beef/dairy production; (3) take advantage of the carbon credit market; (4) to differentiate 'green' products on the basis of an improved carbon footprint, and healthier product.

Operationalizing the Sub-Wedge

See summary at the end of Section 3.2.3

3.2.3 Reductions from Hog, Poultry and some Dairy Operations

Greenhouse gas emissions from swine production systems in Canada totaled 2.9 Mt CO_2e in 2008 (Vergé et al. 2009, Environment Canada 2010). Other livestock production systems (non-beef and dairy) reached 2.2 Mt CO_2e for the same time period, for an overall total of 5.1 Mt CO_2e/yr. Although a small proportion of overall emissions arise from these production systems, many opportunities exist to reduce emissions. Shortened manure storage periods, more frequent application at the right time of year, improved management of protein in non-ruminant diets and increasing feed conversion efficiency of livestock are examples of strategies that will reduce GHG emissions in Canada.

For the hog sector, Verge et al. (2009) found that over the period 1981 to 2001, the growth of the swine population led to an increase in GHG emissions from the pork industry by 54%. The main GHG was CH_4, representing about 40% of the total in 2001. Nitrous oxide and fossil CO_2 both accounted for about 30%. Increases in more efficient 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 during the same period.

Mechanism and Methodology for Mitigation

The primary strategies with high confidence for reducing greenhouse gas emissions, and associated manure emissions from swine are:

- Reduce Nitrogen (N) content of the feed (measured as protein) is and/or increase feed efficiency so that the amount of manure and N content excreted by pigs is decreased;

- Reduce the Volatile Solids (Vs) content of the excreted manure through diet re-formulation;
- Empty manure storages in the spring to remove Volatile Solids and avoid methane emissions;
- Spread manure in the spring rather than fall to reduce nitrous oxide emissions from soils.

The quantification approaches used in the calculations for swine reduction strategies are based on the Alberta Swine GHG quantification protocol and analysis conducted by the Strategic Policy Branch in Agriculture and Agri-Food Canada (Vergé et al. 2009, Gill and MacGreggor 2010). GHG emissions using IPCC best practice guidance (IPCC 2006), and Canadian-based Tier 2 emission factors. The calculated tonnes per head shown below are taken from an ARD report completed in 2008; based on an analytical 600 sow farrow to finish operation complex (Vergé et al. 2009).

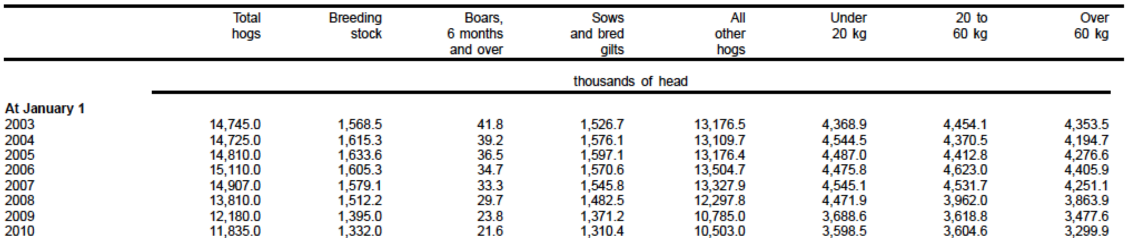
These protocols have been developed through a comprehensive scientific and technical review that engaged Canada's leading experts in beef and dairy cattle science as well as scientists from abroad (United States and overseas experts). The science and quantification represented in these strategies is robust and highly confident. It should be noted that, in adapting this quantification to Canada-wide mitigation estimates, certain assumptions need to be made. These are listed in the next section.

Quantification: Theoretical Mitigation Potential

Baseline Assumptions and Data Sources: Reductions from Hog, Poultry and Some Dairy

Canada's NIR Tier 2 accounting method estimates the 2008 emissions for swine to be 2.9 Mt. Currently, the swine population in Canada is 11.835 million head (Table 34 below) (Statistics Canada 2010c). Since the third quarter of 2005, Canadian hog and pig inventories are down 3.3 million head or 22%. The most recent data shows 4,430 farms in eastern provinces, down about 56% from the number of farms reporting in 1997. In western provinces, there are about 2,605 farms reporting pig inventories, compared to 10,160 farms in 1997, a 75% decline. The trend of reductions in Canadian hog numbers will be difficult to reverse in the next few years given expectations for high feed prices and a strong Canadian currency) National Hog Farmer 2010). For the purposes of this calculation, it is conservative to assume that the hog inventory in Canada will remain stable from the 2007 to 2020 time period.

Table 32. Swine Inventory of Canada



	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	14,745.0	1,568.5	41.8	1,526.7	13,176.5	4,368.9	4,454.1	4,353.5
2004	14,725.0	1,615.3	39.2	1,576.1	13,109.7	4,544.5	4,370.5	4,194.7
2005	14,810.0	1,633.6	36.5	1,597.1	13,176.4	4,487.0	4,412.8	4,276.6
2006	15,110.0	1,605.3	34.7	1,570.6	13,504.7	4,475.8	4,623.0	4,405.9
2007	14,907.0	1,579.1	33.3	1,545.8	13,327.9	4,545.1	4,531.7	4,251.1
2008	13,810.0	1,512.2	29.7	1,482.5	12,297.8	4,471.9	3,962.0	3,863.9
2009	12,180.0	1,395.0	23.8	1,371.2	10,785.0	3,688.6	3,618.8	3,477.6
2010	11,835.0	1,332.0	21.6	1,310.4	10,503.0	3,598.5	3,604.6	3,299.9

Mitigation Assumptions and Activities: Reductions from Hog, Poultry and Some Dairy

Most of the mitigation strategies listed above are efficiency gains in pork production, expressed on emissions level per product output basis (with the exception of emissions from manure management). 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, but for the purposes of this calculation, a tonne per head amount has been rolled up from the 600-sow farrow-to-finish base case in Central Alberta[15]. Quantification estimates below for feed efficiency and manure management utilize the head count of 11.835 million head as of January 2010 (Table 33).

Table 33. Mitigation Potential of Swine.

Mitigation Activity[a]	**Mitigation Potential**[d]
10% increase in feed conversion efficiency[b]	0.013t/hog; up to 0.15 Mt of CO_2e reduced annually
Switch from fall emptying to spring **and** fall emptying and manure application	0.036t/hog; up to 0.43 Mt of CO_2e reduced annually
Reduce protein intake by 15%; balance with free amino acids in swine; 10% reduction of protein in diets of dairy cows and 15% reduction of protein in poultry diets.[c]	With 60% adoption; up to 0.92 Mt CO_2e reduced annually from 2007-2017
Total:	**Up to 1.5 Mt CO_2e/yr**

a – Quantification based on Alberta Offset Pork Protocol, unless otherwise indicated

b – Assumed to be achieved through improved genetics, ration balancing/manipulation, improved feeder designs to minimize waste feed

c – For swine, it's assumed that phytase is also added to the diet to manage Phosphorous impact; estimates taken from Gill and Macgregor, 2010

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[15] This is a coarser approach than taken for beef and dairy, where applicable animal classes were used in the calculations.

d – Note for these calculations, considerations of animal class or exports of animal class (ie, weaners, feeders) were not taken into account, resulting in a possible overestimation of potential.

Constrained Potential: Market, Policy and Technical Overlay

There are a number of constraints to achieving the full potential listed above. 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 limit the producers' 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 mentioned above 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. However, the likelihood of this adoption is 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's been demonstrated that if it makes sense for producers to engage, they will engage. However, the likelihood of this adoption is dependent on cost factors, weather, equipment and perceived risk by producers.

The measuring, monitoring and verification procedures for these kinds of mitigation activities are clearly laid out in the Alberta protocols. The data gathering to support mitigation that is real, measurable and verifiable for these kinds of activities is not insignificant, requiring 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. These can be applied anywhere in Canada.

Table 34. Categorical assessment of hog, poultry and some dairy reduction strategies.

	Feed Conversion Efficiency	***Emptying and Spreading***	***Reducing Protein***	***Explanation Deviation from Criteria described in Section 2.2.2***
Speed	5	5	3	Readily available; amino acids maybe scarce and costly
Magnitude	1	3	3	Not as high as ruminants
Scale	1	3	1	Small dispersed operations; will require aggregation, costs
R&D Stage	6	6	5	
***Total** (of 21)*	***13***	***17***	***12***	

Taking these constraining factors into consideration, and considering these estimates already took into account some initial conservative assumptions, estimates of adoption rates for 2020, would be in the 60 to 70% range, resulting in a potential **0.9 to 1.05 Mt CO_2e/yr**.

The co-benefits arising from these mitigation strategies result in decreased manure produced per animal, as well as decreased excretion of nutrients, which can cause adverse environmental impacts if not managed properly. Further, increased efficiencies of animal production can be gained by implementing new technologies and getting more meat output per animal.

Operationalizing the Livestock Reduction Sub-Wedge

As a whole, a conservative estimate for the livestock sector to mitigate GHG emissions in Canada is 3 to 3.8 Mt CO_2e/yr – not insignificant. However, there are a number of barriers and gaps that need to be addressed to make this happen:

- Economics – the beef and pork sectors are facing some of the tightest margins in years with high feed costs, a strong Canadian dollar, and increasing market demands for animal welfare, food safety and environmental standards.
- Information – traditional extension and support mechanisms have diminished over the years; and several of these mitigation strategies will need this kind of technology transfer, that also speak to the costs and benefits of adopting some of these mitigation strategies.
- Technical assistance – producers have also seen this kind of traditional support diminish as government departments shrink and change mandates. Who will provide the technical assistance to help producers measure, monitor and verify these emissions reductions?

- Lack of science – many strategies are limited by our lack of understanding on the net effect of GHG emissions (methane, nitrous oxide an carbon dioxide). Of particular significance are extensive grazing systems (livestock-pasture interface) where more research is required; as well as more studies on the manure storage emissions and emissions from applying different forms of manure to land.
- Social perceptions and culture – reducing greenhouse gases may not be seen as an imperative for many producers; the fact that only small amounts of tonnes can be reduced at each farm will make this less attractive as well
- Scalability – realizing the reductions at scale is challenging given the small tonnes- many farms nature of the agriculture sector.
- Market pressure – increasingly, environmental groups are working with agri-food supply chains to enact sustainability standards for livestock production. Greenhouse gas reductions are one of the primary targets of these groups.

There are a number of enabling tools that could be implemented to operationalize this sub-wedge opportunity:

- Continue the development of provincial level carbon market initiatives (better yet, consider a national one); a firmer, consistent and wide-spread price on carbon would make these strategies appear more attractive
- Invest in the development of monitoring and reporting systems that would track animals and their production system practices over time
- Conduct more research into the livestock-pasture system to enable more opportunities for cow-calf operators in realizing real, verifiable GHG reductions
- Develop incentive programs that would assist producers in contracting the expertise to help them get set up for tracking carbon reduction opportunities over time
- Develop incentive programs to offset the costs of adopting some of these practices
- Explore how the quantification protocols can be used to develop eco-labeling programs to market or communicate low carbon meat and milk products

3.2.4 Changes in Logging Slash Disposal

Forest harvesting results in substantial accumulations of nominally waste biomass – called logging slash – this material is tops and limbs too small or of inadequate form to be used in the harvesters' manufacturing process. Hacker (2008) estimates that logging slash represents between 25 and 50% of the biomass cut when forests are harvested.

Mechanism and Methodology for Mitigation

At present, a small proportion of logging slash is gathered and shipped to cogeneration or biofuel use facilities. In Alberta, only one forest enterprise actively scavenges logging slash for use in cogeneration – representing approximately 7% of the total harvest. Another forest enterprise is examining the potential of scavenging logging slash for cogeneration. This mirrors the situation across Canada where logging slash is either piled and burned (most of the country) or left to decay in-situ (southern British Columbia coast.) When piled and burned logging slash tends not to burn completely due to accumulated soil, snow, green limbs and foliage, and other contaminants in the pile. This results in an emission of 950 g CO_2, 0.05 g CH_4 and 0.02 g N_2O per kg of wood burned (National Inventory Report, Annex 8); giving a total CO_2e equivalent emission of 957 g CO_2e per kg of fuel burned.

Forest harvest level in Canada is summarized in Table 35, (Natural Resources Canada – State of Canada's Forests – 2009.

Table 35. Annual forest harvest in Canada, 2008.

Annual harvest vs. supply deemed sustainable*	Million cubic metres 2008	Percentage change from previous year	Percentage change over previous 10 years**
Softwood supply	190	-0.4	0.7
Hardwood supply	60	-0.3	-0.2
Softwood harvest	114	-13.2	-2.2
Hardwood harvest	22	-13.4	-3.3

** Includes all land types (provincial, territorial, federal and private)*
*** Average 1998–2008*

Source: National Forestry Database

Conservatively applying Hacker's lower estimate (25%) of proportion of logging slash gives potential slash values of 28.5 million m^3 of softwood slash and 5.5 million m^3 of hardwood slash, totaling 34 million m^3 of slash. (D. Wilkinson, Executive Director, Forest Business Branch identified an average slash value of 25% of harvest at the Alberta Forest Growth Organization conference in October 2010 – which supports use of Hacker's lower bound.) Table 36 provides a conservative estimate of current emissions from logging slash disposal.

Table 36. Estimate of Current Annual Emissions from Burning Logging Slash.

	m^3	Tonnes	CO_2e

Softwood	28 500 000	11 400 000	10 909 800	
Hardwood	5 500 000	2 667 500	2 552 798	
Total			13 462 598	**13.4 Mt CO_2e**

These emissions might be substantially reduced by gathering and transporting harvest debris to biomass fueled facilities.

Constrained Potential: Policy, Market and Technical Overlay

There are several barriers to implementing logging debris scavenging:

- Generally harvesting debris is remote from biomass fueled facilities necessitating long transportation distances.
- Logging debris is less dense requiring post-harvest processing to "densify" it to facilitate transportation. Current, portable technologies to accomplish this are capital-intensive and rely on external fuel sources for power.
- Ownership of logging debris may, in some cases, reside with provincial forest managers – necessitating regulation change or some form of stumpage levy.

A constrained potential slightly less than ¼ of the theoretical potential is based primarily on haul distances. With present recovery technologies – in-block hog fuel processors – a haul distance of ~60 km is the maximum economic distance for slash recovery on good road systems. At present, the average haul distance in Canada is approximately 120 km meaning that likely ¾ of all slash is found beyond the economic haul distance.

Table 37. Categorical Assessment of GHG mitigation potential of logging debris to fuel.

	Logging Debris Salvage	***Explanation/Deviation from criteria outlined in section 2.2.2***
Speed	3	Change would changes to process and improved densification
Magnitude	5	Realized outcome (13.4 Mt)
Scale	3	Scattered and distal from facilities
R&D Stage	3	Bio-char and other fiber to fuel technologies are promising, need to be made operational
Total (of 21)	**10**	

Operationalizing the Sub-Wedge

- Need to develop (or operationalize) self-fueled densification technology.
- Ownership of logging debris in volume-based tenures requires clarification.
- Infrastructure to use this level of biofuel would need to be put in place.

3.3 Waste Management

3.3.1 Anaerobic Digestion - Agricultural biowaste, straw and plant biomass

Anaerobic digestion (AD) is one of the most promising treatment options, for managing livestock biowaste, mainly manure, and other agricultural biowastes and biomass including dead livestock and straw. It is capable of handling both solid organic wastes, such as cattle manure, and wastes that are too wet for composting or combustion/gasification. The technology has been proven to be viable for the cold Canadian winters. The technology processes biowastes, including manure, straw, and other on/non-farm organic wastes as diverse as from animal carcasses, slaughter house wastes to suspended organics in waste water to produce biogas (60% CH_4 +40% CO_2) which can be used directly for heat and electrical energy generation or, after processing, used as fuel replacement for natural gas.

At the same time, the AD process concentrates nutrients in the un-digested residue, called digestate, which can be further processed into bio-fertilizer or a soil organic amendment. AD technology provides the opportunity to recycle nutrients in bio-fertilizer that is compact, has lower weight and higher nutrient concentration, and therefore has higher value and can be applied more economically than raw manure and plant biomass. *The resistance of organic carbon in processed bio-fertilizer means little of the soil carbon sequestration potential of manure and plant biomass is lost in the AD process.* Other benefits of AD process include odor reduction and elimination of pathogens, particularly for processing dead livestock carcasses, the disposal of which has become a significant cost to the producers (Pell 1997, Eckford and Gao 2009).

A major component of agricultural biowaste is livestock manure. Current livestock manure management practices contribute to a significant portion of GHG emission (12%) by the Canadian agricultural sector (NIR 1990-2008, Statistic Canada 2010). Over 75% of the manure can be collected and processed to offset GHG emissions. Table 40 shows amounts of collectable manure produced annually. Particularly for hog manure, it emits over 2 t CO_2e/t.

Table 38. Collectable annual manure production and associated GHG emissions under current management in Canada.

Animal class year 2010	Total animal x1000 head	Dry manure kg/head, day	Total manure t/yr	GHG kg/t, yr	Total GHG t/yr
Beef cattle	7,359	3.5	9,401,250	149	1,400,821
Dairy cattle	980	8.2	2,933,140	259	759,919
Hog	11,850	0.33	1,427,333	2,455	3,504,185
Birds	49,650	0.027	293,830	844	247,988
Total	69,839		14,055,553	421	5,912,913

Canada has 36.4 Mha of croplands, of which more than 85% (32 Mha) are on the Canadian Prairies (Sokhansanj et al. 2006). Cereal crop production on the prairies produces an estimated average of 37 Mt/yr of straw. Assuming on average 1 t/ha is left in the field for protection against wind and water erosion, and 5 kg/day-head is needed for cattle bedding and feeding when it is required, an average of 15 Mt/yr (range 2.3—27.6 Mt/yr) of cereal straw could potentially be available for processing for the three Prairie Provinces (Sokhansanj et al. 2006).

Municipal wastewater treatment systems frequently utilize AD processes to reduce organic solids in wastewater. However, existing facilities do not maximize the utilization of biogas generated from the treatment process and much of the nitrogen in wastewater is lost to the atmosphere through de-nitrification. There is an opportunity to improve the current practice, by fully utilizing the biogas being produced and by capturing and recycling plant nutrients, to achieve significant offset of GHG emissions, as well as eliminate pathogens (Pang et.al 2009).

This section assesses the opportunity of using AD technology to process these agricultural biowastes, as well as available cereal straw and other plant biomass.

Mechanism and Method for Mitigation

The mechanisms to reduce GHG emission associated with biowaste include 1) reduction of retention time in storage under current system, 2) displacement of electricity and fossil fuel with bioenergy, 3) displacement of inorganic fertilizer and improvement of fertilizer efficiency (biofertilizer – Section 3.4; Biomaterials), and 4) enhancement of soil carbon sequestration (soil organic amendment, Section 3.3.1 above). Under the Alberta GHG offset system there are three protocols available for quantifying this mitigation potential:

- Anaerobic decomposition of agricultural materials,

- Anaerobic treatment of wastewater,
- Agricultural N_2O emission reduction.

However, these protocols do not address reduction of retention time of waste onsite and in storage to reduce GHG emission, displacement of inorganic fertilizer, and soil carbon sequestration.

Quantification: Theoretical Mitigation Potential

Livestock waste (manure and dead livestock): The total collectable manure potentially available for AD processes is 13.8 Mt/yr (Table 38). For this amount, GHG emission under the baseline condition of 425 kg CO_2e/t,yr (NIR 1990-2008) gives a total emission rate of 6.3 Mt CO_2e/yr. By adopting AD technology, much of the current emissions could be avoided because of the minimal retention time both onsite and in storage. If treated by AD and bio-fertilizer technologies, the 13.8 Mt/yr of collectable manure could generate 9.1 TWh of renewable energy (Monreal et. al 2010), offsetting 1.8 Mt CO_2e/yr of GHG emission.

MacGregor (2010) projected, based on the Agricultural Anaerobic Digestion Calculation Spreadsheet (AADCS) developed by Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), and based on German experience, that under high levels of adoption, where AD systems can process manure generated from three major categories of livestock: dairy cattle, beef cattle and hog; a total of 1.4 Mt CO_2e /yr GHG emission offset could be reached, close to the 1.3 Mt CO_2e/yr estimated above for renewable energy generation.

Cereal Crop Straw:

The three Prairie Provinces, which account for more than 85% of Canada's arable crop land, produces, on average, 15 Mt/yr of "surplus" straw from cereal crops that is potentially available for industrial utilization without negatively impacting soil quality or livestock requirements (range 27.6—2.3 Mt/yr based on 9 years of data, Sokhansanj et al. 2006). This material is suitable for AD processes (Appendix 1). If this material is processed through AD technology it will result in 9.9 TWh/yr electricity and offset GHG emission of 2 MtCO_2e/yr using the same emission factor.

Wastewater: Total solids, primarily organic, in municipal wastewater potentially available for AD process is 2.2Mt (Statistics Canada 2009, Edmonton Gold Bar Wastewater Treatment Plant). GHG emission rate under the current handling system is 27.8 kg CO_2e/per capita/ yr, contributing to a national total of 0.94 Mt CO_2e/yr (NIR 1990-2008). According to the Eco-Efficiency Centre fact sheet of Dalhousie University (2008), the Canadian food and beverage processing industry generates over 4,000 Mt of wastewater effluents containing approximately 16 Mt digestible solids. Over 96%, in other words, “all”, of the wastewater from this $90 billion/yr industry is not treated for energy and nutrient recovery (NIR 1990-2008). If this material is processed through AD technology it will result in 12 TWh/yr electricity and offset GHG emission of 2.4 $MtCO_2e/yr$ using the same emission factor.

If these materials are processed through an AD system with Co-Gen capacity, 31 TWh of electrical energy and 22 Mt of bio-fertilizer could be produced potentially. The direct GHG emission offset from renewable electricity alone is 6.2 Mt CO_2e/yr, assuming an emission factor of 0.2 t CO_2e/MWh (Canadian average, NIR 1990-2008). This offset does not include elimination of current GHG emissions from the baseline practice, which is over 6 $MtCO_2e/yr$.

Table 39. Summary of assumptions and activities for the proposed mitigation practices.

Baseline (land application for agricultural waste and open lagoon/free discharge for wastewater)	
Assumptions	**GHG emission/mitigation potential**
1. Land application for agricultural biowase 2. Lagoon storage and aeration or free discharge to oceans for wastewater	1. Manure management emission: 6.3 Mt CO_2e/yr; 2. Municipal wastewater emission: 0.94 Mt CO_2e/yr
Anaerobic digestion	
1. Biowaste is processed in an AD system after its production or collection 2. Energy displacement: 657 kwh/t (dry) (90% of electricity generated from biogas) 3. Digestate (material after AD) is processed to produce bio-fertilizer, which requires 25% of electricity generated through AD.	Before fertilizer production: 6.2 Mt CO_2e/yr, bio-fertilizer is produced the offset potential = 4.5 Mt CO_2e/yr
Total	***4.5 - 6.2 Mt CO_2e/yr***[*]

- This calculation does not include the avoidance of current practices to processing these materials, which totaled 7.2 Mt CO_2e/yr since the current protocols do not allow these claims.
- If solid biowastes from current food processing waste are also treated through this process, the theoretical potential is significantly higher then ***4.5 - 6.2 Mt CO_2e/yr***.

Constrained Potential: Market, Policy and Technical Overlay

Current market: current manure management practices are not fully realizing manure's economic value. In most areas with concentrated livestock operations, as well as in areas surrounding many urban centers, soil nutrient contents have reached levels much higher that what is needed for optimum crop production. Manure continues to be applied on these lands because it is not economical to transport and apply them further down the road. Government regulations limit manure application in excess of nutrient limits – hindering expansion of the industry.

The livestock industry requires innovative technologies to help managing its waste to maintain it's social license to operate in an increasingly competitive global market. Anaerobic digestion combined with bio-fertilizer production is one of the most promising technologies to address this issue, but it requires proper policy incentives to kick-start the industry and help it reaching critical mass.

Capital cost of $3500-$6000/kw is a significant barrier for the adoption of AD technology. This barrier cannot be expected to be reduced significantly until the AD industry has reached its critical mass. MacGregor (2010) suggested that governments could provide the right economic environment for commercial uptake of AD technology through financial incentives and through development of institutions such as a carbon market, or feed-in-tariffs. Ontario and Alberta governments are taking the lead in this direction.

In the meantime, technical enhancements that improve efficiency, efficient technologies for recovery of nutrients to be blended with the bio-fertilizer or sold alone, and developing markets and uses for by-products including bio-fertilizer and heat energy will enhance economics of AD technology and its uptake.

Table 40. Categorical assessment of anaerobic digestion.

	Waste-AD	***Explanation/Deviation from criteria described in section 2.2.2***
Speed	4	Can be quickly implemented if incentive to use by-products is in place
Magnitude	5	It has a 5.0 Mt/yr potential
Scale	3	Capital cost impairs market uptake
R&D Stage	4	At the commercialization stage, requires R&D to reduce production costs and increase by-product value
***Total** (of 21)*	***16***	

Co-benefits: Please see bio-fertilizer and organic amendment sections. In addition the co-benefits of this waste management practice will eliminate the potential pathogens associated with these wastes, particularly from dead livestock and municipal wastewater.

Risks: Major risks for AD technology include unplanned releases of biogas and improper management of digestate. Uncertainty in the availability of biomass, such as cereal crop straw, is an important risk factor. Industrial facilities require a steady supply of feedstock. Available plant biomass, however, varies widely from year to year depending on climate, market conditions, changes in cultivation practice, and phases of crop rotation. Willingness of producers to sell straws is also not certain. One survey found only 1 in 4 famers are willing to consider selling straw.

The estimation of constrained potential is based on availability of materials and predicted AD uptake by MacGregor (2010):

1. 40% of collectable manure (MacGregor, 2010), 60% of biowaste from wastewater (CCME, 2009) and less than 30% of straw can be processed through AD; and
2. while applying AD for processing these wastes additional 15% of energy can be recovered by using co-substrates, such as biowaste from food processing solid wastes.

Operationalizing the Sub-Wedge

- Revise current AD protocols to include upstream and downstream management for calculating avoided emissions.
- Provide estimates of GHG reductions under AD management and improve the ability to compare multiple scenarios in a C footprint context, as well as provide estimates of economic impacts on producers.
- Invest in training program at colleges or institution for training AD operators.
- Invest in colleges or institutions to produce a national inventory of biowaste regarding its size, geological distribution and energy/nutrient potential.
- Require incentives for applying organic amendments and quantification protocol for GHG emission offsets or feed-in tariff program.
- Require incentive for applying bio-fertilizer, as well as quantification protocol for GHG emission offsets.

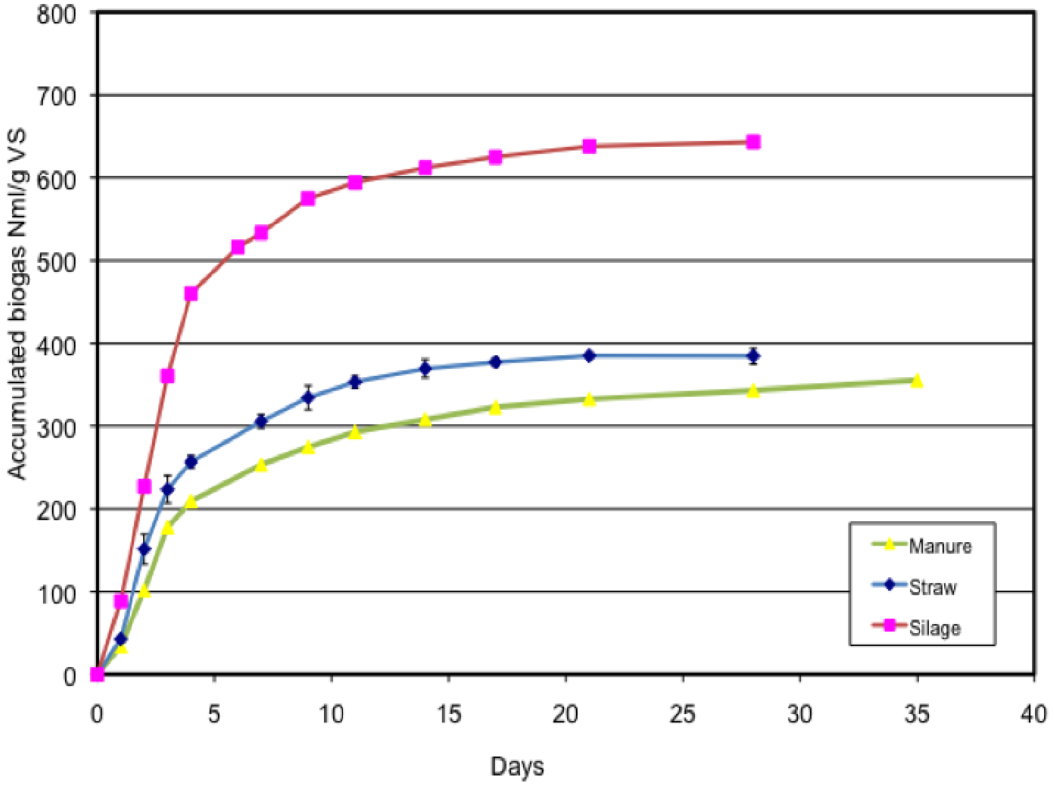


Figure 14. Biogas Potential of barley straw in comparison with beef cattle manure and silage in laboratory incubation. Digested beef cattle manure from a commercial site used as an inoculant.

3.3.2 Reductions in Emissions from the Management of Solid Wastes

The disposal of the organic portion of solid waste in landfills under anaerobic conditions allows naturally occurring microbes to break down the organic constituents of the waste to form the greenhouse gases methane and carbon dioxide. The composition of the landfill gas is approximately 50% methane (CH_4) and 50% carbon dioxide (CO_2). The net emissions footprint from the disposal of this waste is 20 MT annually, according to the latest published National Inventory for Canada (1990 to 2008) (Environment Canada 2010).

For the purposes of this section, solid wastes include municipal solid waste (MSW) composed of a mixture of organic and inorganic materials from a variety of industrial, institutional, residential and commercial facilities. According to the most recent published survey from Environment Canada, approximately 27.3 million tonnes of waste were disposed of in 2006, up 8% from 2004 (Statistics Canada 2008b). From the same survey, approximately 7.7 million tonnes were diverted from disposal in landfill. As such, the total waste is estimated as 35 million tonnes per year – 13 million tonnes from residential sources and 22 million tonnes from other sources.

The composition of the waste varies considerably geographically and by source. However, Figure 16 provides an average waste composition compiled by Statistics Canada (2005).

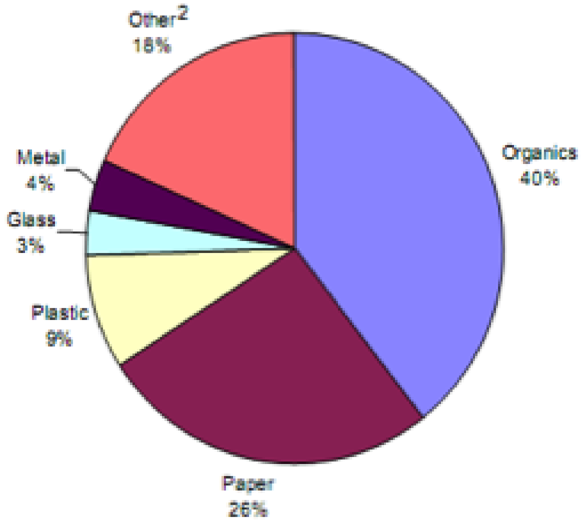


Figure 15. Composition of solid waste by weight, generated by households

Notes:
1. This figure does not represent the composition for any identifiable Canadian community.
Rather it is a national average of various municipal waste composition studies performed across Canada.
2. The other wastes category includes materials such as animal waste, textiles, tires and
wood.

Mechanism and Methodology for Mitigation

There are numerous approaches to the management of the solid waste generated in Canada. This can include recycling of the metals, glass and paper, through to the disposal of the materials in landfills. The leading management approaches are covered in the following sections. The use of the solid waste for biochar production (pyrolysis) is excluded as it will be covered under a separate section.

Landfill Gas Capture

Landfill gas capture with flaring or utilization, referred to in the following section as “LFG Capture”, consists of the installation of a piping network through the landfill connected to a pump that creates a suction to capture landfill gas and hence reducing the amount of gas that escapes into the atmosphere. GHG reductions are realized through the destruction of the methane in the landfill gas and the displacement of grid electricity or fossil fuel derived heat.

There were 51 sites (Canada’s Action on Climate Change 2010) with active LFG Capture projects as of the latest national inventory. Others have subsequently come online (i.e. City of Regina), but the biennial survey results for 2009 are not yet available or could not be found. The facilities achieved emission reductions estimated as part of the national inventory as being 6.9 Mt CO_2e in 2007.

Aerobic Landfill Bioreactors

Alternatively, landfills can be operated under aerobic conditions through the injection of air into the landfill and the regulation of the moisture content. These projects are referred to as Aerobic Landfill Bioreactors, and have been implemented in other jurisdictions (US and Israel). These projects reduce the methane generation capacity of the waste in landfill to 85% of their existing potential, more quickly than does landfill gas. However, these projects do not have the opportunity to generate electricity or heat as co-benefits. Further, there are no active Landfill Bioreactor projects in Canada with multiple in the planning stage.

Composting

Diverting the organic component of the solid waste stream for composting avoids the potential for methane emissions from the material were it placed in a landfill. The material is converted aerobically to carbon dioxide using any number of approaches. This can include highly mechanized in-vessel approaches as well as open windrow. Nutrients contained in the finished compost can then be returned to the land. This provides additional benefits.

In 2006, data was compiled by Statistics Canada on composting in Canada (Statistics Canada 2006). According to that study, composting accounted for approximately 2.0 Mt of waste diverted from landfill each year. This represented an increase of approximately 32% relative to 2002. Sixty-five percent of the composted material comes from residential sources, with the remainder coming from other sources. Composting accounts for 26% of the total waste material diverted from landfill.

Anaerobic Digestion

The organic component of the solid waste can also be diverted for anaerobic digestion. These materials may be digested on their own, or in combination with manures. The methane produced through the digestion process can either be combusted for heat and/or electricity, run through a fuel cell, or sold as a biogas. Nutrients contained in the digestate and any liquid byproducts can then be returned to the land.

There is not much data on potential and existing anaerobic digestion of solid wastes. Most of the content is focused on digestion of sludges and manures. The only facility known to the authors that is solely purposed for municipal waste is operated by The City of Edmonton.

Incineration and Related Thermal Treatments

The solid waste (inorganics and organics) material can also be incinerated or thermally treated to convert the waste to energy. There are a number of technologies for this including some older incinerators, plasma-based conversion technologies and the use of refuse derived fuels.

The latter two of these technologies can be used to produce heat and/or electricity
There is little recent data available on incineration. The most updated information found from Statistics Canada, stated that in 2000, there were 21 incinerators in operation in Canada, processing 1.1 Mt of material.

Each of the project types, with the exception of pure incineration of waste, has a quantification protocol under the Alberta Offset System (Climate Change Central 2009). Further, there are quantification protocols available under the Clean Development Mechanism (exception is incineration and related) and Climate Action Reserve (Compost, Co-Digestion, Landfill Gas). The science and quantification represented in these protocols is robust and highly confident.

Quantification: Theoretical Mitigation Potential

Baseline Assumptions and Data Sources: Solid Wastes

Landfill gas systems have typical capture efficiencies of 75% for the period that they are operational (USEPA 2010a) and may only be economic in larger landfills. The LFG systems are not operated over the full time-scale that the waste is in place, as they cannot be implemented in the operating section of the landfill and become inefficient in the tail end of the operation.

The potential for aerobic bioreactor projects is considerable as the reduction in emissions extends forward over time. By reducing the methane potential of the material in the landfill, the annual emissions of LFG are greatly reduced on a go-forward basis. However, the material may produce methane once in landfill, prior to the initiation of the aerobic treatment process.

Composting, anaerobically digesting, and incinerating (or otherwise thermally treated) the solid waste is inherently more efficient for reducing the greenhouse gas emissions, relative to disposal in landfill. Firstly, as the material is never sent to landfill, the methane produced during the initial period prior to application of landfill gas or aerobic biodigester systems is avoided. Also, landfill gas or aerobic biodigester systems are not completely effective, and may not be efficient to apply for the tail end of the period the material is in landfill.

In 2005, ICF Consulting completed a report for Environment Canada and Natural Resources Canada on the emission reduction potential of several of these approaches. These values cover food scraps (as a proxy for organics in MSW) and apply to composting (1.04 t CO_2e/t), anaerobic digestion (0.9 t CO_2e/t) and incineration (0.78 t CO_2e/t).

Mitigation Assumptions and Activities: Soild Wastes

Each of the mitigation activities have been outlined previously and are summarized in Table 41 below.

Table 41. Mitigation potential of solid wastes.

Mitigation Activity	**Mitigation Potential**
Landfill Gas Collection[a]	27 Mt CO_2e/yr of emission every year with a 75% collection efficiency resulting in 20.3 Mt CO_2e/yr of potential emission reductions.
Aerobic Bioreactor	20 Mt CO_2e/yr of emissions not already under LFG with a 85% reduction over time resulting in an average of 17 Mt CO_2e/yr. Given the nature of the accounting for the emission reductions, these could be achieved in shorter period.
Composting	40% of the 27.3 Mt/yr of waste could be composted at 1.04 t CO_2e/t resulting in 11.4 Mt CO_2e/yr.
Anaerobic Digestion	40% of the 27.3 Mt/yr of waste could be digested at 0.9 t CO_2e/t resulting in 9.8 MT CO_2e/yr.
Incineration and Related Thermal Treatments	40% of the 27.3 Mt/yr of waste could be incinerated at 0.78 t CO_2e/t resulting in 8.5 Mt CO_2e/yr.
Total:	The range of opportunities is from 8.5 Mt CO_2e/yr to 31.7 Mt CO_2e/yr, depending on the mix of landfill operation and diversion programs.

a- 75% * 20 Mt plus the 7 Mt already collected.

Constrained Potential: Market, Policy and Technical Overlay

There are a number of potential constraints on the implementation on any of these technologies. Each of these constraints are summarized in Table 42 relative to each of the mitigation activities:

Table 42. Mitigation Activity Constraints of Solid Wastes.

Mitigation Activity	Constraints
Landfill Gas Collection	• Technical issues associated with application at certain configurations of sites and small sites. • Not applicable to open cells in landfills.
Aerobic Bioreactor	• As of yet unproven technology. • Uncertain fit with LFG capture legislation. • No other economic returns.
Composting	• Odor issues remain a concern • Shift to source separated organics is on-going and not as effective in some settings
Anaerobic Digestion	• Economic challenges relative to other options
Incineration and Related Thermal Treatments	• Public perception is poor as air emissions issues remain prevalent without extensive controls for existing technologies. • New technologies continue to undergo commercialization.

Table 43. Categorical Assessment of Solid Waste Strategies.

	Landfill Gas	*Aerobic Bioreactor*	*Composting*	*Anaerobic Digester*	*Incineration and other Thermal*	*Explanation/ Deviation from Criteria in Section 2.2.2*
Speed	5	3	5	3	1	Permitting issues, project economics and public perception may limit speed
Magnitude	5	3	3	3	3	Magnitude of all but LFG constrained by regulatory, market or other issues.
Scale	3	3	3	3	3	The generation and disposal of waste is widely dispersed. Small sites are prevalent.

R&D Stage	5	4	5	5	5	Only bioreactors have not been tried in Canada.
Total (of 21)	**18**	**13**	**16**	**14**	**12**	

Taking these constraining factors into consideration and acknowledging that multiple uses of the same feedstock are not possible, the resulting potential are estimated for each mitigation activity. For LFG and aerobic bioreactors, this will likely account for approximately 50% of the emissions from the waste in place **or approximately 13 Mt/yr.** This would represent a doubling of the current emission reductions from these activities.

For composting and anaerobic digestion, a similar doubling of activity is likely **to approximately 5 Mt/yr.** This is most likely with some additional policy implementation to support diversion of organics from landfills. Incineration emission reductions are likely to remain largely flat with limited growth from the emerging thermal conversion technologies. The potential is suggested **to be up to 2 Mt/yr,** representing almost a doubling of activity.

Operationalizing the Sub-Wedge

To assist in operationalizing this sub-wedge:

- Recognize benefit from landfill diversion relative to landfilling of organics through policies and other means (i.e. elevated tipping fees).
- Support development of markets for end products from compost and anaerobic digestors.
- Complementary programs to support electricity production from landfill gas, anaerobic digestion and thermal treatments (i.e. RPS or FIT programs).
- Support municipal project development through agencies such as the Federation of Canadian Municipalities.
- Acknowledge the equivalency of alternatives to LFG for meeting passive landfill gas emission reductions.

3.3.3 Biochar Production and Use

Biochar is produced through the pyrolysis of organic feedstocks in the absence of oxygen. Biochar production may employ a variety of different processes and approaches. Slow pyrolysis is characterized by lower temperatures over longer residence times. These characteristics support the optimization of biochar production. Fast pyrolysis is characterized by higher temperatures which allow for shorter residence times. This process optimizes energy production, primarily in the form of bio-oil production. Flash pyrolysis, is a mid-point between slow and fast pyrolysis in that it produces, under pressure, higher yields of biochar with higher temperatures and shorter residence times. Gasification produces the smallest volume of biochar while maximizing gas production. Lastly, hydrothermal conversion is the newest of these processes, converting a wet feedstock to a less stable char – but with a higher biochar yield.

The potential feedstocks for biochar include forestry and agriculture crops and residues, municipal solid wastes (organic component), livestock wastes, and other sources of organics. The feedstocks are then processed with heat in the absence of oxygen for a sufficient period as to render a significant portion of the carbon in the material stabilized as a solid biochar (which has a mean residence time in soils on the order of 1,000 to 10,000 years)

The biochar can then be used as an additional tool in agriculture and/or land management. For example, biochar may be applied to agricultural soils, where it improves soil quality; it may be used as a product for turfgrass establishment; it can be substitute for peat or coconut shells in horticultural applications; it may be used in land restoration; or it may be used as a means of mitigating water pollution. In each situation, biochar containing stabilized carbon is nearly permanently sequestering the carbon therein. In some cases, the biochar may be stored permanently as fill in mining operations or similar applications to traditional carbon capture and storage (CCS) techniques. The use of biochar as a solid biofuel would not be considered as applicable to these project types, as there is no sequestration of the carbon.

During the pyrolysis process, various energy-rich gas and liquid streams may be produced. These energy streams may be used to offset the use of fossil fuels, to produce electricity or used parasitically within the pyrolysis process.

Mechanism and Methodology for Mitigation

Under business as usual, the feedstocks for biochar would otherwise be burned or decompose. Disposing of the feedstocks releases carbon dioxide and black carbon (BC). Decomposition can result in either the releasing either carbon dioxide (if decomposition occurs under aerobic conditions), methane (if decomposition occurs under anaerobic conditions), or nitrous oxides under fluctuating conditions (aerobic / anaerobic). The process and production of biochar stabilizes these organic sources such that decomposition happens over thousands of years, not a few years, and avoids these emissions.

Production and use of biochar offers great potential for greenhouse gas emission reductions and the removal of carbon dioxide from the atmosphere through carbon capture and sequestration, and renewable energy production. The mechanisms for achieving emission reductions from the production or use of biochar extend across the project lifecycle.

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 and Alberta Offset System. The science and quantification approaches under this protocol initiative draw on aspects of existing protocols and current best practice.

Quantification: Theoretical Mitigation Potential

Baseline Assumptions and Data Sources: Biochar

The BIOCAP Canada Foundation estimated the potential agriculture and forestry feedstock in Canada for use in biochar (BIOCAP Canada Foundation 2003) as approximately 60 million tonnes per year. This is said to represent approximately 40% of the total biomass harvest. However there would be other uses for this feedstock for use in bioproducts, digestors and composting operations.

Assuming no land-use change and no related change in the management of forest/agricultural systems, all of the carbon (45% to 50% by mass (Bioenergy Feedstock Information Network 2005)) in these feedstocks is available for sequestration. Further, an assumption of 80% feedstock use efficiency would be applied to account for wastage in processing.

In addition, there is the potential to use solid waste feedstocks. According to the most recent published survey from Environment Canada, approximately 27.3 million tonnes of waste were disposed of in 2006, up 8% from 2004 (Statistics Canada 2008b). From the same survey, approximately 7.7 million tonnes were diverted from disposal in landfill. As such, the total waste is estimated as 35 million tonnes per year – 13 million tonnes from residential sources and 22 million tonnes from other sources.

The composition of the waste varies considerably geographically and by source. However, Figure X provides an average waste composition compiled by Statistics Canada (2005). This reports organics as 40% of the waste, by mass.

The conversion of the feedstock to biochar ranges in efficiency from 20 to 30%, on a mass basis, depending on the pyrolysis technology, feedstock, temperature and residency time (Amonette and Joseph 2009, Woolf et al. 2010).

Mitigation Assumptions and Activities: Biochar

Assuming all available feedstock is converted to biochar, the calculation of the emission reduction potential would include the diversion of the organic wastes from landfill and the sequestration of the carbon in the biochar. The benefits from reduced fertilizer use and increased crop production, as may occur, are excluded.

To calculate the benefit from diverting the organics from landfill, the emission reduction potential would be similar to that within the compost, anaerobic digestion and incineration. The emission reduction potentials are 1.04 t CO_2e/t (composting), 0.9 t CO_2e/t (anaerobic digestion) and 0.78 t CO_2e/t (incineration) (ICF Consulting 2005). Given the thermal nature of the conversion of biomass to biochar, applying the factor for incineration appears most appropriate.

As such, the emission reductions from conversion of the solid waste would be calculated as follows:

Mass of Solid Waste: 27.3 Mt/yr
Percent Organic: 40%
Emission Reduction Factor: 0.78 t CO_2e per tonne
Emission Reduction: 8.5 Mt CO_2e/yr

The emission benefit for the conversion of the biomass to biochar would be calculated as follows:

Mass of Biomass: 27.3 Mt/ yr (* 40%) + 60 Mt/yr = 70.9 Mt/yr
Conversion Factor: 20% to 30%
Carbon to CO_2e: 44/12
Emission Reduction: 52 to 78 Mt CO_2e

As such, the total theoretical emission reduction potential is between 60.5 and 86.5 Mt CO_2e year. These values are consistent with the potential for Alberta summarized by Alberta Innovates Technology Futures (Anyia et al. 2010).

Constrained Potential: Market, Policy and Technical Overlay

There are a wide range of constraints on the development of biochar, discussed below:

1. Markets for Biochar. There are limited markets for biochar as a soil amendment or for other uses. The benefits for producers have not yet been demonstrated broadly across the range of chars and applications. The economics of biochar projects must assign some value for the resulting biochar. Alternatively, projects will optimize for energy production, which will decrease biochar production.

2. Financing for Projects. There are few industrial scale biochar projects in operation. The returns include waste handling fees, energy produced and the biochar. Carbon credits are not yet a reality for these projects – without a protocol. Each of these value mechanisms have significant uncertainties (consistency of feedstock, energy production, char quality/market).

3. Availability of and Competition for Feedstocks: The distribution of feedstocks is spread across Canada and varies season-to-season with the core agricultural production. As such, there will be difficulty in optimizing use of the feedstock at a scale that would cover all available feedstocks. Further, a portion of the feedstock is currently being recycling nutrients through incorporation directly to land, composting and anaerobic digestion, creating competition for the feedstock.

4. Lack of consistent standards to determine biochar quality. Chars differ in their stability and longevity in soils. Standardization needs to occur, and testing of the stability of chars in soils in Canada.

Table 44. Categorical Assessment of Biochar.

	Biochar	***Explanation/Deviation from criteria outlined in section 2.2.2***
Speed	5	Numerous projects awaiting financing. Largely pending connection with grids and markets for biochar.
Magnitude	5	Significant opportunity based largely on sequestration of carbon in biochar.
Scale	3	Projects will have to be distributed among project sites
R&D Stage	3	Range of technologies being developed across the project scales and feedstocks. No large scale implementation projects

Total (of 21)	**16**

Taking these constraining factors into consideration, the potential for emission reductions from biochar projects is likely to be in the range of 10% of the potential. This would sum to 6 to 9 Mt of CO_2e /yr.

Operationalizing the Sub-Wedge

To assist in operationalizing this sub-wedge:

- Support the development of markets for the biochar through research into its efficacy and stability in soils.
- Recognize the GHG environmental benefits from biochar production.
- Sponsor projects that are commercializing the range of potential technologies.
- Conduct LCA/C footprinting studies on the alternate feedstocks and production systems associated with biochar, vis a vis conventional diesel, electricity and natural gas.

3.3.4 Biomass Combustion

Canada has 36.4 Mha of cropland, of which more than 85% (32 Mha) are on the Canadian Prairies (Sokhansanj et al. 2006). Cereal crop production on the prairies produces an estimated average of 37 Mt/yr of straw. Assuming on average 1 t/ha is left in the field for protection against wind and water erosion, and 5 kg/day-head is needed for cattle bedding and feeding when it is required, an average of 15 Mt/yr (range 2.3—27.6 Mt/yr) of cereal straw could potentially be available for processing for the three Prairie Provinces (Sokhansanj et al. 2006; Table 45).

Table 45. Annual biomass production in three prairie provinces.

Type of Straw	Alberta		Saskatchewan		Manitoba		Total	Total N
	Mt/yr	t/ha	Mt/yr	t/ha	Mt/yr	t/ha	Mt/yr	Kt/yr*
Wheat	5.09	1.86	7.18	1.15	1.59	1.05	13.85	69.3
Barley	2.61	1.46	1.78	1.06	0.46	0.94	4.85	24.3
Oat	0.53	1.63	0.91	1.47	0.49	1.34	1.94	9.7
Flax	0.02	0.75	0.20	0.42	0.03	0.12	0.24	1.2

Total	***8.78***	***1.81***	***9.75***	***1.09***	***2.40***	***0.92***	***20.93***	***105***
Total Available	***5.57***		***7.94***		***1.51***		***15.02***	***75***

[*] N content of straws vary considerably with crop, fertilizer, soil and climate. Reported values are generally between 0.4% and 0.9%, with significant overlap among different crop species. An average value of 0.5% is used here, considered to be somewhat conservative.

This section assesses carbon emission implications of two biomass management options, AD+biofertilizer and direct combustion.

Mechanism and Methods for Mitigation

The option of using AD and bio-fertilizer technologies is discussed in Organic Amendments and Waste Management sections. Anaerobic digestion of straw produces biogas, which could be used to produce electrical power or used as a fuel replacement for natural gas. Digestate produced by AD has a high concentration of nutrients and can be processed into bio-fertilizer. Storage of stable organic carbon resulting from bio-fertilizer application leads to further GHG emission offset by soil carbon sequestration. This has been previously discussed.

Another option is to use available straw from cereal crops directly as source of green energy, including direct combustion for power generation and processing through gasification technologies. Combustion of straw generates green power and offsets GHG emissions. Most of the nitrogen and sulfur in the straw, and a large portion of phosphorus, however, are lost to the atmosphere, generating air pollution by SO_x and NO_x. These are not considered in this assessment.

In contrast to fossil fuel products, biomass fuels including straw can be highly variable in terms of moisture content, heating value, and availability. In particular, heating value of biomass is greatly influenced by moisture content. The assessment below is therefore performed at two assumed moisture contents, 45% for wet and 15% for dry straws. Both AD and direct combustion require harvesting and transportation of straw to localized facilities. Emissions from these activities make up a small fraction of the total emission, smaller than the uncertainties in the conversion coefficients used in the assessment. As such they are not included in the assessment. The main activities considered in this section are:

- Anaerobic decomposition of agricultural materials,
- Diversion of biomass to energy from biomass combustion facility

Quantification: Theoretical Mitigation Potential

Anaerobic Digestion and BioFertilizers:

An average of 15 Mt/yr of straw could produce 9.9 TWh of electrical power with AD technology, resulting in a mitigation potential of 2.0 Mt CO_2e/yr. The resulting bio-fertilizer contains 3.75 Mt of organic carbon and 75,000 t of nitrogen. Displacing 75,000 t of chemical fertilizer results in *0.2 Mt CO_2e/yr* of emission offsets for fertilizer production alone. Lower N_2O emission from bio-fertilizer compared to chemical fertilizer could lead to further reductions. The IPCC Tier 1 emission factor for N_2O is 1% of fertilizer N applied. The N_2O emission from bio-fertilizer is lower than chemical fertilizer. Assuming 50% reduction, replacing 75,000 t of inorganic N results in a reduction of 0.39 Mt CO_2e/yr. Application of organic fertilizer, assuming similar efficiency as manure, leads to soil carbon sequestration of **3.03 Mt CO_2e/yr.**

Direct combustion:

Energy value of biomass, including straw, is strongly influenced by moisture content. Heating value of straw as fuel is negatively related to its moisture content. Average efficiency of electrical energy generation in Canada, using “wood and others” as fuel, is 34% (OEE, 2010). Assuming 15% water, 15 Mt of straw could be converted to 27.7 TWh of electrical energy, offsetting GHG emissions by 5.55 Mt CO_2e/yr. At 45% water content, the electrical generation is 25.5 TWh, with an emission offset of **5.1 Mt CO_2e/yr**. Higher values of emission offset could be achieved if the waste heat from power generation could be utilized. This potential is not included in the assessment.

Comparison:

Total GHG emission offset potential for the AD+bio-fertilizer option is 5.5 Mt CO_2e/yr, compared to 5.1-5.6 Mt CO_2e/yr for direct combustion. Overall, there is little difference in carbon emission offsets of the two options. Economics, other environmental considerations, such as SO_x and NO_x emissions, and availability of other input stocks could be the driving variables for selection between these two options.

Constrained Potential: Market, Policy and Technical Overlay

Current market:

AD option is discussed in Waste Management and Organic Amendment sections. For both options, capital cost could be a major barrier. Proven technologies exist for both options.

A reliable, low-cost, long-term supply of biomass fuel is essential to the successful operation of biomass energy facilities. Governments can provide the right economic environment for development of biomass energy industry through financial incentives and through development of institutions such as a carbon market.

Risks:

Uncertainty in the availability of straw biomass is an important risk factor. Industrial facilities require a steady supply of feedstock. Available plant biomass, however, varies widely from year to year depending on climate, market conditions, changes in cultivation practice, and phases of crop rotation. Estimates of available straw yield for the three Prairies Provinces show as much as one order of magnitude inter-annual fluctuations. Willingness of producers to sell straw is also not certain. One survey found only 1 in 4 famers are willing to consider selling straw. Unlike AD facilities, direct combustion requires a centralized facility that will increase collection difficulties. The ash also requires disposal in some cases, which will increase operational costs. Constrained potential is based on the readily available materials.

Table 46. Categorical Assessment of Biomass Combustion.

	Biomass Combustion	***Explanation/Deviation from criteria outlined in section 2.2.2***
Speed	4	Requires centralized facility
Magnitude	5	It has (>5Mt/yr) potential
Scale	5	Capital cost impairing the market uptake
R&D Stage	6	Mature technology
Total (of 21)	**20**	

Operationalizing the Sub-Wedge

- A comparative life-cycle assessment with AD process is required to make a reasonable recommendation to industry.
- Cost and benefit analysis comparing biomass combustion with other waste management options is needed.

3.4 Material Switching

3.4.1 Biofertilizers

Global production of fertilizers is responsible for 1.2% of the total greenhouse gas emission in 1997 (Kongshaug Agri, 1998). A significant of emission reduction was achieved in the last decade. By 2008, GHG emission from this sector represented 0.93% of the total global emission (IFA 2009). Canadian synthetic fertilizer production, represented by ammonia production, is responsible for 1.1% of the national GHG emissions (Environment Canada 2010). Canadian agricultural fertilizer market size and GHG emissions in the period between June 2009 and July 2010 are summarized in Table 47.

Table 47. Canadian agricultural synthetic fertilizer market and GHG emissions from production only (2009-2010)

	Market	**Emission factor**[1]	**GHG**
Fertilizer	**t/yr**	**t CO_2e/t nutrient**	**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 factor is based on estimates form the International Fertilizer Industry Association 2009.

While synthetic nitrogen fertilizer represents 68% of total Canadian fertilizer usage, it contributes over 97% of GHG emissions from this sector. Therefore discussions in this section will focus on the GHG emission implications of switching from synthetic nitrogen fertilizer to bio-fertilizer, defined as plant nutrients, particularly nitrogen, phosphorus and potassium of biological origin, either in organic form or loosely absorbed by organic materials. When applied to soils, these plant nutrients will be slowly released to the soil environment for plant growth.

Mechanism and Methods for Mitigation

The overall level of agricultural greenhouse gas emission will likely continue to rise for the foreseeable future as agricultural production expands to keep pace with growing food, feed, fiber and bioenergy demands. This is evident in the jump in Canadian synthetic nitrogen fertilizer consumption from 1.2 Mt to 1.9 Mt from 1990 to 2008. Increasing efficiencies in energy and fertilizer inputs is critical for keeping overall emissions as low as possible and for reducing 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 biowastes, can be one of the strategies for keeping agricultural GHG emissions low. Its benefits include reducing the need for chemical fertilizers, improving soil quality and productivity, and reducing energy intensity of tillage and other soil management practices.

Figure 17 illustrates the nitrogen cycle in agriculture. A major source of nitrogen supply is through industrial fixation, which is an energy intensive process as indicated in Table 44. Conventional agricultural practices focus on using synthetic nitrogen fertilizer for crop production. Livestock operation concentrates nutrients at feedlot operation areas primarily in the form of manure. The value of animal manure as a source of plant nutrients and in improving soil quality is generally recognized. However, because of its high moisture content, low nutrient concentration, low density and large volume, the cost of manure application per unit of plant-required nutrient is relatively high, limiting direct land application of manure to ≈10—80 km radius from the source, depending on cropping systems, land productivity and properties of manure, particularly the nutrient value (Araji and Stodick 1990).

This creates large scale imbalances in nutrient distribution: a one-direction nutrient flow towards urban centers and concentrated livestock operations in the forms of feeds and food stuffs, often over long distances, creates local nutrient excess in the forms of manures and other waste products, and associated environmental problems. In areas where crop products are exported, depletion in soil nutrient reserves must be compensated with fertilizer. Attention has largely been concentrated on the two ends of this nutrient imbalance: synthetic fertilizer and crop production on the one hand and nutrient excess and environmental degradation on the other.

Relatively little has been done with regard to rebalancing the nutrient distribution by creating nutrient flows in the other direction. The long-term implications of this imbalance in nutrient distribution will be felt more for nutrients that rely on finite, non-renewable natural resources, such as phosphorus. 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.

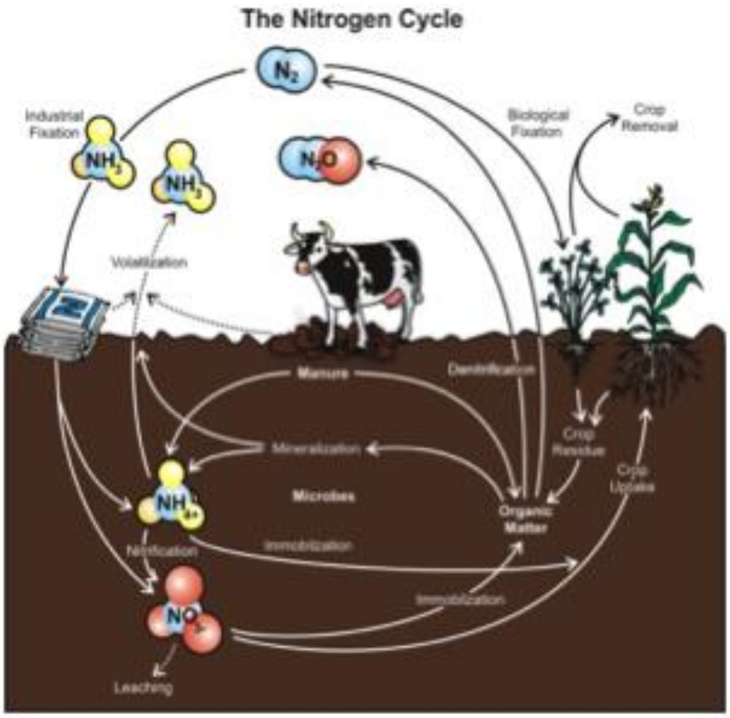


Figure 16. Illustration of the Nitrogen Cycle in agricultural soils.

Recycling nitrogen and improving nitrogen use efficiency by crops are two important strategies to minimize direct emissions from synthetic nitrogen fertilizer and at the same time contribute to the creation or expansion and maintenance of carbon sinks (IFA 2009).

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. There is a need for bio-fertilizer to improve the quality of prairie soils. Farmers are gradually accepting the fact that bio-fertilizer enhances soil quality besides providing essential nutrients for crops. Full benefits and economic value of bio-fertilizer for soil quality and fertility need to be understood and recognized by policy makers and farming industry. Of course, research and demonstration efforts are needed to establish this market.

Although a large body of research literature has been generated in the past, a comprehensive approach to quantifying bio-fertilizer’s potential for replacing inorganic fertilizer and enhancing soil carbon sequestration, particularly the cost/benefit of bio-fertilizers in addressing the imbalance of nutrient distribution is needed.

Quantification: Theoretical Mitigation Potential

Two major sources of nutrients for bio-fertilizer are:

1) livestock manure
2) nitrogen fixing plants, e.g. alfalfa, that can be produced effectively on marginal land.

Table 50 summarizes the potential feedstock for producing bio-fertilizer according to the data by:

Livestock manure:
Table 48 also summarizes quantities of manure that are generated by animals raised at feedlots, which can be most effectively collected and processed (Statistics Canada 2010).

Table 48. Manure generated in the Canadian livestock industry that can be collected and processed for bio-fertilizer production.

Animal	Total animal[1]	Dry manure[2,3]	Total manure	Total N
year 2010	X 1000 head	kg/head, day	t/yr	t/yr
Beef cow	7,359	3.5	9,401,250	282,038
Dairy cow	980	8.2	2,933,140	87,994
Hog	11,850	0.33	1,427,333	42,820
Poultry/egg	49,650	0.027	293,830	8,815
Total			14,055,553	421,667

[1] Statistic Canada 2010 census; [2]ASAE 2005; [3] average of 3% N content in manure was used (Alberta biowaste inventory, to be published in 2011).

Legumes:
Canada has over 37 million hectares of marginal land (Milbrandt and Ocerend, 2009) with a potential biomass yield of ≈2.6 t/ha. If one assumes that 15% of these lands can be used to grow legumes (represented by alfalfa), it can produce 15 Mt of biomass annually. With average nitrogen content of 2.9% (in alfalfa), this will result in a total of 425,000 t N/yr.

To grow, harvest, and process this biomass is energy intensive. A plausible scenario is to use this biomass for livestock production, converting it into animal products and 5 Mt of manure (dry), which can be used to produce 3.3 TWh of renewable power, offsetting 0.66 Mt CO_2e/yr of GHG emission, and bio-fertilizer containing 360,000 ton of nitrogen.

Combining nitrogen in collectable manure and legumes produced on Canadian marginal land, results in a total of 780, 000 t N annually in bio-fertilizer, which has a potential of reducing GHG emissions by 416,000 Mt/yr. Bio-fertilizer potential is summarized in Table 51.

Table 49. Bio-fertilizer potential from Canadian livestock manure and marginal land legume production.

Baseline (synthetic N fertilizer)

Assumptions	**GHG emission/mitigation potential**
1. N-fertilizer production only	5 Mt CO_2e/yr emission
2. 20008 usage: 1.9 Mt	
3. Emission factor: 2.67 kgCO_2e/kg N	
Bio-fertilizer	
1. Livestock manure: N content in manure = 3%	1. From manure offset: 1.1 CO_2e Mt/yr
2. 15% of Canadian marginal can grow alfalfa	
3. Alfalfa yield =2.6 t/ha [1]	2. From Alfalfa offset: 1.3 CO_2e Mt/ye
4. N content in alfalfa = 2.9%	
5. Energy requirement for producing bio-fertilizer will be offset by harvesting energy from processing these materials through AD process	
Total (from production)	***2.5 CO_2e Mt/yr***
Additional potential from crop production	***5.5 CO_2e Mt/yr***

[1] biomass yield was used for this calculation is from Milbrandt and Ocerend (2009), which is an average estimation for all available Canadian marginal land. The yield can be significantly higher, such as reclaimed disturbed land for oil sand operation.

This calculation does not include the N_2O emission resulted from fertilizer application from agricultural land. Gregorich et al., (2005) reported that the N_2O emission solid manure application is only 35% of from the land associated with synthetic N fertilizer application. Thus, if this potential is considered in this calculation, it will result in additional ***5.5 CO_2e Mt/yr.***

Constrained Potential: Market, Policy and Technical Overlay

Current market:

The current market is limited to existing organic farm operations, which is less than 0.9% of Canadian farmland (Conference Board of Canada, 2006). It requires government policy to promote the switch. This potential market can be expended if municipal organic waste is processed through either compost technology or anaerobic digestion.

Risks:

Major risk for this switch is that it will depend on the process used. It may require extra energy to produce/process the raw materials (both manure and legume). If biogas technology is used to process these materials, a net gain of energy will be produced, In addition, this technology provides a platform for concentrating nutrients in bio-fertilizer products. (please refer to the waste management section). One may argue that the manure is already used as a fertilizer source through land application. Regulatory constraints around concentrated livestock operations limit producer's ability to fully utilize manure's nutrient value since they are concentrated to the limited area. Constrained potential is based on the assumption of that less than 50% of theoretical potential will be realized when the quantification protocol is in place.

Table 50. Categorical Assessment of Biofertilizers.

	Bio-fertilizer	***Explanation/Deviation from criteria outlined in section 2.2.2***
Speed	5	Many field research sites have been operated
Magnitude	3	It has 2.5Mt/yr potential
Scale	3	There is no incentive to make the switch and requires quantification procedures
R&D Stage	4	Requires commercial demonstration
Total (of 21)	**15**	

Co-benefits:

- Increasing soil fertility: Bio-based fertilizer contains balanced micronutrients required for plant growth besides nitrogen, phosphorus and potassium.
- Improving soil structure: The organic matter, in humus form, provides basic binding agent for soil aggregates, which are basic elements that build an ideal soil structure; organic matter also provides a substrate for growth and functioning of soil microorganisms.
- Reducing nutrient loss: Over 50% of nitrogen and phosphorus in bio-fertilizer are in organic forms. These nutrients are released during the mineralization process, a microbe-regulated process. Although reliable data are not currently available in the

literature, researchers are generally in agreement that the nutrient use efficiency of plants grown with bio-fertilizer is greater than that of plants grown with chemical fertilizers.

- Increasing soil organic matter: While the soil organic matter has been recognized as a carbon sink, it also improves soil quality through resistance to soil erosion, increased soil buffering capacity, which in turn increases the soil's capability to resist chemical contamination or ability de-contaminate, increased soil water infiltration and retention, therefore can enhance crop production.

Operationalizing the Sub-Wedge

- May require incentives for switching to bio-fertilizer
- Develop a comprehensive quantification protocol
- Requires a demonstration site for growing legume on marginal lands for proven carbon benefits
- Regional nutrient balances to determine sending and receiving zones of nutrients and biofertilizers

3.4.2 Forest Sustainability – Building Material Switching

The primary forest-based material switching opportunity is to replace non-renewable material such as plastics, metal or cement with wood products. Material switching is contingent on recognizing carbon storage in harvested wood products (HWP) contrary to International Panel on Climate Change (IPCC) protocol. Furthermore, forest product based material switching must be based on other uses besides wood products in single-family residential construction, which is already effectively saturated with wood products use (McKeever *et al*, 2006). Canada is a large net exporter of forest products – 80% of Canada's production is exported to the United States (Dufour, 2002) – therefore any baselines or quantification of material switching should be based on the United States market if they are to achieve a meaningful level of greenhouse gas reduction.

Quantification of storage in harvested wood products is a crucial first step in determining the GHG mitigation potential of using forest products to displace non-renewable building materials. Skog (2008) estimated that storage in HWP in the United States of America represented an annual removal of 110 to 161 Mt of CO_2e from the atmosphere – representing 17 to 25% of carbon removals from forests. Skog *ibid*, Skog and Nicholson (2000) and Ryan *et al* (2010) suggest that storage in HWP accrue at the point of end use, not at the point of production. They further make the case that carbon storage in HWP should only be acceptable when a country's carbon stock balance in forests is increasing. (See the section on forest management for carbon storage.) Chen *et al* (2008) used FORCARB-ON (a provincial forest carbon model for Ontario) to predict an increase in storage in HWP (primarily as sawn lumber, veneer and composites) of 4.4 Mt/year of CO_2e between 2001 and 2100. At present, no projections of storage in HWP have been made for Alberta or for Canada as a whole. Appendix 1 presents an overview of storage in HWP.

Mechanism and Methods for Mitigation

Forest products based material switching depends on the production and deployment of wood-based materials, resulting in less greenhouse gas emission than production and deployment of alternative building materials. To quantify material switching, a displacement or expansion factor is necessary to determine the difference in emission profile between forest products. (See Appendix 1 for a detailed review of expansion and displacement factors from the literature.) For purposes of this analysis the modal displacement factor of 2 was used. A displacement factor of 2 means each tonne of forest products used in building construction will displace 2 tonnes of CO_2e in emissions associated with "conventional" building products (generally concrete and/or steel).

At present, adoption of forest products to replace concrete and steel is hampered by a number of factors, including regulation, cost of materials, and cost of installation. Regulatory constraints are primarily fire codes and structural requirements. These constraints limit use of wood in taller (greater than three story) buildings and in locations with high fire spread potential. McKeever *et al, ibid* address both regulatory concerns by identifying a specific structure well-suited to material switching with wood: low rise, non-residential construction. They identified an annual potential for 4.9 billion board foot equivalent switch to wood within current building codes, and a potential for 8.6 billion board foot equivalent switch to wood with changes to building codes, in construction of low rise non-residential buildings. Envisioned changes to building codes included: increasing area and height limits through addition of automatic fire protection sprinklers, use of firewalls to subdivide large buildings, and provision for substantial frontage to the building to enable easy firefighting access. In a more recent paper (2008) McKeever showed a modest 770 million board feet (fbm) of 29% increase in wood use in non-residential buildings. This increase was mostly attributable to increased construction as wood use increased from 9.2% to 11% of total construction.

Considerable effort has been devoted to examining the potential of material switching using wood products. Sathre and O'Connor (2008) reviewed 48 papers (from Canada, UK and Scandinavia) that examined use of wood products to displace non-renewable materials. The potential of wood products to replace other material was assessed in a ***meta-analysis (drawn from 20 of the papers)*** that found displacement factors ranging from -2.3 to 15.0, with most falling between 1.0 and 3.0 and an average displacement factor of 2.0. Valsta *et al* (2008) linked forest management and material switching to examine two case studies using ***life-cycle analyses***, finding displacement factors of 1.3 and 2.0 for multi-story apartment buildings. Heath *et al* (2010) used ***an encompassing full life-cycle analysis of forest management and forest products*** in mitigating greenhouse gas emissions to estimate 7.2 Mt CO_2e of avoided emissions in 2004-2005 attributable to use of wood as a building material.

Quantification: Theoretical Mitigation Potential

Quantification combines information about the magnitude of individual opportunities (displacement factors) with information about scale to estimate overall magnitude of the opportunity. Unfortunately, there is a dearth of information about scale – McKeever (2008 *ibid*) and McKeever *et al* (2006 *ibid*) are the only references that quantitatively assess scale of the opportunity. These papers suggest a theoretical opportunity of 7 (2008) to 8.6 billion fbm and a current opportunity (constrained by building current building codes) of 4.9 billion fbm. No similar data for the Canadian construction market exists. Given that 80% of Canada's lumber production is sold in the United States the American opportunity was "calibrated" to Canadian product flow:

Canadian proportion of US lumber market = 9.4/34.5 billion fbm = 0.2724

Current building codes 4.9 billion board feet = 11.564 million m^3
Revised building codes 7.0 billion board feet = 16.520 million m^3
Realized use (2008 data) = 3.4 billion board feet = 8.0 million m^3

Canadian wood product proportion = 3.15 million m^3 (current regulation)
= 4.50 million m^3 (revised regulations)
= 2.19 million m^3 (realized to determine net)

GHG displacement per m^3 = 0.75 tonnes (Eriksson *et al* 2007)
Theoretical potential emission reductions = **4.14 Mt** CO_2e reduction (**2.5 Mt** net)
Current potential emission reductions = **2.35** Mt CO_2e reduction (**0.7 Mt** net)
Or
GHG displacement factor = 2 (Sathre and O'Connor 2008, Ryan *et al* 2010)
Wood mass = 4.63 – 8.12 million tonnes

Theoretical potential emission reductions = **4.42 Mt** CO_2e reduction (**2.8 Mt** net)
Current potential emission reductions = **2.52 Mt** CO_2e Mt reduction (**0.9 Mt** net)

Constrained Potential: Market, Policy and Technical Overlay

A number of potentially critical barriers to material switching must be addressed:

- Determine where in the value chain ownership of material switching mitigation value accrues. Skog (2008) suggests only countries with rising forest carbon inventories would be able to include storage in HWP in their reporting inventory; he includes storage in imported HWP in the United States inventory, as do Ryan *et al* (2010).

- The need for building code changes to align with the International Building Code to facilitate material switching and its quantification (McKeever *et al*, 2006).

- Business case evaluation of material switching must be undertaken to determine if material switching is cost effective. This evaluation should include any revenues or values arising from GHG emission mitigation outcomes

- Achieving success in material switching will take a considerable length of time.

The constrained potential of approximately 1/3 of theoretical potential represents the amount of material switching that might take place in Canada or is currently taking place in the United States. This pessimistic view is taken pending trade negotiations with the United States over ownership of GHG mitigation potential associated with use of forest products. The US has clearly taken the position that mitigation potential associated with product deployment resides with the user of harvested wood products not with the producer. Until this has been resolved it would be optimistic to expect to accrue that mitigation potential to Canada.

Table 51. Categorical evaluation of forest products based material switching mitigation opportunity.

	Building Material Switching	***Explanation/Deviation from criteria outlined in section 2.2.2***
Speed	3	Time requiremd to amend regulation, challenges with ownership (user vs. producer)

Magnitude	3	Realized outcome (approx 1 - 1.25 Mt)
Scale	3	Many locations, contractors, suppliers, therefore verification will be challenging
R&D Stage	5	Know this will work. Cost:Benefit assessment and incenting market change required.
Total (of 21)	**14**	

Operationalizing the Sub-Wedge

- Clarification that carbon storage in HWP is mitigation.
- Establish that "ownership" of mitigation/sequestration resides with producers not consumers of HWP.
- Change building code(s) for low-rise non-residential buildings in United States to align with International Building Code Standards.

3.4.3 Bio-based materials

For the purposes of this section, the substitutions with bio-based is considered to include the substitution of bio-based materials for petrochemicals and the alternative use of residual agricultural fibres in other materials. A summary of the variety of options available for Canada is summarized in a joint Pollution Probe and BIOCAP Canada Foundation report (2004)

Petrochemicals that can be substituted are summarized in the following table taken from a WWF report (WWF Denmark 2009).

Table 52. Petrochemicals that can be substituted.

Reference Biochemical	Bio-based Chemical	Maximum Potential Substitution
HDPE (high density polyethylene)	PHA (plyhydroxyalkaonates)	100%
PTT (polytrimethylene terephtalate), Nylon 6	PTT from 1,3 propanediol	100%
PET (polyethylene terephtalate); PS (polystyrene)	PLA (poly lactic acid)	100%
Ethyl lactate	Ethyl lactate	100%
Ethylene	Ethylene	100%

Maleic anhydride	Succinic acid	85%
Adipic acid	Adipic acid	100%
Acetic acid	Acetic acid	25%
n-butanol	n-butanol	90%

The report discusses the pathways for achieving these substitutions. The key feedstocks are categorized as starch, hemicelluloses, cellulose, lignin, bio-oil and protein. From the analysis, the report suggests a global emission reduction potential of between 87 and 116 Mt/yr by 2020.

The alternative uses of agricultural fibres extend across a wide and expanding range of applications. These applications are grouped as follows where numerous specific fibre/application combinations are possible (BioProducts Canada and Industry Canada 2004).

- Textiles (including industrial textiles)
- Building and construction materials (including insulation)
- Composites (including automotive and aerospace)
- Reclamation/horticulture
- Papers and coatings
- Packaging and consumer products

Biofuel production and use are not included as part of this analysis, as per the limitation to the overall scope of work.

Mechanism and Methodology for Mitigation

In all cases, the carbon in the feedstock is sequestered in the materials through period of use (and re-use) of the material. This differs from biofuels, where the carbon is returned to the atmosphere upon combustion. However, for some materials, this carbon could then be released upon aerobic or anaerobic decomposition of the material upon disposal. This may apply to the materials and or the waste materials created during manufacturing of the bioproducts themselves.

In addition, there can be indirect GHG emission impacts from the use of bioproducts. There may be decreasing emissions associated with the fossil fuels previously used as feedstocks for petrochemicals. However, there may be increased net emissions from land-use change and/or increased use of fertilizers to increase yield.

There are currently no quantification protocols that specifically target emission reductions from biomaterial substitutions. The forestry protocols that address harvested wood products represent the closest approximation to how bio-material substitutions could be handled. Given the processing involved, it is likely that individual life cycle assessments would be required to estimate emission reduction potentials.

Quantification: Theoretical Mitigation Potential

Baseline Assumptions and Data Sources: Biomaterials

The Bioproducts Roadmap (BioProducts Canada and Industry Canada 2004) reports that the entire petrochemical/biochemical market is estimated at 30 million kg/yr. A USDA report on bio-based products (USDA 2008) suggested that in 2008, US market penetration for bio-based products could reach 20% by 2020, up from the current estimate of approximately 5%.

The potential feedstock in Canada for use in bioproducts was estimated by the BIOCAP Canada Foundation (Wood and Layzell 2003) as approximately 60 million tonnes from both agriculture and forestry. This is said to represent approximately 40% of the total biomass harvest. Assuming no land-use change and no related change in the management of forest/agricultural systems, all of the carbon (45% to 50% by mass (Bioenergy Feedstock Information Network 2005)) in these feedstocks is available for sequestration. Further, an assumption of 80% feedstock use efficiency would be applied to account for wastage in processing.

Mitigation Assumptions and Activities:

For petrochemicals from biomaterial feedstocks, it is assumed that the net GHG benefit would be neutral as the carbon would be available to return to the atmosphere within in a short period. This does not account for the indirect benefits from the avoided processing of the fossil fuel feedstocks, and the detriments from land use change and changing cropping practices (i.e. fertilizer). Given the lack of available information, this appears reasonable.

The sequestration of carbon from within the available biomass used for bio-material substitution is calculated as follows:

Feedstock: 60 million tonnes per year
Use Efficiency: 80%
% Carbon: 45% - 50%
Carbon to CO_2e: 44/12
Total Sequestration: 79 to 88 Mt CO_2e/yr

Full lifecycle GHG assessments need to be completed for each set of bioproducts to get a better sense of the emission reduction potential.

Constrained Potential: Market, Policy and Technical Overlay

There are a number of potential constraints on the use of biomaterials. Each of these constraints, highlighted in the Innovation Roadmap report (BioProducts Canada and Industry Canada 2004), are summarized in the following table relative to each of the mitigation activities:

Availability of Feedstocks: The distribution of feedstocks is spread across Canada and varies season-to-season with the core agricultural production. As such, there will be difficulty in optimizing use of the feedstock at a scale that would cover all available feedstocks

Market Uptake: Two key factors are identified in limiting market uptake: public demand and lack of clear standards in some sectors. The lack of public demand is suggested to be a result of insufficient market awareness.

Speed of Innovation: It will take significant innovation to increase demand for the biomaterials. This will require financing, supporting policy, government support, and linking/networking services.

Table 53. Categorical evaluation of biomaterials.

	Biomaterial Used in Petrochemicals	***Biomaterial Used in Other Materials***	***Explanation/Deviation from criteria outlined in section 2.2.2***
Speed	5	5	Already seeing numerous research and product development activities
Magnitude	1	5	Significant opportunity depending on how sequestration of carbon in biomaterials is handled.
Scale	3	1	Petrochemicals are scalable with difficulty given limited number of producers. Biomaterial production is likely to be fragmented and dispersed across locations where feedstock is available

R&D Stage	4	2	Range of R&D stages across the variety of products. Scores given are indicative.
Total (of 21)	**13**	**13**	

Taking these constraining factors into consideration, the potential for emission reductions from the use of biomaterial in other materials is likely to be closer to 10% to 20% of the potential. This would sum to 8 to 16 Mt of CO_2e/yr.

Operationalizing the Sub-Wedge

To assist in operationalizing this sub-wedge, the existing Roadmap suggests the following[47] :

- Improved coordination among market participants.
- Technology development and innovation.
- Government support of research and development.
- Increased focus on awareness and market development.
- Development of case studies with full GHG lifecycle profiles.
- Support development and access to international markets.

3.5 Strategic Carbon Management

3.5.1 Landscape Scale Carbon Management

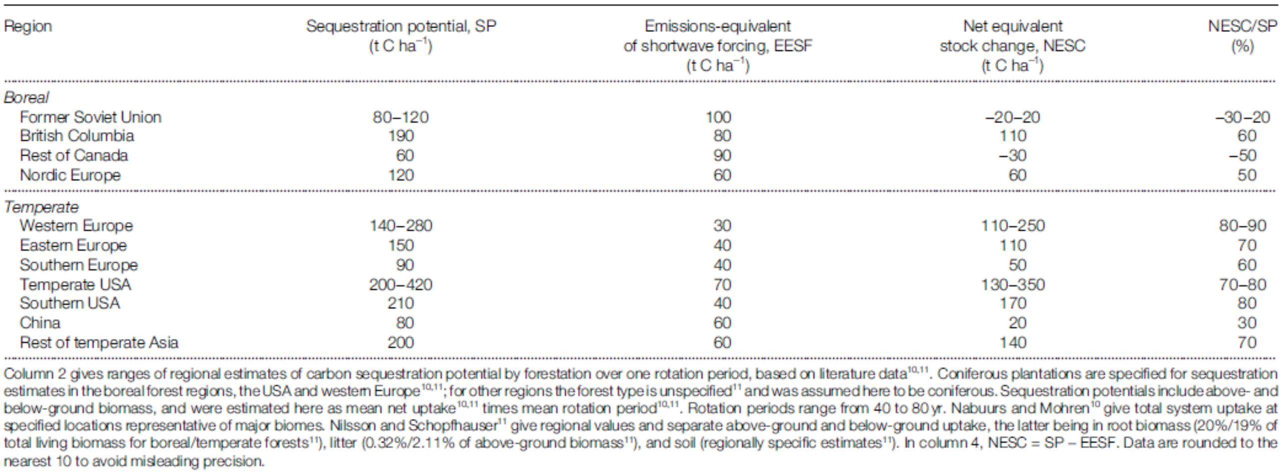
Forest management in Canada is currently evolving from simply sustaining fibre flow to wood processing facilities to one of managing ecosystems for a wide array of ecosystem functions and services; wherein wood supply to mills is only one of a stream of ecological services. The forest industry is struggling to adapt to the demands this new management paradigm places on it during a time of unprecedentedly low prices. The forest industry and forest regulators must recognize that the emerging ecosystem services management paradigm is ideally suited to participating in the carbon economy.

In particular, forest carbon management will require forest managers to integrate several of the sub-wedges discussed in the Sequestration and Bio-fuels sections with broader, landscape-scale ecosystem components. Included in these broader scale components are changes in albedo and forest disturbance regime. Both albedo and forest disturbance regime are likely to be highly responsive to climate change. They will be affected by climate change and will, in turn, affect climate change. There is considerable concern that these landscape-scale factors are likely to act as positive feedback mechanisms to climate change. Therefore, prior to discussing landscape-scale carbon management a brief discussion of albedo and disturbance is warranted

Albedo and Climate Change

Albedo plays a significant role in how forested landscapes interact with climate change. Betts (2000) brought attention to the potential for reduced albedo of forested landscapes to overwhelm the benefits of carbon capture. He suggests that replacing agricultural lands at high latitudes with forests (afforestation) can result in an exacerbation of climate change due to reductions in albedo, causing positive climate forcing greater than the negative climate forcing accruing to carbon capture by the young forests. Table 54 (taken from Betts) summarizes outcomes of his modelled comparison of changes in albedo and changes in carbon capture. Betts suggests afforestation in much of Canada might result in net losses in carbon stocks equivalent to 50% of the carbon sequestered through afforestation.

Table 54. Balance in radiative forcing between changes in albedo and carbon capture by afforestation (from Betts, 2000)



Region	Sequestration potential, SP (t C ha^{-1})	Emissions-equivalent of shortwave forcing, EESF (t C ha^{-1})	Net equivalent stock change, NESC (t C ha^{-1})	NESC/SP (%)
Boreal				
Former Soviet Union	80–120	100	−20–20	−30–20
British Columbia	190	80	110	60
Rest of Canada	60	90	−30	−50
Nordic Europe	120	60	60	50
Temperate				
Western Europe	140–280	30	110–250	80–90
Eastern Europe	150	40	110	70
Southern Europe	90	40	50	60
Temperate USA	200–420	70	130–350	70–80
Southern USA	210	40	170	80
China	80	60	20	30
Rest of temperate Asia	200	60	140	70

Column 2 gives ranges of regional estimates of carbon sequestration potential by forestation over one rotation period, based on literature data[10,11]. Coniferous plantations are specified for sequestration estimates in the boreal forest regions, the USA and western Europe[10,11]; for other regions the forest type is unspecified[11] and was assumed here to be coniferous. Sequestration potentials include above- and below-ground biomass, and were estimated here as mean net uptake[10,11] times mean rotation period[10,11]. Rotation periods range from 40 to 80 yr. Nabuurs and Mohren[10] give total system uptake at specified locations representative of major biomes. Nilsson and Schopfhauser[11] give regional values and separate above-ground and below-ground uptake, the latter being in root biomass (20%/19% of total living biomass for boreal/temperate forests[11]), litter (0.32%/2.11% of above-ground biomass[11]), and soil (regionally specific estimates[11]). In column 4, NESC = SP – EESF. Data are rounded to the nearest 10 to avoid misleading precision.

Bird *et al* (2008) modeled a broad array of factors to more closely examine the interaction between albedo and carbon sequestration by forests; they examined the interaction between surface albedo, solar radiation, latitude, cloud cover, and carbon sequestration. They concluded reductions in albedo associated with afforestation reduced carbon sequestration by 30%, and this was not sufficient to render afforestation for carbon capture ineffective. They further suggested it might be possible to optimize carbon sequestration and albedo effects through density management. Interestingly, Bird *et al, op cit* did not point out that Betts was addressing afforestation and that his comments are moot when considering routine reforestation of harvested forests. Using the Siberian BioClimatic Model, Tchebakova *et al* (2010) found albedo played a critical role in climate change. Their modeling outcomes suggested that changes in albedo due to forest advance onto the tundra is likely to result in increased climatic forcing; whilst increases in albedo arising from steppe advancement into current forest landscapes is likely to result in decreased climatic forcing. They did not attempt to quantify a net balance in albedo effects on climatic forcing. Thompson *et al* (2009) make a sensible case that albedo and carbon capture need to both be considered in modeling expected climate change lest the potential of carbon-capture to mitigate climate change be overestimated. Chapin *et al* (2010) speculate that albedo in Alaska's boreal forest is likely to decline despite a change toward deciduous composition, due to a shorter winter season resulting in a reduction in duration of snow cover.

Forest disturbance regime

Changes in Wildfire: The largest effect of climate change in northern forests might be changes in the disturbance regime. Flannigan *et al* (2005) identify several fire severity factors likely to increase with climate change: more severe fire weather, more area burned, more ignitions, and a longer fire season. These factors are likely to increase area burned by 74% (Canadian General Climatic Model (GCM)) to 118% (Hadley GCM) by the end of the 21st century. Wotton *et al* (2010) arrive at a similar range of increase in fire occurrence (75% (Canadian GCM) to 140% (Hadley GCM)). This magnitude of increase coupled with the potential for large forest fires to release substantial quantities of GHGs (mostly CO_2, but also CH_4, long-chain hydrocarbons, and carbon particulates) suggests changes in disturbance are likely to substantially change forest carbon fluxes. Amiro *et al* (2001) found that Canadian wildfires released an average of 27Mt of carbon (99 Mt CO_2e) annually between 1959 and 1999; in severe fire years this may exceed 100 Mt of carbon (370 Mt CO_2e). Large, severe wildfires are likely to generate positive climatic forcing through sustained release of carbon dioxide from decomposition of fire-killed trees not salvaged for commercial use and through reductions in albedo due to darkening of the soil surface by char. (It might be argued that winter albedo values will increase for a period due to loss of canopy shading with a resultant increase in snow exposure.)

Johnstone *et al* (2010) speculate that while climate change (in Alaska) may increase susceptibility to forest fire disturbance at the stand level, it may in fact reduce fire susceptibility at the landscape level. They contend climate change may stimulate a change to a more deciduous dominated landscape which is generally more resistant to ignition than the current conifer dominated landscape.

Changes in Forest Insects: Kurz *et al* (2008) modelled the recent (and on-going) mountain pine beetle (MPB) outbreak in British Columbia applying the CBM-CFS 3 to project changes in carbon flux across 374,000 km^2 of forest using a range of outbreak induced mortality values. The authors acknowledge that salvage harvest would result in carbon storage in harvested wood products and in emission offset opportunities arising from biomass to energy, but did not address this in their modelling. Their results should thus be considered changes in carbon stock, not releases to the atmosphere. They found the study area changed from a small net sink prior to the outbreak to a large net source of carbon, with an average release of carbon (from stock) of 36 g/m^2/year (990 Mt CO_2e total over the modeled area) over the 20-year course of the outbreak. Using the more conservative British Columbia Ministry of Forests estimate of a total outbreak area of 84,000 km^2, a total emission value of 250 Mt CO_2e is estimated. British Columbia Ministry of Forests, Mines and Lands data shows that approximately 113.6 Mt of wood fibre was salvaged for use in sawmills and pulpmills during the first 5 years of the outbreak. Suitability of mountain pine beetle killed wood for use in mills diminishes with time, so these data should be extrapolated with caution. Treating this value as 2/3 of total salvage to conventional forest products, using a mill efficiency of 270 board feet per m^3 and assuming ½ the sawmill "waste" goes to paper and the other half goes to waste, the following estimate of storage in HWP can be estimated:

Raw CO_2 *= 113.6mm m3 X 0.40 density X 50% carbon X 44/16 carbon to* CO_2
X 3/2
= 125 mm tonnes
Net CO_2 *Storage = (125 mm tonnes X (270/424) X .75) +*
*(125 mm tonnes X 0.5 X (154/424)*0.07)*
= 60 Mt + 3 Mt
=63 Mt

In addition, a total of 400,000 tonnes per year of MPB-killed trees are being salvaged for use as biomass-to-energy fuels via wood pellets. Assuming 80% energy efficiency in harvesting and processing and a project life of 10 years before dead wood becomes unsuitable for conversion to pellets; this translates into a total biomass-to-energy conversion of:

Biomass-to-energy conversion = 1,000,000 X 0.8 X 10
= 8 Mt
Total reduction in CO_2***e = 71 Mt or between 7 and 28%***

This gives a net predicted CO_2e emission of between 180 and 990 Mt.

Kurz *et al* 2008 identify numerous potential insect disturbances that should be considered when modeling forest carbon interactions – these include outbreaks of spruce beetle, eastern spruce budworm, and forest tent caterpillar.

Net effect of changes in forest disturbance: Kurz et al (2008) examined the potential for increases in boreal forest ecosystem productivity to offset carbon losses arising from increased disturbance. They used the CBM-CFS-3 to determine levels of change in forest growth needed to offset carbon release from stocks arising from wildfire (using estimates from Flannigan et al op cit) and other disturbances (particularly insect outbreaks). The authors modelled carbon removals from stock (i.e. they did not include storage in HWP or biomass-to-energy). Under these conditions the authors found sustained, substantial increases to forest growth over broad areas were necessary to offset increased removals of carbon from stock due to disturbance.

Erosion of forest landbase: Urbanization, industrial development for mineral or petroleum extraction, and land clearing for agriculture all contribute to decreases in forest land-base across Canada. The 2008 National Inventory Report (Environment Canada 2010) shows a net global warming potential of 19 Mt CO_2e due to conversion of forest lands. This is down from 27 Mt CO_2e arising from forest land conversion in 1990.

Implications of broader scale factors: Effective models and monitoring programs support examining the interaction of forests and climate change (Kurz et al, 2007; Ryan et al, 2010; Li et al, 2006; and Calef 2010). Calef (2010) predicts substantial releases of carbon dioxide from the boreal forest due to warming, which has led to an earlier arrival of spring thaw and thus has extended the growing season by 2-4 days from 1988 to 2000. Longer growing seasons lead to warmer soils which translate into increased amounts of formerly locked-up soil carbon available for decomposition and release. “Satellite data suggest an extensive decline in forest productivity (browning) in the circumpolar boreal forest which is in sharp contrast to the greening observed in tundra areas.”

Kurz *et al* (2007) modeled landscape-scale boreal forest response to climate change and arrived at a similar conclusion: “This study indicates that boreal forest C stocks may decline as a result of climate change because it would be difficult for enhanced growth to offset C losses resulting from anticipated increases in disturbances.”

Calef’s arguments are all the more compelling because they are empirical. More recent arguments by Euskirchen *et al* (2010) suggest positive changes in boreal forest energy flux will likely arise from effects of climate change on the boreal forest: “Research generally suggests that the net effect of a warming climate is a positive regional feedback to warming…. Fewer negative feedbacks have been identified, and they may not be large enough to counterbalance the large positive feedbacks."

Integration of effects

From the foregoing discussion it becomes apparent that Canada's forests are an important factor in climate change. The abundance of evidence suggests their role will likely depend on impacts of climate change, with a strong likelihood that increases in extent and severity of disturbance may well tip the balance toward forests acting as carbon sources. In face of this prudence dictates a proactive, quantitative assessment would be of great value. Canada is fortunate in having detailed forest inventory information and an internationally recognized forest carbon scenario tool in the Carbon Budget Model – Canadian Forest Sector 3. These combine to provide an opportunity to integrate activity specific changes in GHG mitigation with landscape-scale estimates of climate change effects on forest carbon budgets. It is strongly suggested that empirical validation of the predictive capabilities of the CBM-CFS 3 be undertaken expeditiously as forest managers urgently need the ability to accurately scenario GHG mitigation strategies and climate change effects as part of the forest management planning process. Further, there is a great need for tools to integrate forest growth and inventory, soil organic carbon and peatlands quantitatively and seamlessly into the carbon realm.

Interim management strategies

In the absence of strong quantitative guidance forest managers should act on common sense principles articulated by several of the references cited in this review. For example, Kurz *et al* 2007 provides a good starting point for a holistic assessment of boreal carbon balance and flux. Metsaranta and Kurz (2010) used the CBM-CFS 3 to examine a wide array of potential interactions between climate change and forest management regimes depending on how anticipated effects of climate change on forests are realized. They suggest a number of prudent strategies, including:

- Evaluation of mitigation opportunities against a forward looking baseline derived from realistic estimates of the influence of climate change on disturbance regimes and albedo;
- Increase or maintain forest area (using afforestation if necessary);
- Increase stand-level carbon density through silvicultural treatments and process improvement;
- Increase landscape-level carbon density through increasing rotation length (i.e. delayed harvesting);

- Reduce or eliminate slash burning;
- Increase carbon storage in forest products.

Soil organic carbon maintenance strategies should be added to these. They include:

- Minimize soil surface disruption when harvesting or reforesting;
- Minimize soil surface warming by maintaining or rapidly re-establishing forest cover;
- Eliminate slash burning.

Vitt (2006) recommends that peatlands should be maintained as sinks, wherever possible:

- Do not remove the actively growing top few centimeters of the ground layer when grading access lines;
- Keep the time between the end of peat harvesting activity and revegetation as short as possible. In western Canada, develop a clear management plan for restoration of cut over bogs back to fens;
- Avoid nutrient inputs to peatlands during construction activities. This includes minimizing the introduction of mineral soil to peatland areas;
- Adequate buffer zones should be maintained around peatland complexes;
- Buffer zones should be designed relative to peatland size, runoff amount, and watershed extent in order to protect small, sensitive peatlands as well as larger, less sensitive peatland complexes;
- Road construction engineering should endeavor to understand peatland hydrology in order to avoid changes in water levels.

Albedo is difficult to manage directly but its effects might be minimized by:

- Reforesting harvested or burned-over forests promptly to minimize the effect of char on albedo;
- Managing reforestation density to maintain or increase “sky view” of snow;
- Using species mixtures for reforestation to increase albedo of young to middle aged forest stands.

3.5.2 Integrated Waste Management Strategies

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 wastes, from household waste to animal waste to food processing waste, need 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 the last among 17 countries, receiving a “D” grade on the municipal waste generation indicator by the United Nations (Conference Board of Canada).

Each Canadian, on average, generates 791 kg per capita of municipal waste each year. Furthermore, Canada’s municipal waste generated per capita has been steadily increasing since 1980. In addition, modern livestock operations and the food processing industry also generate a significant amount of wastes.

Many technologies and solutions have been developed and used to address waste management issues. It is clear that there is no “silver bullet” in this regard since wastes are generated with widely different properties and characteristics. Composting, anaerobic digestion and gasification/pyrolosis all have been used for handling these wastes and had various degrees of success. For organic wastes that have significant energy and nutrient values, an integrated approach may be the best option.

The anaerobic digestion process is a technology that has demonstrated many advantages. It changes wastes with a disposal problem into a resource that generates profits (livestock waste section). It allows wastes to be converted into valuable fuel and can significantly reduce the need for synthetic fertilizer by nutrient recovery (bio-fertilizer section). Recovered nutrients can be processed into bio-fertilizer with considerably higher nutrient values to make it economical to be transported and applied over long distances, providing a solution for the problem of excess soil nutrients around intensive livestock operation sites. More importantly it can be used as a hub to integrate a number of other waste treatment technologies, livestock productions, and other bioprocess facilities. Figure 17, adopted from Alberta’s bioenergy program document, illustrates this integration concept.

For example, if both anaerobic digestion and composting are deployed together for treating municipal wastewater and solid waste, it will reduce significant amount operation costs as well as energy requirements and, as a consequence, reduce GHG emissions. 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 to process 200,000 t MSW and 25,000 t waste water treatment sludge annually.

If these wastes are processed with AD first, it will provide at least 8.3 MW of electrical power, produce the same amount of compost, while reducing a significant of amount of GHG emissions. The heat generated from this system can be used to heat both the AD system and bio-fertilizer production.

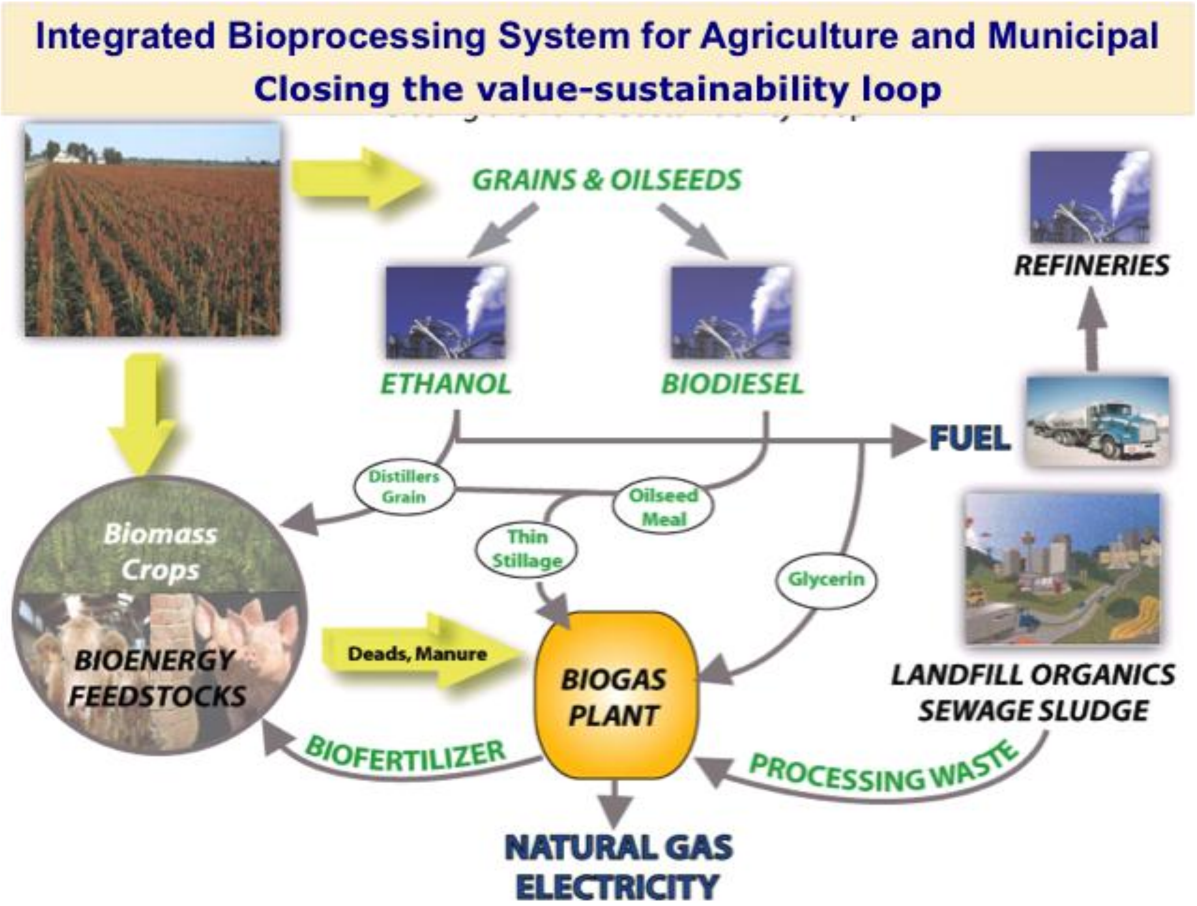


Figure 17. A conceptual view of integrated bioprocessing system for agriculture and municipal wastes.

In the case of AD technology integrated with feedlot operations and bio-ethanol production, energy consumption for ethanol production can be reduced by 30%, the operating cost of ethanol production by 10%, along with reduced transportation costs for animal feed. Water consumption for ethanol production can be reduced by at least 50%, and GHGs reduced by 50% (Jenson and Li, 2003).

As food-for-thought, consider the following example. We throw away vast quantities of organic waste: our household organic waste including solid waste and wastewater, animal waste, and wastewater from the Canadian food processing industry (does not include solid wastes from this industry). A great deal of money and energy are spent to treat them and we complain about how these wastes are fouling our environment. If these wastes are used instead as feedstock for anaerobic digestion, nutrient recovery, composting/bio-fertilizer production and gasification, it is enough to generate 1800 kWh/yr of electrical power ***per person***, equivalent to our per capita household electrical power consumption (Table 55).

At the same time, it will provide over 500 kg bio-fertilizer/soil organic amendment, which will support approximately 360 kg of barley or wheat production. Our entire household power and food could be produced from our waste and at the same time reduce ***464 kg CO_2e*** of GHG emission per capita per year.

Table 55. Total collectable wastes (municipal solid waste, municipal wastewater, and manure).

Source of Energy	Weight (dry)	AD process[3]	Gasification[4]	Bio-fertilizer[3]
	kg/pc, yr	kWh/pc, yr	kWh/pc, yr	kg/pc, yr
Municipal solid waste[1]	190	125		95
Municipal wastewater	65	43		33
Food processing wastewater	472	310		236
Manure[2]	425	279		213
Sub-total	1152	757		576
Papers and plastics[1]	396		1065	
Total	-	-	**1822**	**576**

[1] data source, Statistic Canada, OECD environmental data 2006-2008, and section waste management; [2] section water management, total collectable manure divided by Canadian population; [3] sections bio-fertilizer and waste management; and [4] heating value of waste papers/plastics 15 MJ/kg, Ucuncu, 1990.

4.0 Summary and Recommendations

This paper is a snapshot of the opportunity for biologically based GHG reduction and mitigation potential in Canada to 2020, calculated on an annual basis; for practices (grouped into "wedges"), identified by the CCEMC management committee and the authors. The paper estimates theoretical potential using the most reliable accounting methods, examines constraints to realizing that potential, and identifies critical requirements to making the specific sub-wedges operational. Most of this information was derived from literature searches and the authors' quantification estimates. It must be recognized that some of the barriers and gaps will require further evaluation and explication on the part of the Knowledge Network. The biologically based GHG mitigation potential is summarized in Table 56.

Table 56 Summary of Canadian biologically based GHG capture and reduction opportunities.

Wedge	Sub-wedge	Protocol in Place	Theoretical Potential (Mt CO_2e/yr)	Constrained Potential (Mt CO_2e/yr)
Carbon Sequestration				
3.1.1	Afforestation/Reforestation	no	0.6	0.2
3.1.2	Generic Increases in Forest Productivity	no	~	0.29
3.1.3	Carbon Storage in Forest Soils	no	~	?
3.1.4	Improved Forest Management	no	0.075	0.075
3.1.5	Carbon Sequestration in Peatlands	no	<0.01	<0.01
3.1.6	Avoided Forest Conversion	no	~	~
3.1.7	Delayed Forest Harvesting*	no	7.2	2.4
3.1.8	Agriculture Soil Carbon Sequestration		11.38	3.6 to 6.1
3.1.9	Wetlands Sequestration	yes	10.14	2.0
3.1.10	Sludge Application to Agricultural lands	yes	0.76	0.41
3.1.11	Soil Amendments	no	5.3	2.7
SubTotal			**35.76**	**11.26 - 13.77**
GHG Reductions				
3.2.1	Soil Nitrogen Management	yes	2.72-4.54	0.25 - 1.36
3.2.2	Beef and Dairy Cattle - Reductions of CH_4 & N_2O	yes	6.82	2.0 - 2.27
3.2.3	Reductions from Hog, Poultry and some Dairy	yes	1.5	0.9 - 1.05
3.2.4	Changes in Logging Slash Disposal	no	13.4	3.0
SubTotal			**24.4 - 26.26**	**6.15 - 7.68**
Waste Management				
3.3.1	Anaerobic digestion	yes	4.5-6.2	2.2 - 3.1
3.3.2	Management of Solid Wastes	yes	8.5-31.7	20
3.3.3	Biochar Production and Use	no	52 - 86.5	7.6 -9.0
3.3.4	Biomass Combustion	yes	5.1	1.5
SubTotal			**70.1 - 129.5**	**31.3 - 33.6**
Material Switching				
3.4.1	Biofertilizers	no	2.5	1.1
3.4.2	Building materials switching	no	4.42	1.5
3.4.3	Bio-based materials	no	79 - 88.0	1.6 - 8.0
SubTotal			**85.92 – 94.92**	**4.2 - 10.6**
Total			**216.18 - 224.42**	**52.91 - 65.65**

The Canadian theoretical biological GHG mitigation potential is over 200 Mt CO_2 e /yr. Applying the constrained potential, the more achievable estimates range from 52.91 to 65.65 Mt CO_2 e /yr. In either case, over 53% of this potential is associated with waste management and utilization. The next largest is the carbon sequestration wedge with 20% of the total estimated mitigation potential. The GHG reduction and materials switching wedges share a similar potential of around 12%.

Figures 18 to 21 summarize the implement-ability assessment of each wedge.

Figure 18 illustrates that the carbon sequestration potentials of improved forest management and pulp paper sludge application are small but readily implemented. The carbon sequestration potential of agricultural soil and soil amendments is substantial and readily achieved. Afforestation – reforestation and delayed harvesting have substantial carbon sequestration potentials but will require time and changes in paradigms to implement. Many of these sub-wedges have substantial environmental or social co-benefits that merit acknowledgement.

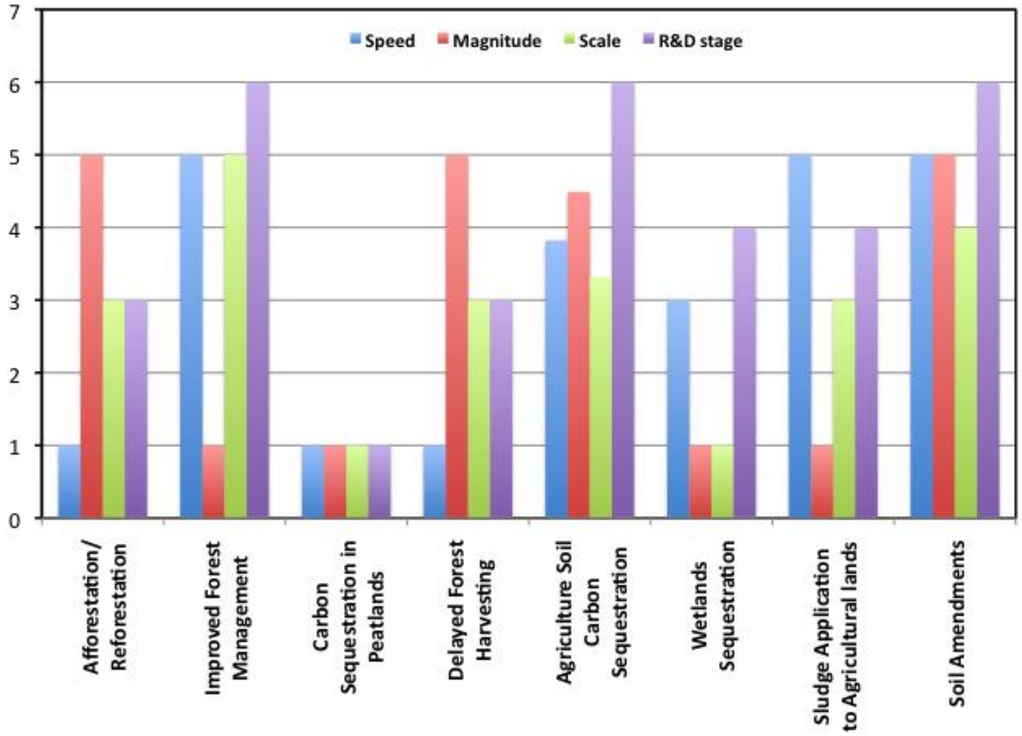


Figure 18 Summary of the carbon sequestration wedge

Figure 19, the GHG reduction wedge shows identified sub-wedges have substantial potential to mitigate GHG emission but will likely be challenging to make operational.

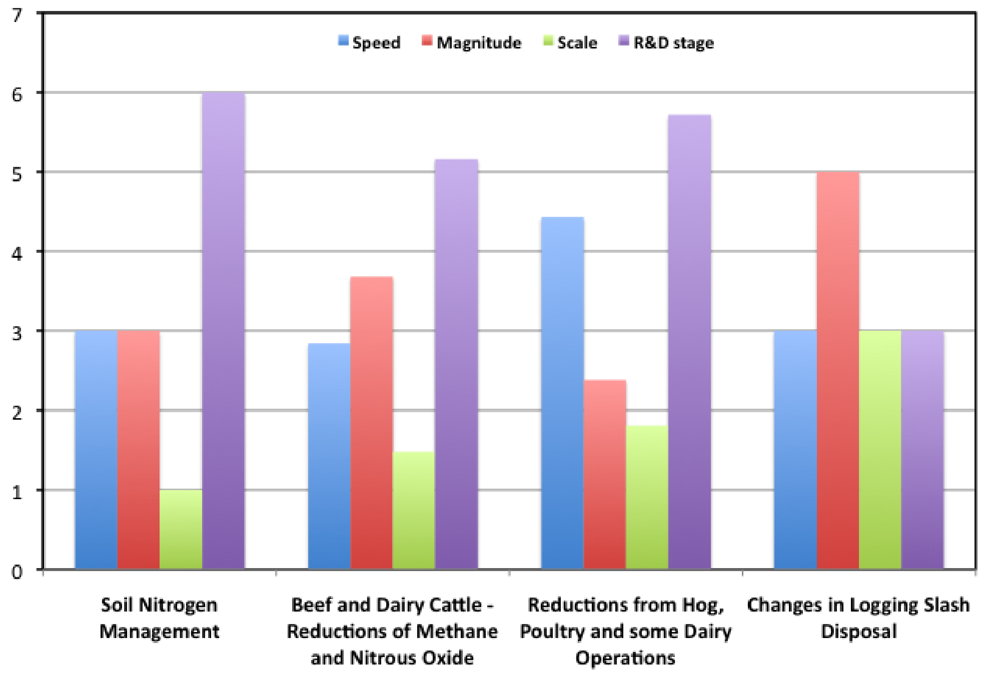


Figure 19 Summary of the GHG Reduction wedge

Figure 20 shows all waste management sub-wedges have great potential to mitigate GHG emissions; however, more R&D may be needed to render biochar operational. This wedge generally has substantial environmental and social co-benefits which merit consideration in deciding on operational deployment. Furthermore an integrated waste management approach maybe an attractive solution.

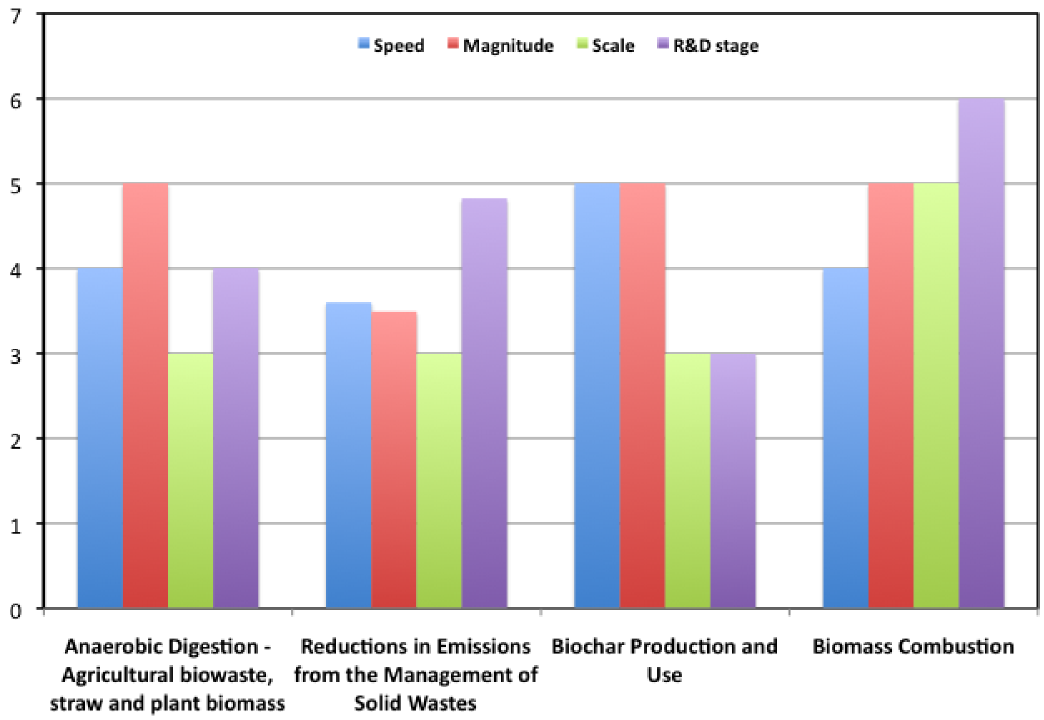


Figure 20 Summary of the Waste Management wedge

Material switching (Figure 21) shows great potential for GHG mitigation with slight to moderate challenges to operational implementation.

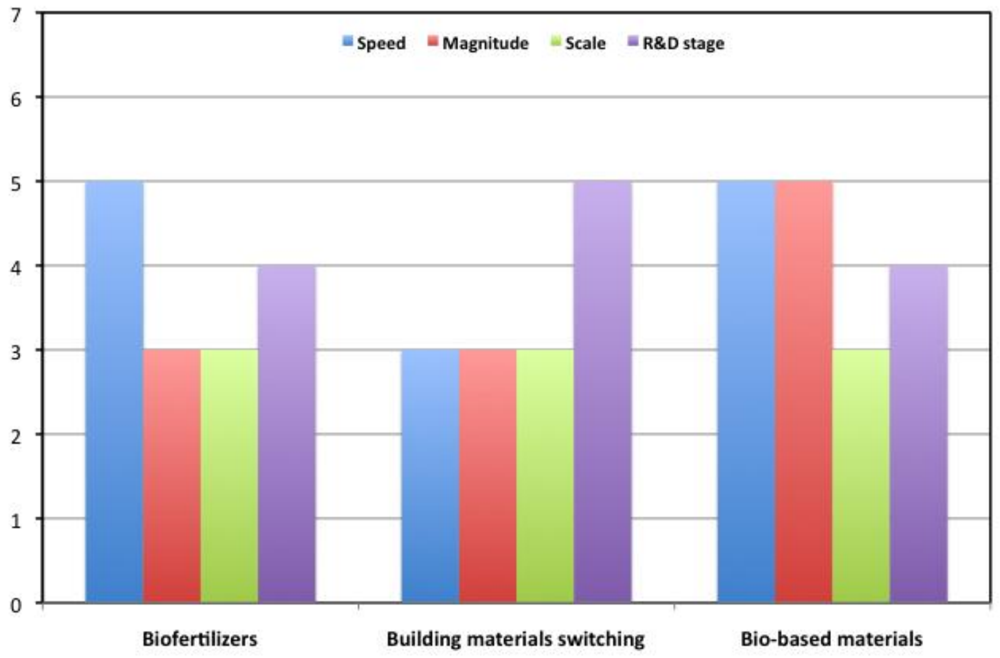


Figure 21 Summary of Materials Switching wedge

To achieve the mitigation potentials identified CCEMC should develop practical and measurable short- and long-term strategic plans.

The short-term strategic plan should address:

- Quantification tools and enabling policy for large-scale opportunities currently constrained by operational or quantification constraints. These include: bio-fertilizers, building material switching, and biochar, changes in logging slash disposal.
- Several quantification protocols require revision or development, including: material switching, biochar production, soil amendments, anaerobic digestion, improved forest management, and integrated waste management.

The long-term strategy should focus on enabling large-scale opportunities, which require significant changes in policy or infrastructure. These include the waste management wedge and delayed forest harvesting. To better enable these opportunities CCEMC should consider supporting:

- Refining the precision of, and improving access to, the current national biomass inventory.
- Developing a national bio-waste inventory will assist industries and investors in selecting waste management strategies and technologies. The inventory should include bio-waste physical, chemical and biological properties, locations, and quantities.
- Developing a national life-cycle analysis database for greenhouse gas mitigation options and opportunities. For example, most current wastewater treatment facilities in Canada

require significant amount energy to operation and therefore the associated GHG emissions are significant suggesting a need for adoption of new technologies to realize mitigation options.

- Initiating a dialogue between project developers and provincial forest land managers around the ownership of incremental carbon stored in trees on provincial forest lands.
- CCEMC might want to consider supporting developers in seeking incentives or policy changes to enable new technologies or novel applications of existing technologies. For example, making biochar generation portable might result in a synergy between reduced open burning of logging debris and biochar as GHG mitigation tool.
- CCEMC might want to provide all current and emergent climate registries in Canada a clear set of priorities from CCEMC's perspective to foster development of protocols arising from the roadmap.

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