GREEN ANALYTICS

GAP ANALYSIS OF BIOLOGICAL CARBON CAPTURE AND STORAGE IN ALBERTA

KEY GAP AND OPPORTUNITY ANALYSIS

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-Final Report-

REPORT PREPARED FOR / ON BEHALF OF
ALBERTA INNOVATES – BIOSOLUTIONS / CCEMC

About Green Analytics

Green Analytics is an independent consulting firm that specializes in the social and economic dimensions of land, resource, and environmental management. Through research, analysis, writing, and networking, Green Analytics supports policy analysis and management strategy development for governments, corporations and non-profit organizations. Green Analytics also provides an interface to bring together associates from a range of disciplines related to the ecological, social, and economic aspects of resource and environmental management. Green Analytics has offices in both Guelph, ON, and Edmonton, AB.

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Executive Summary

Green Analytics was commissioned by Alberta Innovates Bio-Solutions (AI-Bio), on behalf of CCEMC, to conduct an assessment of the priority gaps in biological carbon capture and storage (CCS) opportunities in Alberta. This report captures the outcome of that work.

Biological CCS opportunities are referred to in this section as groups of strategies and associated actions that contribute to mid and long-term reductions in GHG emissions.

To provide AI-Bio and CCEMC with information that meets their needs the project is focused on achieving three objectives:

- Provide AI-Bio and CCEMC with a comprehensive understanding of the leading science, data, policies, and practices to support biological GHG emission reductions through CCS in forests, agriculture soils, wetland and peatlands in Alberta.
- To identify the key gaps in science, data, policy, and practice as it relates to biological CCS in Alberta.
- Provide recommendations for filling these gaps for Alberta to become a leader in biological GHG emission reductions.

Through this research a number of key priorities for biological CCS are identified, which have been organized into 3 broad categories. Each category is composed of a set of biological CCS strategies than can be explored to achieve the outcome of GHG emission reductions.

Focus area	Strategy
Improved land management	Extended rotation age
	Alternative harvest techniques
	Afforestation
	Application of soil amendments
	No-till agriculture
Intensive land management	Genetically modified organisms
	Intensive silviculture
	Purpose selected cultivars
Land disturbance avoidance	Protecting carbon stores on public land / avoided deforestation

To inform decisions on what type of GHG emission reduction strategies are likely to be of the highest value to CCEMC, a set of evaluation criteria were identified. The evaluation criteria used to assess each of the biological CCS opportunities includes:

- The scale of the GHG emission reduction opportunity
- Additionality
- Leakage
- Permanence
- Verification and validation
- Co-benefits

Using the evaluation criteria each of the strategy types for biological CCS is quantified to capture an understanding of the magnitude of the GHG emission reduction opportunities. Further, the evaluation criteria are used to screen for those strategies that hold the most promise for programming or funding by CCEMC. The results of the GHG emission reduction assessment for each strategy type are presented below.

Focus area	Strategy	t CO2e ha-1 potential	Province-wide potential
Improved land management	Extended rotation age	11-33 t CO2e / ha	2.5 Mt CO2e / yr over 10M ha for a 3 year extension of rotation
	Alternative harvest techniques	Data gaps too extensive to estimate	Data gaps too extensive to estimate
	Afforestation	5 – 14 t CO2e / ha / yr	Max 20,000 ha in Alberta afforested. 0.1 – 0.25 M t CO2e/ yr
	Application of soil amendments	-7.71 – 0.37 t CO2e / ha	Number of hectares of potential area for application is unknown
	No-till agriculture	1 – 1.7 t CO2e / ha / yr	4.7 – 9.0 Mt CO2e / yr
Intensive land management	Genetically modified organisms	0.25 t CO2e / ha – 1.0 t CO2e / ha	0.25 Mt CO2e / yr – 1 M t CO2e / yr (about 1 M ha of planted forest in Alberta)
	Intensive silviculture	0.25 t CO2e / ha – 0.5 t CO2e / ha	0.25 Mt CO2e / yr – 1 M t CO2e / yr. Difficult

Focus area	Strategy	t CO2e ha-1 potential	Province-wide potential
			to de-couple from plantations though.
	Purpose selected cultivars	0.25 t CO2e / ha – 1.0 t CO2e / ha	0.25 Mt CO2e / yr – 1 M t CO2e / yr (about 1 M ha of planted forest in Alberta)
Land disturbance avoidance	Protecting carbon stores on public land / avoided deforestation	One time 200 – 400 t CO2e / ha pulse followed by up to 17 t CO2e / ha / yr depending on pre-deforestation types	3.5 – 4 M t CO2e / yr emitted yearly through deforestation with about 20,000 ha / yr deforested on private and public lands

Each of the strategy areas for biological CCS was assessed to determine where the key gaps are in Alberta that might hinder full scale implementation. The gaps were categorizes into science, data, policy or practice gaps. The table below indicate the type of gap that emerged for each strategy type.

Strategy Type	Type of Gap			
	Science	Data	Policy	Practice
Extending forest rotation		X	X	
Alternative harvest techniques		X	X	X
Afforestation			X	
Application of soil amendments	X			
No-till agriculture	X		X	
Genetically modified organisms	X		X	X

Strategy Type	Type of Gap			
	Science	Data	Policy	Practice
Intensive silviculture use		X		X
Purpose selected cultivars	X	X		
Maintain carbon stores through disturbance mitigation	X	X	X	X

Through the gap analysis and the assessment of each strategy relative to the evaluation criteria, four strategies are recommended for further exploration as a promising opportunity for CCEMC to consider as an investment area to promote biological CCS. To ensure that these strategies realize the potential for biological CCS as outlined in Section 4, the key gaps described below need to be addressed.

Extended forest rotations

There exists data and policy gaps that must be addressed in order for this strategy to be implemented as a biological CCS strategy. This strategy ultimately becomes an exercise in forecasting growth and yield on selected areas. Further, sufficient data and modelling is required to allow a third-party body to verify that the GHG emission reductions are credible.

The main gap that needs to be addressed with extending forest rotations is to develop a forest inventory system that is annually updated and automated to reduce long-term verification and validation costs. Currently, there are initiatives underway to develop automated inventory processes for forest management using 4-band multi-spectral imagery and lidar remote sensing.

Key Gaps Related to Afforestation

There are two types of gaps that need to be addressed for afforestation to gain considerable uptake. First, there is a policy gap surrounding the ownership of the C in afforestation projects, especially on Crown Land. The development of new property right legislation to allow for co-ownership of any emission reductions generated from afforestation would be a critical market driver. Secondly, there is a lack of data on the amount of land area that would be eligible for afforestation in the province. Using afforestation protocol information and geo-spatial data analysis a detailed inventory of eligible lands in Alberta could be approximated and serve as a market enabler.

Key Gaps Related to Intensive Silviculture Use

The major gap that needs to be addressed to promote the use of intensive silviculture as a biological CCS strategy relates to empirical data on the actual C gains from further investments in silviculture.

More specifically, data from established permanent sample plots that capture the actual volume gain, or systematic development of wood quality improvements associated with undertaking intensive silviculture management practices in Alberta are required to adequately verify the opportunity that this strategy holds.

Key Gaps Related to Avoided Land Disturbance

There are a number of key gaps that need to be addressed to deliver the potential GHG emission reductions from avoided disturbance strategies. These gaps include:

- Data sets to support a provincial spatial identification of important C reservoirs in Alberta. The creation of a spatial dataset which outlines the important C reservoirs could help provincial land managers to identify where and what would be impacted by deforestation or other land disturbances from development. Work is underway in this area at Green Analytics, the Land Use Secretariat and the University of Alberta.
- The lack of C related conservation targets for Alberta. Collaboration between SRD, ARD and the Land Use Secretariat to develop a framework for including strategic C stores in land use planning could begin to address this gap.
- A key practice gap that needs to be addressed to thwart the pace and scale of land disturbance in the province is the piloting of a new market-based instrument, such as conservation offsets, to validate the proposition that the environmental externalities associated with land disturbance can be internalized in existing land and resource use markets.

1. Introduction

Green Analytics was commissioned by Alberta Innovates Bio-Solutions, on behalf of CCEMC, to conduct an assessment of the priority gaps in biological carbon capture and storage (CCS) opportunities in Alberta. This report captures the outcome of that work.

As society moves closer to reaching an atmospheric concentration of 450 ppm CO_2e,[1] a critical threshold in climatic greenhouse gas (GHG) concentrations, communities, governments and companies will require a suite of tools and options to reduce GHG emissions. Decisions related to land use and land-use change provide particularly important opportunities for governments to take a leadership role in this regard. In Alberta this is particularly true due to the concentration of fossil fuel resources in the province. Development in the oil and gas sector across Alberta is expanding rapidly which offers government opportunity to shape the intensity and ecological impact of the growth.

One way the intensity and the shape of economic growth can be influenced is by managing land and resources in a way that absorbs more biological forms of carbon dioxide (CO2) in absolute or in relative terms, depending on the management objectives being sought. By absolute terms we mean that GHG emissions (measured in Co2e[2]/year[3]) would be reduced to a new long-term baseline. In relative terms it would indicate that the year to year tonnes of greenhouse gas emissions decrease by a particular linear or geometric pattern over a defined time period (e.g. over 10, 30 or 100 years etc..).

By influencing rates of growth in plants across medium to large areas of land, additional carbon can be stored in soils, soil organic layers, organic layers, humus, and plant communities of different species. Each combination of actions taken to store additional care has a unique time period required in order to sequester large amounts of biological carbon (C). Biological carbon

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[1] Carbon dioxide equivalency is a quantity that describes, for a given mixture and amount of greenhouse gas, the amount of CO_2 that would have the same global warming potential (GWP), when measured over a specified timescale (generally, 100 years).

[2] Reducing greenhouse gas emissions

[3] Co2e refers to equivalent greenhouse gas emissions.

capture and storage (biological CCS from herein) presents an opportunity to contribute to the problem of climate change. Indeed, biological CCS can provide measurable benefits to the atmosphere in the mid to longer-term especially. Also, this type of strategy can produce measurable additional benefits to the environment and the economy.

How well biological assets are managed will also factor into the resilience of Alberta's ecosystems to adapt to climate change. These biological assets are interwoven into the fabric of ecological landscapes. Therefore, the complexity of undertaking actions to store vast amounts of carbon in a landscape involves multiple agents (e.g. governments, landowners, private companies, non-government organizations, First Nations etc.) and developing new rules that may or may not have ramifications for our existing land use and resource production related policies.

To support CCEMC in making decisions related to where the key opportunities exist for influencing the management of Alberta's biological assets through biological CCS, this report examines a number of opportunities and their potential to contribute to Alberta's climate change management strategy and policies.

1.1 Project objectives

This project is focused on achieving three objectives:

- Provide AI-Bio and CCEMC with a comprehensive understanding of the leading science, data, policies, and practices to support biological GHG emission reductions through CCS in forests, agriculture soils, wetland and peatlands in Alberta.
- To identify the key gaps in science, data, policy, and practice as it relates to biological CCS in Alberta.
- Provide recommendations for filling these gaps for Alberta to become a leader in biological GHG emission reductions.

1.2 Outline of this report

This report is organized into seven sections:

- Section 2: Opportunities for Biological CCS in Alberta- this section identifies and describes the range of biological CCS opportunities for Alberta.
- Section 3: Evaluation Criteria for Assessing Biological CCS options- this section identifies and defines the evaluation criteria that were used to evaluate the biological CCS opportunities for Alberta.
- Section 4: Assessment of Biological CCS Potential in Alberta- this section presents a best estimate of how each of the biological CCS opportunities can contribute to GHG emission reductions.
- Section 5: Analysis of Key Gaps for Biological CCS in Alberta – this section outlines the science, data, policy and practice gaps associated with each of the biological CCS opportunities identified for Alberta.
- Section 6: Evaluation of Key Opportunities for Biological CCS- this section summarizes the evaluation of biological CCS opportunities for Alberta, selecting those opportunities that have the most promise for deployment.
- Section 7: Summary of Promising Options and Key Gaps for Biological CCS- this section presents a summary and review of the most promising opportunities for biological CCS in Alberta based on the use of the evaluation criteria (Section 3), the assessment of biological CCS potential (Section 4) and the gap assessment (Section 5).

2. Opportunities for Biological CCS in Alberta

Biological CCS opportunities are referred to in this section as groups of strategies and associated actions that contribute to mid and long-term reductions in GHG emissions. The first component of this research was to conduct a detailed scan of publicly available literature, technical reports and policy documents focused on biological CCS opportunities in northern forest regions. Through this research a number of key priorities for biological CCS were identified, which have been organized into 3 broad categories:

1. Improved land management
2. Intensive land management
3. Land disturbance avoidance

In the section below, the priority areas are defined along with a number of associated biological CCS strategies that are being used or considered as a means to reduce or avoid GHG emissions.

2.1 Improved land management

Improved land management is one priority area that focuses on adjusting or modifying specific land management actions so that more carbon is captured and stored. In other words, the question to be answered is what are the key ways land management can be modified to improve the capture and storage of carbon? The key strategies identified are described in detail below.

2.1.1 Extending forest rotation age

Extending forest rotation age beyond the typically economical optimal age for harvest has been shown to increase the relative amount of CCS taking place.[4] Doing so will inevitably result in a number of effects, some of which may be positive or negative depending on the context in which they are viewed. From the perspective of CCS the relevant effects are:

[4] Cooper C.F. 1983. Carbon storage in managed forests. Canadian Journal of Forest Research 13, 155 – 166.

- Less wood and therefore less C is removed from the forest.
- Less wood and therefore less C is transferred to mills, the landfill and to the forest product sector.
- More wood, meaning more C, remains in the forest, forest soils and out of the atmosphere.

Maximum sustained yield[5] forests [6]are generally harvested when peak mean annual increment (MAI) in stands is reached and this always occurs before peak stand-level biomass by a considerable amount of time.[1]

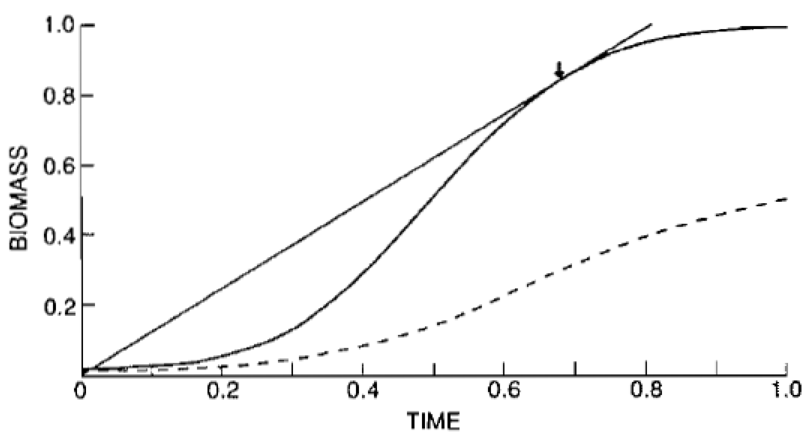

Figure 1. Hypothetical dimensionless growth expectation of an idealized forest stand. Peak MAI is reached when the straight line originating from 0 touches the solid curved line. Peak biomass accumulation occurs after peak MAI. (Adapted from Cooper, 1983).

Extending the rotation age allows forest areas to accumulate more volume, more biomass and more dead organic matter (DOM). A study of spruce, fir and mixedwood forests in New Brunswick found that by reducing the harvest by 10% and increasing the rotation age by an average of 3 years 8 - 30 t CO_{2e} ha^{-1} more was stored above scenarios with the economically optimal rotation age. Depending on the increase of the rotation age there is probably opportunity

[5] Yield – in this case the "yield" means the recoverable timber per hectare of a forest stand and its growth over time.

[6] Maximum sustained yield forests – this refers to the current sustainable forest management paradigm in which stands in a forest management area are harvested at peak MAI at a rate of which the future forest reserves will accrue enough volume to produce a steady state of timber indefinitely, or for a defined period of time, likely 80 – 100 years.

to increase the forest C stocks from 5 – 65 t CO_2 ha^{-1} though any increase in rotation age results in less overall volume harvested.[7] A drawback to this strategy is that anytime wood is left in the forest, the opportunity for catastrophic natural disturbances (e.g. forest fire) to occur and release the C stored increases.

Forest management strategies to increase rotation age could be achieved quite easily, either through a new round of management planning within the province of Alberta or simply by harvesting less wood. However, in a simplistic case reducing the harvest volume (by extending the rotation age) has the potential for socio-economic impacts, carbon leakage[8] and other impacts that may offset any gains made by this strategy like the increased use of fossil fuels to produce the outcomes associated with extending the harvest rotation age.

Socio-economic impacts would appear in communities which depend on forest management for employment, mill workers and other such vocations would also be impacted with a significantly reduced harvest level.

Carbon leakage could occur if mills in Alberta which were used to receiving certain amounts of fibre from Alberta went to Saskatchewan or British Columbia (BC) for fibre due to the reduced harvest levels. This could cause increases in harvest levels in BC and Saskatchewan thus creating leakage of GHG emission reductions.

2.1.2 Alternative harvest techniques

By retaining more forest biomass onsite, carbon stores can improve relative to current baseline conditions (e.g. single tree selection, commercial thinning). This is particularly beneficial when combined with a bio-fuel system in which slash residue is not burned in situ, but rather transported to a bio-fuel plant to replace the use of coal for electricity generation. Clearcutting maximizes the volume of harvested materials per ha. However, full tree clearcutting removes

[7] Kaipainen, T. (2004). Managing carbon sinks by changing rotation length in European forests. *Environmental Science & Policy*, *7*(3), 205-219. doi:10.1016/j.envsci.2004.03.001

[8] According to the IPCC (2007) carbon leakage is defined as the increase in CO_2 emissions outside the [jurisdiciton] taking domestic mitigation action divided by the reduction in the emissions of these [jurisdictions].

most, if not all, of the living biomass from forest stands, save a few "legacy trees" because a large proportion of limbs and tops are piled and subsequently burned.

Removing less wood per ha through different silviculture systems such as single tree selection, partial harvesting and commercial thinning are methods the leave more biomass on site when compared to clearcutting and ultimately harvests less wood per hectare..From a full life cycle perspective, while using single tree selection, partial harvests, or shelterwoods will result in more C stored in the forest over a clearcutting system the total GHG emissions may actually increase due to the use of non-wood construction products. Given this complexity it is difficult to conclude that this biological CCS is actually more positive than the traditional forest management paradigm. Harvesting less wood is a short-term strategy that in the long term fares less well from a GHG perspective when compared to producing a steady, sustainable supply of timber for forest products.

2.1.3 Afforestation

Afforestation, as defined by UNFCCC in 2001, "is the direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or the human-induced promotion of natural seed sources"[9]. Some examples of this include planting underutilized cropland, not sufficiently stocked scrub areas, prairie fringe areas, or areas previously deforested for some other purpose. Areas converted to afforestation remain in the "converted to" land category for a period of 20 years ("cropland **converted to** forest land" for example), after 20 years they are considered in the "remaining" category ("forest land remaining forest land" for example (cropland converted to forest land by afforestation then becomes forest land remaining).[10] Afforestation is generally a positive mechanism in sequestering and storing C as more often than not landowners undertaking afforestation will choose vigorously growing species, such as hybrid poplar, or coppice willow plantations.

[9] United Nations Framework Convention on Climate Change (UNFCCC).2001. Decision 11/CP.7: Land use, land-use change and forestry. Publication FCCC/CP/2001/13/Add.1. Available at http://unfccc.int

[10] Kyoto Protocol. Chapter 4. Intergovernmental Panel on Climate Change. Available at: http://www.ipcc.ch/meetings/session21/doc5to8/chapter421424.pdf

Currently, the rate of afforestation in Alberta that is officially reported to the National Afforestation Inventory is quite low, with only about 1,000 ha per year being afforested. Unfortunately, there remain questions surrounding the ownership of the C in the afforestation projects, especially when it takes place on public lands. The ownership of the C in afforestation projects on private land is clearer, though project managers are typically reluctant to report the afforestation to the National Afforestation Inventory for fear of government intervention in the projects.

In terms of a biological CCS strategy, there is little downside to afforestation as long as the opportunity costs of the land are not too high (i.e. afforestation is not taking place in areas which would otherwise be agricultural land for food production). Afforestation projects can sequester at least 300 t CO_2e / ha with values ranging from 400 – 600 t CO_2e / ha over the course of a forest rotation being possible.[11] However, permanence is an issue with afforestation projects as eventually the crop must either be harvested or tended to in such a way as to renew growth on the sites. Once harvested, the C from the afforestation project must be tracked to ensure that the project is indeed meeting the CCS requirements.

2.1.4 Soil amendments - biochar

A soil amendment is any material added to a soil to improve its physical properties, such as water retention, permeability, water infiltration, drainage, aeration and structure. Biochar is produced through the pyrolysis (a chemical decomposition caused by heat in the absence of oxygen) of organic feedstocks in the absence of oxygen. Potential feedstocks for the production of biochar include forestry and agriculture crops and residues, municipal solid wastes, livestock wastes, and other sources of organics. Under business as usual, these feedstocks would be burned or decompose. They can instead be used to produce biochar which can be amended to soil.

The literature indicates a wide range of potential estimates related to the use of biochar from a GHG perspective. More specifically, the range of values is from a net contribution of 0.37 tCO_2e

[11] Masera, O. R., et al. 2003. Modeling carbon sequestration in afforestation, agroforestry and forest management projects: the CO2FIX V.2 approach. Ecological Modelling. 164 177-199.

per tonne of biomass feedstock used as a fertilizer spread on the land to a net reduction of -7.71 tCO_2e per tonne of biochar used in composting with methane capture.[12]

2.1.5 No-till agricultural practices

No-till or zero-till agriculture is a conservation practice that entails planting crops into the untilled stubble of the previous year's crop.[13] It has been shown to save on fuel, protect against erosion, increase crop yields, and reduce labor costs and fertilizer use. No-till agriculture has increased in prevalence in Alberta since 1991 from occurring on just over 250,000 ha to occurring on more than 3.6 M ha in 2009. Also, no-till agricultural practices greatly reduce the runoff of nutrients including phosphorus, nitrogen from fertilization as well as pesticides. No-till agriculture has the potential to sequester C over conventional tillage or reduced tillage practices. Estimates vary as to the strength of the C sink available in Alberta from no-till practices from 4.7 to 9 Mt CO_2e per year[14].

However, there have been some conflicting reports as to the actual adoption or at least verification of the adoption of no-till agriculture in Alberta. The report of the Auditor General in Alberta in 2011 found that there was "insufficient guidance on how to verify tillage offsets."[15] This will likely be a policy gap that needs to be filled in order for no-till agriculture to count as a biological CCS strategy. Work in Ontario on using remote sensing to verify the tillage practices of farmers may help inform the verification of this practice in Alberta.[16]

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[12] Johannes Lehmann and Stephen Joseph (eds). 2009. Biochar for environmental management: science and technology. Earthscan, Washington DC pg. 317-336.

[13] Baig, M.,N., Gamache, P.,M. 2009. The economic, agronomic and environmental impact of no-till on the Canadian Prairies.

[14] ibid

[15] Report of the Auditor General of Alberta, 2011. Available at: http://www.oag.ab.ca/files/oag/OAGApr2011report.pdf

[16] Mapping tillage and crop residue management practices with RADARSAT. McNairn, H., Wood, D., Gwyn, Q.H.J., Brown, R.J., Charbonneau, F. Available at: http://geogratis.cgdi.gc.ca/eodata/download/part6/ess_pubs/219/219178/3321.pdf

2.2 Intensive land management

In contrast to improved land management, which seeks to modify management actions to promote CCS, intensive land management seeks to change the land management approach such that more aggressive deployment of plant cultivation can lead to higher levels of carbon storage per hectare. As well, through a more intensive land management approach allows governments or land owners to use less land in total, thereby leaving more land untouched and able to support CCS objectives.

2.2.1 Genetically modified organisms

In the forest and agricultural sectors the goal of using improved genetically modified organisms (GMOs) is to either increase productivity or the resistance to pest disturbance, both of which increases the potential for biological CCS but for different reasons. Increasing the productivity of a given forest area through the use of improved genetic stock has proven successful in New Brunswick and other jurisdictions.[17] The New Brunswick Tree Improvement Council has been in effect since the 1970s and has found that a conservative estimate of the value of improved genetic stock is at least a 10% volume gain. Interestingly, in the case of New Brunswick, the rotation age of the improved stock has been reduced while maintaining a higher volume. While it is difficult to quantify the per ha t CO_2 gains resulting from this intervention without undertaking a detailed modeling exercise, there is potential that further gains in biomass and forest C could be attained by extending the rotation age in combination with using genetically superior seed stock.

In the agriculture sector, the use of GMOs is more widespread. In Canada, there are several major agricultural export crops, including wheat, canola oil and canola by-products, and potatoes. Genetically modified canola, wheat and potatoes are the majority of the volume produced in Canada. The prevalence of GMOs used in Alberta and Canada has increased significantly in the past 15 years.

[17]The New Brunswick Tree Improvement Council. Tosh, K. Available at: http://nbforestry.com/?section=13&subsection=66&PHPSESSID=97d013bef596dbba15350e5c3ef50515&PHPSESSID=97d013bef596dbba15350e5c3ef50515

2.2.2 Intensive silviculture

Silviculture is the term used to describe the stand interventions that occur in a managed forest over the productive life-cycle of the forest, beginning with forest stand establishment and continuing to harvest. Silviculture activities include stand tending, harvesting methods, in order to produce a more productive forest as well as decrease the regeneration delay following stand eplacing interventions. From a biological CCS perspective, silviculture must ensure that there is more C in the forest, and produced by the forest than would otherwise be realized in the absence of such activities. Forest plantations following the clearcutting silviculture system have been shown to effectively increase the merchantable volume of wood on the site when compared to the previous rotation.[18] However, it is not clear whether or not the actual biomass and detritus, and hence C volume, is increased through plantation forestry. If the total forest biomass volume is increased through plantations, then the C storage on these sites will also increase. Intensive silviculture in Alberta can therefore realize quicker re-establishment of C stores following clearcutting activities. Note that Sustainable Resources Alberta legislates that certain silviculture systems be in place before, during and after forest harvesting.[19]

It may be difficult to claim credit for additionality when it comes to intensive silviculture use in Alberta. Generally in Alberta, forests are managed to produce the maximum volume of harvested product possible. If intensive silviculture methods are already being followed and legislated, additionality will be an issue when it comes to incorporating silviculture as a biological CCS strategy. Despite this, there remains good reason to practice silviculture in Alberta and most likely increasing the intensity of silviculture would increase the C stored in forests.

To address this challenge, a full lifecycle of using managed forest land for intensive silviculture from a biological CCS point of view should be explored. Leaving C in the forest instead of harvesting the wood and using it to make wood products does not make sense from a GHG perspective when compared to some alternative products. For example, forest products can be used instead of more C intense materials such as concrete and steel. As such, a decrease in

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[18] Sedjo, R.A. 1999. The potential of high-yield plantation forestry for meeting timber needs. New Forests 17:339-259

[19] C5 Forest Management Plan 2006-2026. Appendix 9A. Silviculture. Available at: http://www.srd.alberta.ca/LandsForests/ForestManagement/ForestManagementPlans/documents/ForestManagementUnitC5/Appendix9A-Silviculture.pdf

harvest volume that results in an increase in the use of more C intense material will ultimately result in an increase in life-cycle GHG emissions.[20] The use of shelterwood harvest and commercial thinning results in more C being left in the forest than with clearcutting. However, commercial thinning in Alberta is really only applicable in the montane and sub-alpine areas. As this discussion demonstrates, the use of intensive silviculture as a biological CCS strategy is complicated and difficult to assess without a full system lifecycle modelling exercise.

2.2.3 Purpose selected cultivars

The agricultural cultivars for winter wheat, barley and canola grown in Alberta have traditionally been selected for higher yields, pest and disease resistance, and profitability. By selecting cultivars which are likely to produce more biomass per hectare than other commercial crop cultivars there exists a theoretical opportunity to contribute to a biological CCS activity. Marginal profits per hectare have been shown to be directly linked to the cultivars used in Saskatchewan[21]. Ideally, cultivars selected for profitability and biomass per hectare potential would likely produce the greatest biological CCS potential in Alberta. Purely selecting cultivars for relative increased biomass production may not produce the highest profit, and the most profitable cultivars may not produce the most biomass. Therein exists a trade-off which would likely need to be analysed from a CCS perspective. It should be noted that to satisfy the additionality requirement, purpose selected cultivars for biological CCS would have to be shown to be above and beyond the business as usual of higher yields. This may contribute to this not being a successful bio CCS strategy.

2.3 Land disturbance avoidance

Another key pathway for improving biological CCS is through avoiding land disturbances that release large stores of C, such as deforestation, pest outbreaks and forest fires.

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[20] A synthesis of research on wood products and greenhouse gas impacts, 2nd edition. Vancouver BC. FPInnovations. 117 p. (Technical Report TR-19r). Available at: http://www.forintek.ca/public/pdf/Public_Information/technical_rpt/TR19%20Complete%20Pub-web.pdf

[21] Cultivar considerations and pod sealants for direct-combined canola. Holzapfel, C., Vera, C., Phelps, S., Nybo, B. 2011. SaskCanola. Available at: http://www.saskcanola.com/media/pdfs/cropweek2011-holzapfel-directcombined.pdf

2.3.1 Maintain C stores through land disturbance avoidance

The United Nations Framework Convention on Climate Change (UNFCCC) defines deforestation as the act of clearing a forest and changing the primary land-use from that of being a forest to that of either agriculture, oil and gas, recreational use, for municipal use or other industrial land classes in which no forest grows. The definition of a forest in the UNFCCC dictates what is considered deforestation: at least 1 ha of contiguous forest must be removed with certain restrictions on the width and size of the opening. At present, any linear features under a certain size are not considered deforestation. In Alberta, this is significant as there are literally thousands of oil and gas linear features that are not considered deforestation activities but are in fact achieving the same effect of a deforestation activity. Currently, Alberta emits about 4 M t CO_2e / yr through reported deforestation activities,[22] reducing this number would have an immediate impact on overall provincial emissions. Deforestation of productive, fully stocked, forest land results in one-time emissions of up to 400 t CO_2e / ha with concurrent emission of up to 17 t CO_2e / ha / yr as such when and where areas are deforested become important.

Development projects that involve the drainage of peatlands and wetlands are especially C intense from an emissions perspective. Peatlands hold massive reservoirs of organic C within their soils. Wetlands contain high concentrations of organic C while providing several other benefits including water purification and the provision of migratory bird habitat. If at all possible, development projects would be wise to avoid areas of high C density such as peatlands and wetlands and attempt to deforest low productivity upland sites as opposed to these more productive sites.

The government of Alberta has undertaken an aggressive strategy to combat the spread of the mountain pine beetle from British Columbia. By avoiding a massive outbreak of this pest in lodgepole and jack pine forests in Alberta, the government has avoided direct and indirect emissions that would result from the mortality and growth loss of the trees. Strategies to avoid a mountain pine beetle infestation include removing infested tree communities, single tree

[22] National Inventory Report. 1990-2009 Greenhouse Gas Sources and Sinks in Canada. Executive Summary. Environment Canada. Available at: http://www.ec.gc.ca/Publications/default.asp?lang=En&xml=A07097EF-8EE1-4FF0-9AFB-6C392078D1A9

removal and aggressive action on the eastern foothills and northern areas of Alberta.[23] It is difficult to quantify the absolute reductions in emissions resulting from the mountain pine beetle control strategy. The current outbreak in British Columbia is an order of magnitude larger in area and severity than any other outbreak previously recorded with over 270 Mt C released over a 20 year period[24]. It is possible that an outbreak in Alberta that is even 1/10th of the size of the one in British Columbia would result in C lossed from 20-30 Mt C in 20 years from the forests.

Forest fire prevention is and has been underway in Alberta for a number of years. Protecting forest resources from fires reduces the overall GHG emissions released from the forest sector. However, the forest fire protection strategy in Alberta qualifies as the "business as usual" approach and likely would not qualify as a biological CCS strategy.

Integrated land management (ILM) offers the opportunity to reduce the ecological footprint of industrial activities taking place on public and private lands in Alberta. ILM aims to coordinate the activities of multiple stakeholders when the use of resources is concerned. For example, instead of forest companies simply going about the business of building roads, harvesting resources, restocking resources and creating products with minimal communication with oil and gas and other industries using resources on the same land, the ILM approach coordinates and optimizes land use activities. As outlined on the ILM website, a good example of an ILM success story is the coordination of an oil and gas company with a forestry company to build one road to access resources instead of building two.[25] Essentially, with ILM, the overall industrial footprint of activities taking place on Crown land is reduced through careful planning and coordination, which translates to reductions in overall GHG emissions.

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[23] Mountain Pine Beetle in Alberta. Frequently Asked Questions. Website. Available at: http://www.mpb.alberta.ca/faq/albertasfight.aspx

[24] Kurz, W.K., Dymond, C.D., Stinson, G., Rampley G. et al. 2008. Mountain pine beetle and forest carbon feedback to climate change. Nature. 989-900.

[25] Describing the integrated land management approach. Government of Alberta. Available at: http://www.srd.alberta.ca/LandsForests/IntegratedLandManagement/Default.aspx

Defining and measuring the amount of GHG emissions avoided through ILM on a per hectare basis is currently difficult. There are definite data gaps when it comes to quantifying the impact of an ILM approach.

3. Evaluation Criteria for Assessing Biological CCS Opportunities

To inform decisions on what type of GHG emission reduction strategies are likely to be of the highest value to CCEMC, a set of evaluation criteria were identified. The evaluation criteria are described below. In section 6 the evaluation criteria are used to assess the relative merit of each biological CCS strategy as it relates to the mandate of CCEMC.

3.1 Scale of the GHG emission reductions

CCEMC has a mandate to invest in GHG emissions reductions on behalf of the province of Alberta. As such, a critical criterion used to make decisions on where to invest public dollars in GHG emission reductions is the total amount of emission reductions that can be expected. As such, it is anticipated that heavier weight will be given to biological CCS options associated with high GHG emission reductions.

3.2 Additionality

Additionality is one of the most important considerations when assessing forest carbon offsets. To be additional, an offset project must result in emission reductions that would not have otherwise occurred (i.e., they must be in addition to the business as usual or baseline emissions scenario).[26] While the concept of additionality is straightforward, determining in practice whether a project is additional or not can be quite complicated.

The best assessments of additionality rely on a combination of tests:

- **Financial Viability:** A financial test enables project developers to establish whether the extra revenue realized from selling GHG offsets was critical in the decision to develop the project. If the project requires offset revenues to be financially viable, it is most likely additional.

[26] In the Federal governments Federal Offset Protocol Developers Guide the government refers to Incremental in a similar way as we refer to Additionality. http://www.ec.gc.ca/creditscompensatoires-offsets/default.asp?lang=En&n=7CAD67C6-1.

- **Legal Barriers:** In the case of forest carbon offsets, to be additional the offset must involve activities/actions beyond what is currently demanded of forest managers in provincial forest policies or land use policies.
- **Technical Barriers:** The technical barrier test addresses whether there are specific non-financial barriers, like a lack of relevant technical expertise in a region that the project would have to overcome, or whether the project is "common practice" in the region where it is being developed. For example, if monoculture tree planting were a general practice of an industrial forest company, accounting for forest carbon offset credits from this activity would not meet additionality requirements.

The most widely recognized test for additionality was created under the Kyoto Protocol and is known as the CDM additionality tool.[27] Projects that qualify as certified emission reductions under the Kyoto Protocol must meet this test, and it is also used for offsets that qualify as Gold Standard.[28] The CDM has recently come under scrutiny for crediting projects that do not meet strict additionality requirements.[29] Specifically, most criticisms of projects fall to the inability to adequately assess or verify the financial analysis and the barrier analysis presented above.

To ensure that project emission reductions are additional and to promote consistency with international offset systems, governments should adopt a CDM-like testing approach for additionality. However, given the inherent difficulties with ensuring projects are truly additional, governments should limit the number of offsets allowed in emission reduction compliance

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[27] UNFCCC. Methodological Tool: tool for demonstrating the assessment of additionality [CDM-Executive Board, Bonn, Germany: 2008] www.cdm.unfccc.int/Reference/tools/ls/meth_tool01.pdf (accessed July 7, 2009).

[28] The Gold Standard is a best practice methodology and a high quality carbon credit label for both Kyoto and voluntary markets established by the World Wildlife Fund.

[29] Oko-Institut. *Is the CDM fulfilling its environmental and sustainable development objectives? An evaluation of CDM and options for improvement.* http://www.google.ca/url?sa=t&source=web&ct=res&cd=1&url=http%3A%2F%2Fwww.wwf.org.uk%2Ffilelibrary%2Fpdf%2Fcdm_fill_objectives.pdf&ei=QfJpSrL3Goe4NoTP5c8M&usg=AFQjCNETXMW3Hn1KeLelG6lfRy6xsAKeuQ&sig2=bKc_i9ukXZMF0MH70Ww6Bw (accessed July 22, 2009).

systems and also apply a discount rate to offsets to account for the potential non-additional components of the project.[30]

3.3 Leakage

Leakage is defined as the unanticipated decrease or increase in GHG benefits that occur outside of a project's accounting boundary (the boundary defined for the purposes of estimating the project's net GHG impact) as a result of project activities. For example, conserving forests that otherwise would have been deforested for agricultural land may displace farmers to an area outside of the project's boundaries. There, the displaced farmers may engage in deforestation to pursue agriculture activities and the resulting carbon emissions are referred to as leakage.

Projects may also yield greater GHG benefits than anticipated-this is referred to positive leakage or "spillover." For example, if a project introduced a new land management approach or technology-such as increased use of agroforestry or cover crops or increased saw mill efficiency-and this change was adopted outside the project's boundaries, the net GHG benefits derived would be larger than initially estimated.[31]

3.4 Permanence

Permanence, or lack thereof, refers to the reversibility of carbon sequestration by the biosphere. Among all climate change mitigation activities, only those related to forestry, land-use, and land-use change entail the sequestration of carbon from the atmosphere into so-called 'GHG sinks.' Unlike the reduction or avoidance of GHG emissions resulting from other types of climate change mitigation activities, GHG sequestration into biomass, or GHG sinks, is not permanent since, sooner or later, the sequestered carbon will be re-released into the atmosphere. In the

[30] Ibid. 70.

[31] Land Use, Land-use change and forestry. Intergovernmental Panel on Climate Change. Available at: http://www.ipcc.ch/ipccreports/sres/land_use/index.php?idp=263

case of forests, this can result from fires, natural hazards, pests, land-use decisions, and other events.[32]

Permanence can be addressed in a number of ways including maintaining buffer pools of emission reductions, discounting emission reductions based on a risk factor and/or posting a bond against the pool of emission reductions.

3.5 Verification and Validation

Auditing in the form of validation and verification provide assurance that statements made about emission reductions are true and correct. Validation takes place before the project activity is underway, and is an independent assessment of the project design. Its purpose is to review the baseline and all calculations for accuracy, and to confirm that the emission reductions will be additional and achievable.[33]

Verification occurs after the project has been implemented and has generated reductions, and involves independent confirmation of the emission reductions that occurred. A verification does not ensure that emissions reductions are additional, only that a certain number of reductions have taken place.

In order for governments to promote objectivity, both validation and verification should be performed by credible and qualified, third-party auditors not related to the project developers. Furthermore, validation and verification for the same project should ideally not be performed by the same third-party auditor.

[32] Making forests competitive exploring insurance solutions for permanence. 2008. Concept paper by the UNEP FI Climate Change Working Group & UNEP FI Insurance Working Group. Available at: http://www.unepfi.org/fileadmin/documents/Exploring_Insurance_Solutions_for_Permanence.pdf

[33] C.S. Rowland et al. *Carbon offset verification project* Environmental Change Institute, University of Oxford, Oxford, U.K. http://www.eci.ox.ac.uk/research/biodiversity/downloads/linkcarbon.pdf (accessed July 13, 2009).

One of the most widely recognized standards for auditing of GHG emission reductions is ISO 14064. ISO 14064 and ISO 14065 provide the basis for accounting and certification of company and provincial inventories and for offset projects.[34]

3.6 Co-benefits

Many biological CCS strategies are located in regions where economic development is needed and also where environmental degradation is prevalent (e.g. rural areas). At a minimum, biological CCS strategies should comply with all relevant regulations and should not have negative environmental or social impacts, whether they are covered by regulations or not.

While the primary role of forest carbon offsets is GHG emission reductions, governments must ensure that no harm is done to other environmental values and should seek to develop projects that enhance a broad suite of ecosystem services.

In this regard, the evaluation of potential biological CCS strategies should take into account the opportunity a project may create to advance other environmental and social co-benefits. These include but are not limited to:

- Benefits to biodiversity, wildlife and water
- Benefits to communities in terms of jobs, incomes and the creation of local business.

[34] Canadian Standards Council. *Greenhouse Gas Accreditation Program* http://www.scc.ca/en/programs/ghg/index.shtml (accessed July 13, 2009).

4. Assessment of Biological CCS Potential in Alberta

Using the classification structure outlined by the literature review and jurisdictional scan, the potential for biological CCS in Alberta is described and assessed in the following sections.

4.1 Overview

Fluctuations in biological carbon stores can be measured using an array of monitoring tools that estimate atmospheric composition (concentrations of CO_2 and other gases). Options for the actual measurement of biological carbon changes include the use of remote sensing; flux and process measurements from intensive study sites; *in situ* vegetation and soil monitoring; weather, climate and hydrological data; and contemporary and historical data on land use, land-use change and disturbance.[35]

For the purposes of this report, we have reviewed the academic and technical literature related to biological carbon stores to derive an estimate of the potential GHG emission reductions (measured in CO_2e/ha) that might be realized from the range of strategies outlined to reduce or avoid biological GHG emissions (Table 1 below).

Table 1.Summary of the assessment of biological CCS strategies.

Focus area	Strategy	t CO2e ha-1 potential	Province-wide potential
Improved land management	Extended rotation age	11-33 t CO2e / ha	2.5 Mt CO2e / yr over 10M ha for a 3 year extension of rotation
	Alternative harvest techniques	Data gaps too extensive to estimate	Data gaps too extensive to estimate
	Afforestation	5 – 14 t CO2e / ha / yr	Max 20,000 ha in Alberta afforested. 0.1 – 0.25 M t CO2e/ yr
	Application of soil amendments	-7.71 – 0.37 t CO2e / ha	Number of hectares of potential area for application is

[35] M.R. Raupach et al. (2005). "Model–data synthesis in terrestrial carbon observation: methods, data requirements and data uncertainty specifications" *Global Change Biology* Vol. 11 (3): 378-397.

Focus area	Strategy	t CO2e ha-1 potential	Province-wide potential
			unknown
	No-till agriculture	1 – 1.7 t CO2e / ha / yr	4.7 – 9.0 Mt CO2e / yr
Intensive land management	Genetically modified organisms	0.25 t CO2e / ha – 1.0 t CO2e / ha	0.25 Mt CO2e / yr – 1 M t CO2e / yr (about 1 M ha of planted forest in Alberta)
	Intensive silviculture	0.25 t CO2e / ha – 0.5 t CO2e / ha	0.25 Mt CO2e / yr – 1 M t CO2e / yr. Difficult to de-couple from plantations though.
	Purpose selected cultivars	0.25 t CO2e / ha – 1.0 t CO2e / ha	0.25 Mt CO2e / yr – 1 M t CO2e / yr (about 1 M ha of planted forest in Alberta)
Land disturbance avoidance	Protecting carbon stores on public land / avoided deforestation	One time 200 – 400 t CO2e / ha pulse followed by up to 17 t CO2e / ha / yr depending on pre-deforestation types	3.5 – 4 M t CO2e / yr emitted yearly through deforestation with about 20,000 ha / yr deforested on private and public lands

It should be noted that further refinement of these estimates is required to provide additional clarity on the size of emission reductions possible as well as to estimate the extent (geographic scope) of the emission reductions that are possible. The section below describes the approach taken to approximate the estimates of per hectare and total province-wide emission reductions presented in Table 1.

4.2 Description of the estimates

4.2.1 Extended rotation age

For the extended rotation age estimate we assume about a 50% effectiveness rate from the sources provided, one from Scandinavia and one from New Brunswick, to account for the relative productivity rates for the two areas. Also, we assumed that 10% of the green zone in Alberta was eligible for rotation age extension (2.7 M ha). This method is susceptible to leakage and may result in undesirable socio-economic and political impacts due to reduced revenue from managed forest areas. Also, extending the rotation age only results in short-term gains of C in the forest as Inevitably a new equilibrium is established at which the forest will no longer be sequestering C above and beyond the normal rate as there will be a new “normal”. At that point, the rotation age will once again need to be extended, which may or not be possible or effective in actually increasing forest C stocks.

4.2.2 Alternative harvest techniques

This strategy is essentially about removing less C from the forest for each entry into the forest. However, removing less volume per ha harvested may lead to an increase in the number of access roads as more roads are needed to obtain more harvestable wood. The C associated with the increase in roads might override any gains in C realized in the forest. As with extending the rotation age, if leakage occurs to other jurisdictions in Canada, or leads to the use of more C intense products, then this strategy simply fails to be effective at reducing the overall GHG concentration of the atmosphere. Also, the harvest of residual biomass for bioenergy purposes has caused some NGOs to raise concerns regarding nutrient deficiencies in the forest. As well, only when offsetting coal does biomass appear better than fossil fuel use from a GHG emissions perspective, and this gain is only realized after a number of decades once the forests have fully recovered from post-harvest interventions. A recent study by the Pembina Institute concluded that biomass in Alberta could provide about 15,000 MW of electricity at a cost of 60$/MWh.[36] It is not entirely clear as to the feasibility or actual potential of that figure. Currently, biomass provides about 3% of the total energy produced in Alberta, with coal contributing about 58%[37] so the potential for biomass to take a more prominent role is certainly possible.

Overall, there is potential for alternative harvesting techniques to influence biological CCS. However, as described above, it is dependent on a large number of factors for which existing data gaps prevented a suitable estimation of the potential for Alberta.

4.2.3 Afforestation

Afforestation is an effective biological CCS strategy; however this activity is bound by the amount of area eligible for afforestation which is usually found on prairie fringes. Lands eligible for afforestation must not carry high opportunity costs when it comes to food, or other

[36]The Pembina Institute. 2010. "Greening the Grid" available online: pubs.pembina.org/reports/greeningthegrid-fs.pdf accessed February 2012.

[37]Government of Alberta. "Electricity Statistics" available online: http://www.energy.gov.ab.ca/Electricity/682.asp accessed February 2012.

agricultural production. Alberta seems to have afforested very little (comparatively) in the past 20 years (only about 2000 ha were planted from 1990-2002 in Alberta, or about 180 ha per year[38]. However, in general, there is little negative to find in afforestation as a biological CCS strategy. One issue relates to who owns the afforestation projects on public and private land in Alberta, though this could likely be resolved with clearly worded legislation.

4.2.4 Application of soil amendments

The literature on this subject indicates a wide range of potential estimates for biochar, a common soil amendment. More specifically, values range from a net contribution of 0.37 tCO_2e per tonne of biomass feedstock used as a fertilizer spread on land to a net reduction of 7.71 tCO_2e per tonne of biochar used in composting with methane capture. At the time of writing, no information was available to approximate the amount of land using biochar as a soil amendment in Alberta. Consequently, it was not possible to estimate the potential for this strategy in Alberta.

4.2.5 No-till agriculture

No-till agriculture in Alberta has shown the ability to sequester anywhere from 1 to 1.7 t CO_2e / ha. Estimates of the amount of no-till agriculture taking place in Alberta vary from 4 to 5 M ha, increased from 250,000 ha in 1990[39]. With 1 – 2 t CO_2e / ha and up to 5 M ha of area under this strategy, potential CCS of 5 – 9 M t CO_2e is theoretically possible.

4.2.6 Genetically modified organisms

In forestry, increases in volume usually take decades to be seen. Agricultural settings are much quicker to realize volume increases. In Alberta, there is about 1 M ha of plantations established already, of which the majority would likely be from the tree improvement program of genetically improved stock. If increases in volume from 5% to 25% are possible, than a CCS potential of 0.25 M t CO_2e / yr – 1 M t CO_2e / yr is theoretically possible, through it would be difficult to measure. Permanence is an issue with this forestry strategy as ultimately forest companies

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[38] Hall, R.J., Joss, B.N., Sidders, D.M., Keddy, T.J. 2004. The FAACS backcast: Afforestation activity in the prairie provinces (1990-2002). Forestry Chronicle. 80, 727-735.

[39] Statistics Canada. 2007. Selected Historical Data from the Census of Agriculture. Table 5.1.Available at: http://www.statcan.gc.ca/pub/95-632-x/2007000/t/4129758-eng.htm (accessed July 3, 2008).

would most likely want to recoup the costs of implementing the tree improvement plan plantations.

4.2.7 Intensive silviculture

If intensive silviculture is limited to just plantations, then it would be difficult to de-couple from genetically modified organisms strategies as planting is essentially establishing the GMOs in situ. However, given the high degree of uncertainty with regards to low-intensity silviculture and the system development life-cycle of managed forest lands, it is difficult to quantify the effects of this as a biological CCS strategy.

4.2.8 Purpose selected cultivars

The cultivars in use today in the agricultural sector of Alberta are likely the highest yielding, and most profitable due to years of research and field experiments. Hybrid canola has been in use in the Canadian prairies since at least 1989 with years of field testing and research on cultivar productivity and profitability[40]. It is difficult to quantify where the opportunities for increase biomass sequestration would be as most industrial agricultural operations have already undergone genetic improvement programs with their crops. There is little doubt that optimizing the cultivars in use for maximum biomass production would lead to an increase in C storage. However, the data gaps surrounding this currently make this a difficult question to answer. The literature suggests that the expected emission reduction potential from selected cultivars is similar to the magnitudes expected under genetically modified organisms[41].

4.2.9 Maintain C stores through land disturbance mitigation

Avoid deforestation and the degrading of peatlands and wetlands is often considered a "low hanging fruit" in terms of C protection. Note that there is evidence that the CH4 and N2O emissions from peatlands may overcome the value of them as a sink for C. Some of the evidence in this regard is from studies completed in Europe, though the same general ecological processes should apply here. With about 20,000 ha / yr deforested and about 4 M t

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[40] Zand, E., Beckie, H.J. 2002. Competitive ability of hybrid and open-pollinated canola (*Brassica napus*) with wild oat (*Avena fatua*). Canadian Journal of Soil Science. 473- 480.

[41] Ibid.

CO_2e / yr emitted by deforestation in Alberta, opportunity exists improve biological CCS through reduced deforestation.

5. Analysis of Key Gaps for Bio CCS in Alberta

To assess the gaps in each strategy identified above, the project team focused efforts on gathering information related to realizing actual GHG emission reductions. The focus of the research was to identify the key gaps and related questions:

- **Science gap**: explores the conclusiveness of the theoretical and applied research in the area of interest.
- **Data gap**: explores the quality and availability of relevant publicly available data in the area of interest to support verification and validation of GHG emission reductions.
- **Policy gap**: explores the gap in current policy or the presence of adverse policy incentives.
- **Practice gap:** explores the experience within Alberta for the area of interest, and outlines any learnings and/or barriers to implementation.

Table 2. Overview of the scope of the analysis of gaps for biological CCS strategies.

Strategy Type	Type of Gap			
	Science	Data	Policy	Practice
Extending forest rotation		X	X	
Alternative harvest techniques		X	X	X
Afforestation			X	
Application of soil amendments	X			
No-till agriculture	X		X	
Genetically modified	X		X	X

Strategy Type	Type of Gap			
	Science	Data	Policy	Practice
organisms				
Intensive silviculture use		X		X
Purpose selected cultivars	X	X		
Maintain carbon stores through disturbance mitigation	X	X	X	X

5.1 Improved land management

5.1.1 Extending forest rotation age

5.1.1.1 Data gaps

There are two major data gaps associated with implementing a strategy to extend forest rotation ages in Alberta.

First, there is a gap in the public availability of growth and yield data to estimate the optimal C based rotation age for all major tree species in each eco-zone in Alberta. Currently, Alberta Vegetation Inventory (AVI) data provides the highest level of resolution of growth and yield data for the province. Individual forest companies hold detailed data privately. In an effort to fill this data gap, a collaborative arrangement between CCEMC and the forest companies is required. Currently, Green Analytics is exploring this type of collaborative arrangement for the Bio-Resource Information Management System.

Secondly, delaying harvest may result in an immediate reduction in harvest levels. The reduction in harvest levels in Alberta may result in leakage occurring within the markets in which Alberta competes for forest products- thereby shifting the intensity of forest harvest to other regions of the continent (and hence increasing CO_2e emissions) and potentially negating any emission reductions the atmosphere would see from reducing harvest in Alberta. If extending harvesting rotations is a strategy to be considered further economic analysis is needed to understand the likely impact of carbon leakage associated with reducing harvest levels for a range of industry adoption levels.

5.1.1.2 Policy gaps

There are a two key policy gaps that should be considered when exploring the role of extending forest rotations. First, there is currently no incentive in place to manage public forest stands beyond the maximum sustained yield age class structure- in fact current AAC based harvest allocations establish a direct incentive to harvest according to a sustained yield principle. Secondly, Crown land forests are publicly owned and the introduction of a monetized value for reducing GHG emissions through extended forest rotations would require a rent capture instrument or tenure reform.

5.1.2 Alternative harvest techniques

5.1.2.1 Science gaps

Alternative harvest techniques are adopted in many other jurisdictions in Canada and the U.S. as a means to increase forest yields and to improve the efficient use of the forest resource. In Alberta's forests, where the majority of managed forestlands are in slower growing Boreal forests, the role of alternative harvest and silviculture techniques is questionable. Currently, there is a gap in the measurement of C gains or losses due to implementation of different silviculture and harvest systems. Particular, those forests in the White and Green Zones in Alberta.

5.1.2.2 Data gaps

Given the gap associated with the science of adopting alternative harvest techniques in Alberta to increase C stores, this also presents a gap in the data available to assess the full lifecycle GHG impacts of adopting these strategies over and above the traditional clearcutting system.

To address the data gaps, there is a need for decisive modelling or measurement exercises to discern which alternative harvest techniques would provide the "best" C benefit for CCEMC in terms of absolute GHG emission reductions across alternative silviculture systems.

5.1.2.3 Policy gaps

Similar to the case of extending forest harvest rotations, there are a two key policy gaps that should be considered when exploring the role of alternative harvest techniques. First, there is currently no incentive in place to manage public forest stands beyond the maximum sustained yield age class structure- in fact current AAC based harvest allocations establish a direct incentive to harvest according to a sustained yield principle. Secondly, Crown land forests are publicly owned and the introduction of a monetized value for reducing GHG emissions through extended forest rotations would require a rent capture instrument or tenure reform.

5.1.2.4 Practice gaps

The project team was unable to identify any small or large-scale field trials currently being undertaken to assess the potential for alternative harvest techniques to improve C sequestration in Alberta. In other parts of Canada (BC and NB) these types of alternative harvest techniques are being deployed to increase forest yields. Such techniques thus hold some promise for application in AB. When discussed with industry representatives, the gap in applying these types of harvest techniques in AB was assumed to be from lack of policy incentive to shift away from a clearcut system.

5.1.3 Afforestation

5.1.3.1 Data gaps

Growth and yield data of afforestation projects are likely the major data gaps in terms of quantifying the C sequestered on sites from afforestation. Also, there exists concern over the ownership of the C within the afforestation projects on public land which could be easily resolved by clear documentation by the province of Alberta. Afforestation on private land would likely have a data gap on the density per ha of C on site.

5.1.3.2 Policy gaps

5.1.4 Application of soil amendments (biochar)

5.1.4.1 Science gap

Currently, there is contradictory evidence on the lifecycle benefits of many soil amendments (e.g. biochar). Biomass is burned to create the biochar, which possibly offsetts any potential gains in future C uptake through increased productivity. A lifecycle based analysis in Alberta on the potential for soil amendments to reduce GHG emissions would help address this gap.

5.1.5 No-till agriculture

5.1.5.1 Science gap

The science seems clear on the benefits of no-till agriculture as a GHG mitigation strategy. It can be difficult to measure the amount of C sequestered over large areas, however.

5.1.5.2 Policy gap

There are relatively new revisions to the Conservation Cropping Protocol implemented in January 2012 which aims to clarify whether no-till projects actually meet the requirements for tillage offsets in Alberta. More rigorous proof of adoption of no-till will become the new norm.

5.2 Intensive land management

5.2.1 Genetically modified organisms

5.2.1.1 Science gap

Currently, there is a large amount of research underway in this area but no comprehensive assessment has been done to examine the role of GMO's in promoting C storage. Collaboration with industry and academic research organizations to support research and development in the area of GMO use for forest and crop C stores would begin to address this gap. However, if there was specific data on the expected volume increases resulting from GMOs in relation to traditional feedstocks, then extrapolating to total C storage values would not be overly difficult.

5.2.1.2 Policy gap

Existing forest management planning restricts the use of GMO use to private lands. If GMOs are indeed shown to be a significant contributor to C storage than provincial policy should reflect this. As such, collaboration with Alberta Agriculture and rural Development and Alberta Sustainable Resource Development to better assess the efficacy of using GMOs to increase C stores would begin to address this gap.

5.2.1.3 Practice gap

Currently, there is a lack of large scale applications of GMO use for promoting C stores though research has been undertaken on the use of hybrid poplar in this regard. Collaboration with industry and academic partners to undertake field trials using GMOs for enhanced productivity and resistance to disease and pests would begin to address this gap.

5.2.2 Intensive silviculture use

5.2.2.1 Data gap

Currently, there is a gap in the availability of data to definitively determine the increases in C storage from different silviculture options. There exists data on plantation growth and yield increases, though there remain gaps in the actual C storage increases from these plantations. Collaboration with industry and research institutions to cost-share the investment in growth and yield research would address this gap.

5.2.2.2 Practice gap

Currently, a lack of field trials to explicitly study increasing C stores through the use of intensive silviculture practices exists in Alberta. There are studies underway, though it is difficult to say definitively which silviculture blend of prescriptions deliver the highest C storage capabilities in different ecozones or natural subregions of Alberta. What works in some areas may not necessarily be applicable in other areas due to various naturally occurring differences in factors such as moisture stress, drought, or other environmental factors. Collaboration with industry and academic institutions could begin field trials in order to answer some of these questions.

5.2.3 Purpose selected cultivars

5.2.3.1 Science gap

There exists a gap with cultivars which accrue biomass faster than their counterparts as to the long term sustainability of the cropping. To oversimplify the example, if all cultivars in use in the Alberta agricultural sector were maximized for biomass production the question of how long that could be sustained is yet to be answered. Also, some crops may do well with less overall biomass produced. Certain vegetables fare poorly if they are overly leafy, however in the case of canola, generally the higher the biomass the more profitable the end-product.

5.2.3.2 Data gap

Currently a lack of specific available data with which cultivars accrue biomass in a comparison with other cultivars in use in the Alberta agricultural sector exists. There exists research on overall biomass gained in trial plots in Saskatchewan which may be applicable. Given that Alberta's agricultural sector has most likely optimized the profitability of the crop rotations, there may be little room for increases in biomass available. However, it would take a meta-analysis of current practices to evaluate whether there are opportunities for CCS potential in Alberta.

5.3 Land disturbance avoidance

5.3.1 Maintain C stores through land disturbance avoidance `

5.3.1.1 Science gap

Further research is required on the drivers of natural disturbance for forest and cropland. Stochastic events will inevitably occur in the boreal and montane areas of Alberta which will impact the C storage capacity of biological systems. Support for risk vulnerability based research for forests and cropland will address this gap, though certain management schemes are likely already underway to minimize potential impacts from natural disturbances.

Further research is required to estimate the change in C resulting from improved land management practices with support for longitudinal research focused on measuring the dose-response between land management practices and C stores.

5.3.1.2 Data gap

Currently there exists no reliable spatial data set on the carbon stores in Alberta. A thorough assessment of the carbon stores in Alberta to identify the most critical areas and the scale of areas needed for conservation to maintain ecosystem integrity is needed. Linking with existing initiatives like the AI-Bio Bio-Resource Information Management System (BRIMS) would help address this gap.

While analyses have focused on the likelihood of disturbance events, support for modelling and analysis to conduct a province-wide forest and crop-based C-vulnerability indexing system would provide a definitive guide for land managers and policy makers. Also, a lack of spatial data on forest carbon stores by ecological feature (forest, soil, and peatland/wetlands) currently exists or at least is not readily available. Contribution to the Bio-Resource Information Management System initiative funded by AI-Bio would address this gap.

Currently, there is no reliable spatial data set on the carbon stores on private land in Alberta. To address this gap, private landowners could support a similar strategy as that applied to public lands (described above) as the methods would likely be the same.

Also, there exists no specific carbon related conservation targets in Alberta. Collaboration with SRD and LUS to develop a framework for including strategic C stores in the conservation planning being conducted under the Land Use Framework would begin to address this data gap.

5.3.1.3 Policy gap

Forest planning can be encouraged to include a vulnerability modelling and planning framework in AAC calculations. Coordination with ARD and SRD will better assess the gaps in management and fiduciary policy related to vulnerability.

Crop-based insurance currently does not factor in all forms of crop risk. C related risks should be considered in this regard. Support for the development of pilot projects using conservation offsets as a tool to mitigate land disturbance would address this gap.

Currently, there is no provincial policy in place to mitigate or remediate damage to wetlands and peatlands. Collaboration with Alberta Environment and Water on the development of a comprehensive wetlands and peatlands policy to protect C stores would address this gap. Wetlands play multiple roles besides C retention as they are integral in natural water purification and migratory bird habitat. Wetlands should be given the highest protection priority.

Currently, there are no policy drivers to mitigate linear land disturbance. Collaboration with LUS on the development of linear disturbance limits would address this gap.

Ownership of the C on public land will remain an issue with any GHG mitigation portfolio. In order for industry and government to maintain C stores, some incentive is needed.

5.3.1.4 Practice gap

The use of genetically modified pest and disease resistance organisms can improve maintenance of C stores. Support for developing pest and disease resistance forest and crop species and links to the C storage capabilities would address this gap.

Currently, no system for tracking province-wide land disturbance exists and there is no active pilot projects examining the use of policy instruments to mitigate land disturbance. Support for the Ecosystem Service Roadmap initiative could help address this gap.

6. Evaluation of Key Opportunities for Biological CCS

This section of the report provides a summary of the evaluation of key priorities for biological CCS in Alberta. Using the evaluation criteria discussed in Section 3, the estimates of potential emission reductions in Section 4, and the assessment of key gaps in Section 5; this section provides a qualitative evaluation of each strategy and identifies those that are most promising for further investments in terms of research, data collection and implementation. Section 7 presents a summary of the most promising options and the key gaps for biological CCS for Alberta in the short-term. The table below summarizes the results of evaluation of the biological CCS opportunities, which are discussion in further detail below. In reading Table 3 it is important to note the iconography:

+ indicates that the strategy meets the criteria

- indicates that the strategy does not meet the criteria

! indicates that the strategy may or may not meet the criteria but a critical gap exists.

Table 3. Summary of biological CCS strategy evaluation.

Strategy	Scale of GHG emission reductions	Additionality	Leakage	Permanence	Measurement	Co-benefits
Extending forest rotation	!	+	-	-	!	+
Afforestation	+	+	+	-	+	+
No-till agriculture	!	-	+	+	!	+
GMOs	!	-	+	+	!	!

Intensive silviculture	**!**	**+**	**+**	**-**	**!**	**!**
Purpose selected cultivars	**!**	**+**	**+**	**-**	**!**	**+**
Avoided C disturbance	**!**	**+**	**-**	**-**	**!**	**+**

It should be noted that based on the qualitative assessment summarized in the table above, two strategies have been screened out. These strategies and the reason they were screened out are:

- Alternative harvest techniques - non-compliance with the majority of the evaluation criteria.
- Application of soil amendments - insufficient information to support a thorough assessment and it was expected to be covered in the gap analysis related to waste management.

6.1 Extended rotation age

Extending the rotation age of the forests has the potential to be an effective biological CCS strategy, though many barriers exist that influence the ability to properly implement this strategy.

Extending the rotation age clearly meets the following evaluation criteria:

- Scale of the tonnage of GHG emission reductions - extending forest rotation ages by 3 years would provide GHG reduction of a suitable scale.
- Additionality – extending the rotation age will only meet this criteria if it can be proven that the rotation age currently in effect on forest lands in Alberta is indeed the "business as usual."

- Creating co-benefits – by extending the rotation age the collective impact of forest operations on forest ecosystems is lessened to some degree. This is likely to improve water quality (due to less forest road development), habitat reserves and overall forest diversity.

Extending the rotation age presents a challenge for the following evaluation criteria:

- Leakage – reducing the harvest volume in Alberta by extending the rotation age may well increase the harvest volume in neighbouring provinces or States. If harvest rates do not increase in neighbouring provinces and States then the opportunity for high GHG intense materials may fill the gap left by conventional forest products.
- Permanence – eventually the managed forests will be harvested for the timber within them. At this point, the C stored in the forest will be released as the harvested material is turned into a forest product or combusted. If the forest product is combusted the stored C will be released back to the atmosphere. Also, risks of large-scale natural disturbances increase as forests age increases, which could also result in releases of the extra C stored.
- Ability to measure - while it is possible to track the change in carbon stored across a forest estate, it is often a costly exercise. Remote sensing or other forms of landscape scale imagery procurement and analysis is required.

6.1.1 Scale of GHG emission reductions

Extending the rotation age has shown the ability to store anywhere from 2 to 33 t CO_2e / ha depending on how many years beyond economic maturity the forests are allowed to age. If 10 M ha are managed in this way, then the storage of 1 – 3 Mt CO_2e / yr over the next 20 years would be theoretically achievable. This strategy is completely dependent on the amount of area eligible for an extended age rotation. However, given the scale of the potential emission reductions, this strategy may be considered as a viable option for Alberta to meets it's mid-term (2050) emission reduction targets,

6.1.2 Ability to measure (validate and verify)

The ability to measure and verify that extending the rotation age actually results in an increase in C storage is difficult without monitoring or modelling exercises. Monitoring 10 M ha of forests would be exceedingly expensive. Through remote sensing or some other form of forest estate modelling, it would be possible to estimate the increases in C stocks across the proposed area. While computer modelling may be the lesser expensive of the two options, the model results may still need to be validated. Remote sensing of the forest estate would have to be conducted for a number of consecutive years along with monitoring to compare estimated C stock increases or decreases. Either way, it is rather difficult and expensive to accurately justify the C gains through this activity.

6.1.3 Maturity of the scientific and technical knowledge

The science is generally accepted that leaving forests to age beyond economic maturity, results in increases in biomass accumulation when compared to peak MAI harvest scheduling. There is widely accepted evidence that older forests store more C than younger forests of the same productivity and species composition.

6.1.4 Readiness of the marketplace or policy environment

Extending the rotation age effectively means harvesting less wood from areas which are under this form of management. This has economic ramifications for communities and people who depend on the fibre produced from forest harvest operations. Harvesting less wood would result in some human resource issues with forestry professionals, millworkers as well as anybody in the production cycle that is related to forest harvest operations. While the harvest is not stopped altogether, it is inevitable that some impact will be felt in the timber harvesting operations.

6.1.5 Co-benefits

The co-benefits of extending the rotation age are largely ecological. Reducing the overall impact of forest operations on the wilderness will surely increase the habitat of certain species, improve water quality due to less road building and erosion, and biodiversity may increase in the forest areas which are left to become older than average. Also, in the short term, extending the rotation age will sequester more C in the forest than would the business as usual approach of maximizing timber production. There is conflicting evidence however, with respect to whether storing more C in the forest would actually decrease the overall GHGs in the atmosphere due to substitution effects. Substitution effects, which are related to displacement factors, attempt to capture the inherent GHG incorporated with products, in this case forest products. Every cubic metre of wood used in construction lumber, or as paper, or as any end product has a specific GHG balance. By using wood instead of concrete in construction, society is substituting the use of concrete by using wood. Every unit of concrete used in construction generally has a higher

GHG balance associated with the production of the material. In the case of concrete, the resources used to create the products are generally non-renewable. However, the cubic metre of wood is created by a biological system that given sustainable forest management is renewable. Also, the GHG balance is lower to produce a cubic metre of wood product. Essentially using wood instead of higher GHG intense material creates a substitution effect. If the supply of wood is reduced, given the same market for construction material, the result will be more non-wood products such as concrete. The GHG emissions as a whole will increase as the GHGs needed to make concrete is higher than those to make wood products.

6.1.6 Economics and practicality of implementation

The implementation of this strategy would most likely result in a reduction in revenue for the timber industry. Subsidies would likely be needed to offset the losses of revenue. From this perspective it may not be practical to implement in Alberta.

There is an opportunity cost to implementing this strategy. The lost value of the harvest may or may not be justified by the gained value of the extra C storage.[42] As well, the opportunity cost of implementing this strategy increases as the area of managed forest is allowed to age beyond economic optimality.

This strategy could be implemented in certain geographic locations which make economic sense (areas which are nearing peak MAI and could easily sequester C by extending the rotation age by only a few years). It would require some internal investigation at SRD Alberta to identify areas where extending the rotation age may make economic and ecological sense. However, a blanket approach to the entire province does not seem economically justifiable.

6.1.7 Key gaps that need to be addressed for success

There exist data and policy gaps which must be addressed in order for this strategy to be implemented as part of a biological CCS strategy. This success of this strategy ultimately depends on the ability to forecast growth and yield for selected areas.

The main gap that needs to be addressed is the development of a forest inventory system that is annually updated and automated to reduce the long-term verification and validation costs.

[42] Boyland, M. 2006. The economics of using forests to increase carbon storage. Can. J. For. Res. 36. 2223-2234.

Currently, there are initiatives underway to develop automated inventory processes for forest management using 4-band multi-spectral imagery and lidar remote sensing.

6.2 Afforestation

Afforestation represents a biological CCS strategy in which previously under-utilized land is converted into a forest plantation. Depending on what species are planted, there may exist further potential for considerable co-benefits from these projects.

Afforestation meets the following evaluation criteria:

- Additionality – converting previously under-utilized or marginal cropland to an afforestation project constitutes management above the business as usual paradigm.
- Leakage – so long as the total amount of afforested land does not degrade the agricultural production capacity of the province and the opportunity costs of the land afforested are not too high, then leakage is unlikely to be an issue.
- Permanence – afforestation projects may not store C indefinitely, but they should store C for the foreseeable future.
- Co-benefits – afforestation of willow plantations have been shown to provide a feedstock for biofuels over a 3-year rotation, which could feed into the emerging bioenergy market in Alberta. Also, planting, tending and overseeing the establishment of afforestation projects could result in significant employment opportunities for communities on the prairie fringes of Alberta. Depending on the species established, afforestation can also play a role in increasing overall landscape intactness, which will contribute to biodiversity.
- Effectiveness – there is little doubt of the effectiveness of planting otherwise marginal lands for the purposes of afforestation. C stocks will be increased on these sites, depending on which species are chosen, there may be considerable opportunity for afforestation to act as a biological CCS strategy.

6.2.1 Scale of GHG emissions reduction

Depending on the type of species planted in an afforestation project, the overall tonnage of GHG emissions reduced varies. Willow coppice plantations seem to be on the high end in terms of potential to reduce GHG emissions with “best case scenarios” sequestering up to 18 t CO_2e /

ha / yr. Other projects will inevitably store and sequester less C with expected sequestration rates of 6 to 10 t CO_2e / ha / yr possible. Afforestation projects are only constrained by resources and eligible land available. It is conceivable to expect to store about 1 M t CO_2e / yr with a few tens of thousands hectares of afforestation projects.

6.2.2 Ability to measure (verify and validate)

Either through modelling or measurement, the C stored in afforestation projects can be estimated. In Alberta, the United States, Europe, Asia and Latin America there exists verification and validation protocols for measuring the contribution of afforestation to GHG emission reductions.

If short rotation willow coppice projects are adopted for bioenergy projects, the volume of willow could most likely be measured quite accurately at the cogeneration plants. However, measuring the C volume stored in thousands of hectares of forest would be expensive.

6.2.3 Maturity of the scientific and technical knowledge

Planting a C dense organism such as trees on otherwise underused or barren land will result in more C sequestered than leaving the land as-is. This is widely accepted scientific and biological information. Planting native species to Alberta, such as poplar would not likely cause any significant deterioration of current ecosystems. Developing coppice willow plantations on short rotations has been proposed and studied, though it is not clear whether any such projects have been implemented in Western Canada. There are successful willow coppice operations in Europe, where such projects are undertaken if the opportunity costs of the land use can be justified relative to existing land use practice. Currently, food prices are at an all-time high and the definition of “marginal agricultural” land is dependent on food prices.

6.2.4 Readiness of the marketplace or policy environment

There are two major markets already developed to support afforestation activities. The first market is the burgeoning bioenergy market in Alberta. Providing feedstocks for this market could partially be addressed by short-rotation afforestation projects.

Another marketplace is Alberta’s offset market, which is currently considering the adoption of an afforestation protocol. In this regard the market and policy environments are ideal for the adoption of this biological CCS strategy.

6.2.5 Co-benefits

There are several potential co-benefits of afforestation. A wide-scale afforestation project would result in employment opportunities for the communities which neighbour the projects. The bioenergy market could see its feedstocks increase through the development of short rotation coppice projects. Tending and monitoring afforestation projects will create an opportunity for employment. Afforested areas on previously underutilized or barren land will provide habitat for certain species of flora and fauna. Establishing forests on previously deforested lands could re-stabilize soils and eliminate, or at least greatly reduce, erosion. Water quality would then increase surrounding afforestation projects. Also, silviculture practices on the afforested areas could be aimed at providing specific habitat for certain sensitive species.[43]

6.2.6 Economics and practicality of implementation

To successfully implement a large-scale afforestation project in Alberta, the opportunity costs of the land being afforested must be carefully investigated. Food prices are at an all-time high and may well remain so for the foreseeable future. Defining "marginal agricultural land" is difficult. It would likely make more economic sense to use somewhat underutilized cropland for food production rather than to plant a multi-year, or multi-decadal forest crop to sequester C. Also, there must be a market for the crop of species being afforested. If several thousand hectares of hybrid poplar are to be harvested on a continual basis, some receiver of the wood is needed. The products derived from hybrid poplar are not overwhelmingly valuable and could likely be an expensive way to cogenerate power in coal power plants. There would need to be some market for the willow coppice projects as well, otherwise landowners would be relegated to stockpiling willow for some future use.

The costs found in 2004 of establishing an afforestation project were estimated at $2,000 / ha ±30% with additional costs / year for stand tending at $5 / ha / yr ±30%.[44]s It was also found that the price per tonne of CO_2e sequestered needed to be at least $50 for such projects to break

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[43] Research summaries (#3) from briefing paper topics—theme: co-benefits of climate change and forest-based mitigation activities involving ecosystem services such as wildlife habitat. Available at: http://www.fsl.orst.edu/lulcd/Publicationsalpha_files/Synthesis_III_co_benefits.pdf

[44] McKenney, D.W., Yemshanov, D., Fox, G., Ramlal, E. 2004. Cost estimates for carbon sequestration from fast growing poplar planations in Canada. Forest Policy and Economics. 6, 345-358.

even at growth rates of 14 m^3 / ha / yr. More recent studies suggest that producing bioenergy feedstock from fast growing afforestation sites is more expensive than using low-grade coal.[45] Multiple studies have suggested that the price per tonne of CO_2 sequestered needs to be at least $50[46].

6.2.7 Key gaps that need to be addressed for success

There are two types of gaps that need to be addressed for afforestation to gain considerable uptake, thereby generating substantial GHG emission reductions. First, there is a policy gap surrounding the ownership of the C in afforestation projects, especially for afforestation projects on Crown land. The development of new property right legislation to allow for co-ownership of any emission reductions generated from afforestation would be a critical market driver. Secondly, there is a lack of data on the land area that would be eligible for afforestation in the province. Using the adopted afforestation protocol information and geo-spatial data analysis, a detailed inventory of eligible lands in Alberta could be approximated and serve as a market enabler.

6.3 No-till agriculture

No-till agriculture has been shown to have several positive environmental effects, most notably increased C sequestration in soils. Improved water quality, reduced labor costs, reduced sedimentary deposits and other positive consequences of the practice may also result. In terms of a biological CCS strategy, no-till agriculture meets the following evaluation criteria:

- Leakage – no-till agriculture should not necessarily cause leakage in other jurisdictions. There is evidence of increased yields associated with this practice and as such increased adoption would most likely reduce the overall footprint of agricultural practices.
- Co-benefits – the co-benefits, as outlined above, include reduced fuel usage, increased water retention, reduced erosion, reduced sedimentary deposits, reduced fertilizer runoff, decreased labor expenses, reduced equipment maintenance and many others.

[45] Yamshanov D., McKenney, D.W. 2008. Fast-growing poplar plantations as a bioenergy supply source for Canada. Biomass and Bioenergy. 32. 185-197.

[46] Ibid 46

- Permanence – instilling a no-till agricultural system will permanently increase the C stocks of soils over conventional tilling. This will occur until a new equilibrium is established.

No-till agriculture does not appear to meet the following evaluation criteria:

- Additionality – since 1990 there has been a sharp increase in the amount of area under no-till agriculture, driven predominantly by stewardship concerns for soil erosion. As such, there are major concerns with the existing approach to accounting for no-till agriculture in Alberta's offset system.

6.3.1 Scale of tonnage of GHG emission reductions

There has been an estimated 4.9 – 9 M t CO_2e of possible GHG reductions since 1990 due to no-till agriculture. This is the direct estimate of actual tonnage of C in the soils based on Alberta Environment's current no-till offset protocol that is being amended. In terms of the entire system surrounding agriculture, there may be even more opportunities for C sequestration. Reduced fertilizer use, reduced emissions from farming equipment for tillage, reduced sedimentary losses will also result in emissions reductions though these are difficult to quantify through the use of no-till agriculture.

6.3.2 Ability to measure (verify and validate)

The ability to measure small increases in soil C over large areas of land is difficult. However, small increases in C over large areas can add up to big opportunities for GHG removals. Soil C has been successfully measured through CNS (Carbon Nitrogen Sulfur) analysis. It is relatively easy to compare the C concentration of soils from no-till and conventional tilled soils through CNS analysis, however, it is difficult to do this over several million hectares. Verification standards are employed in Alberta which are supposed to ensure that the no-till agricultural practice does indeed result in increased C stocks when compared to conventional tillage. As such, protocols have been established to address the measurement of C benefits from no-till practices.

6.3.3 Maturity of the scientific and technical knowledge

There is a plethora of studies surrounding no-till practices. The science seems generally in agreement that no-till agriculture will increase the soil C stocks when compared to conventional or minimum tillage systems.

6.3.4 Readiness of the marketplace or policy environment

No-till agriculture is already well established in Alberta and the rate of no-till is still increasing.

6.3.5 Co-benefits

Lower labor costs, higher yields, reduced fertilizer use, lowered fuel consumption, lowered pesticide use, increased mechanical efficiency (fewer passes), reduced soil erosion, reduced sediment losses, and reduced nitrogen losses are all co-benefits associated with this strategy. Other co-benefits exist as well. Of all the biological GHG strategies, this one seems to have the most co-benefits.

6.3.6 Economics and practicality of implementation

Research has shown that, unlike studies in the 1980s and 1990s, which found that no-till was less economical than conventional tillage, today, no-till is at least as economical as conventional tillage or may even be more economical. Not all crops show positive responses to no-till however, barley yields have been found to be 80-93% lower than with conventional tillage. Though, if diversified and extended crop rotations are combined with more inexpensive fertilizers in the context of no-till, higher net returns than conventional tillage have been realized.[47] Baig and Gamache do an extensive review of the literature surrounding the economics of no-till agriculture. Their overall conclusion is that, if implemented properly, no-till agriculture is at least as expensive as conventional tillage and most likely more profitable.

6.3.7 Key gaps that need to be address for success

The auditor general of Alberta found some serious issues with the verification process surrounding no-till agriculture when it comes to the Alberta C offsets system. Specifically, there was insufficient guidance on how to verify tillage offsets. The government of Alberta has released new guidelines in January of 2012 which aim to rectify this situation.[48] It has also created a new summerfallow reduction credit that is related to the no-till strategy. Further, the government released new coefficients and guidelines for farmers that describe how to apply for

[47] Zentner et al. 2002. Economics of Crop Diversification and Soil Tillage Opportunities in the Canadian Prairies. Agronomy Journal 94:216-230.

[48] Agricultural carbon offsets. Information update. Information for Alberta's offset market. Government of Alberta. Available at: www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/cl11618/$FILE/Information_Nov2011.pdf

agricultural C offsets.[49] It appears that no-till as a practice to promote biological CCS is sufficiently mature relative to the other strategies discussed in this report.

6.4 Genetically modified organisms

There are two broad categories in which biological CCS strategies can make use of GMOs, either in agricultural or forestry. Improved genetic stock in forestry applications have been shown to increase yields from 10 – 25%[50]. While these may be overly optimistic expectations, 2.5 – 5% increases may be more likely in the boreal forests of Alberta.

The use of GMOs may contravene the additionality evaluation criteria:

- Additionality – the use of genetically improved stock for tree planting has been underway for several decades in Alberta. It is currently the business as usual practice on Crown land to plant improved genetic stock. Agriculture also incorporates GMOs in the current business as usual management approach. Though with agriculture, the adoption of GMOs has risen in popularity since the late 1990's which may not qualify as a management option above and beyond the business as usual since 1990.

6.4.1 Scale of GHG emission reductions

Estimated GHG reduction potential for this strategy is 0.25 – 1 Mt CO_2e for genetically improved trees for plantations.

In agriculture, the expected tonnage of GHG reductions with GMOs is unclear. Major data gaps exist on the tonnage of crops grown using GMOs as well as the area of land dedicated to it.

6.4.2 Ability to measure (verify and validate)

In forestry applications, yield forecasting and calibration of growth and yields with field data has been underway for a number of decades. Knowing the expected volume gain from using GMOs

[49] Agricultural carbon offsets. Tillage management system. Information for Alberta's offset market. Available at: www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/cl11618/$FILE/184-albertaoffset-tillage-4.pdf

[50] McInnis, B., Tosh, K. 2004. Genetic gains from 20 years of cooperative tree improvement in New Brunswick. Forestry Chronicle. 127- 133.

relative to planting non-GMO species, will go a long way to improving the measurement of the C gains in forestry applications. Volume of wood is estimated prior to harvest, after harvest and at the mills. The expected yield from GMO species would need to be compared to these benchmarks to estimate the increases in volume gained through GMO use. The ability to measure, in a verifiable way, remains a key gap to the success of this strategy as a biological CCS strategy.

Similar methods are likely underway in the agricultural world, where it is generally easier to measure the quantity of volume harvested. According to an AgBio report from the United States, genetically modified insect resistant (GM IR) maize crops in Canada are expected to yield an extra 5% volume using GMOs.[51] Note that the source of this figure is Monsanto, the producer of the GMO seeds. The Canola Council of Canada, an institution funded by the Government of Canada and industry partners, suggests yield increases of 10% may be possible by using GMO canola[52]. Recent reports have shown Canola yields increasing since 1990 from about 1.2 tonnes/ha to almost 1.6 tonnes/ha in 2006[53] which is about a 13% increase. True measurement of crop yields would come from the farmers or producers of crops themselves.

A life cycle analysis (LCA) of using GMOs in an agricultural setting is likely a key gap that needs to be addressed for the adoption of this biological CCS strategy. However, as found in the AgBio Forum report referenced above, GMOs were reported to have contributed to less use of pesticides, less fertilization rates.

6.4.3 Maturity of the scientific and technical knowledge

In the forestry realm, research and the science of improved genetic stock is largely settled. Studies have shown increases in size, diameter classes and overall volume of genetically improved tree species.

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[51] Brookes, G., Barfoot, P. 2006. Global impact of biotech crops: socio-economic and environmental effects in the first ten years of commercial use. AgBioForum 9(3): 139-151.

[52] Canola Council of Canada. 2011. Canola performance trials. Informing seeding decisions. Available at: http://canolaperformancetrials.ca/media/162257/canolaperformancetrialsbooklet_dec2011.pdf

[53] Lifecycle analysis canola biodiesel. O'Connor, D. 2011. Available at: http://www.canolacouncil.org/uploads/1.%20Lifecycle%20Analysis%20Canola%20Biodiesel%20-%20Don%20O'Connor.pdf

In the agricultural realm, the science and technical knowledge is still evolving. From 1997 to 2000 the area of land dedicated to GMO crops increased from 17% to 66%. As such, there has really only been about 12 years of solid research on the actual use of GMO crops in Canada. Most data supports the benefits of using GMO crops, especially canola though the research is still in progress.

6.4.4 Readiness of the marketplace or policy environment

In both forestry and agriculture, the marketplace has already adopted the widespread use of GMOs. While there exists undercurrents of protest against the use of GMOs, these elements have hardly dissuaded the marketplace from using and continuing to make use of GMO products.

6.4.5 Co-benefits

The co-benefits of GMOs in the agricultural realm are associated with reduced pesticide use, reduced sedimentary deposits and improved water quality. Similar benefits exist in forestry applications where pest resistant tree species are selected to be planted in order to reduce the risk of insect and pathogen attacks.

6.4.6 Economics and practicality of implementation

Agricultural GMOs have been reported to increase the profit of Canadian producers, as reported in 2005 for the 10 year period from 1996 to 2005 by over $1 billion. Most of the increases in profits were reported for canola production.[54] The Canola Council of Canada reported that while the costs of the GMOs per acre were slightly higher than conventional canola, the profit margin was consistently higher than the conventional canola crop.

6.4.7 Key gaps that need to be address for success

A key gap that needs to be addresses for successful adoption of GMO use as a biological CCS strategy is the verification of actual yield increases resulting both the forestry and the agricultural sectors. LCAs on the use of GMOs with respect to C benefits would begin to address this gap. There has been work done on using certain aspects of GMOs for GHG benefit, though no comprehensive synthesis seems to exist in Canada.

[54] ibid

6.5 Intensive Silviculture Use

The general goals of intensive silviculture use are to increase both the quality and the quantity of wood produced from given forest areas, to promote a successful regeneration of stands following harvest, and to provide a predictable flow of timber from a forest management area. Through combinations of thinnings, plantings, and other treatments and prescriptions, forest stands are tended to reduce mortality and promote the growth of healthy, quality timber. Increases in volume and wood quality result in increases in forest C stocks relative to stands with no such silviculture practices employed.

Silviculture is generally prescribed on Crown lands in Alberta. For those lands, regulations and frameworks describe the systems that need to be employed. However, silviculture could still be used to increase the forest C stocks over conventional levels.

Intensive silviculture use meets the following evaluation criteria:

- Additionality – given the current regulations and policies surrounding the silviculture systems in place in Alberta now, there are opportunities to add specific interventions with the goal of increasing forest C stocks.
- Leakage – as long as the goal of the intensive silviculture use is to increase C stocks and merchantable volume, then the overall C and volume density of the forests should increase. This would make it possible to harvest less area and still maintain the same amounts of volume harvested. However, if harvest levels are reduced in Alberta for the sake of increased C stocks, then the possibility for leakage would exist.
- Co-benefits – stand tending and silviculture operations require human resources to achieve desired results. This creates employment opportunities. Commercial thinnings, if applicable, also create smaller harvests and provide fiber from the forests.

6.5.1 Scale of GHG emission reductions

The most common form of intensive silviculture use in Alberta is planting following clearcutting with about 60,000 ha planted every year. Given the fact that plantations generally accrue volume faster than naturally regenerated stands, the opportunity for GHG emissions reductions exists. We estimate that about 0.25 – 0.5 Mt CO_2e / yr are possible with this strategy. In Alberta, there is about 1 M or more ha already dedicated to plantations. Other forms of silviculture in Alberta seem to be less common. There is very little pruning, little pre-commercial thinning, less fertilization, a few hundred hectares of commercial thinning, even less selection harvesting, virtually no seed tree clearcutting and a few thousand hectares of shelterwood harvesting. There definitely exists opportunities to increase silviculture treatments in Alberta, though these may not make sense in the boreal forests.[55]

6.5.2 Ability to measure (verify and validate)

Measuring the increased volume in plantations and forest stands with silviculture systems is difficult, but not impossible. Scaling and grading at roadside offer opportunities to cross validate the estimates from growth and yield curves which categorize growth expectations of plantations. Examining harvested volume in relation to the yield curves would address the data gap.

6.5.3 Maturity of the scientific and technical knowledge

Silviculture systems have been used for over 100 years in some form to increase the overall quality and volume of forest stands following harvesting and during regeneration. The science has not specifically looked at the opportunity to increase C stocks or to reduce GHG emissions, however. Generally, if volume per hectare is increased, then it follows that C per hectare is increased and silviculture systems can achieve this.

6.5.4 Readiness of the marketplace or policy environment

Certain forest ecosystems may or may not respond to intensive silviculture practices. In the boreal forests in Alberta, there already exist plantation requirements. Commercial thinning of relatively slow growing black spruce stand types may not make ecological sense. There may be opportunities for commercial or pre-commercial thinnings in the eastern slopes of the Rocky Mountains where the growth rates are better. It would make little sense to invest heavily in intensive silviculture treatments beyond plantations if there is will be limited ecological response or viability.

[55] National Forestry Statistics. “Silviculture- National Tables” available online: http://nfdp.ccfm.org/silviculture/national_e.php accessed February 2012.

6.5.5 Co-benefits

One of the co-benefits of intensive silviculture practices is a shortened regeneration delay in the establishment of new stands. Also, employment derived from tree planting and stand tending is a co-benefit of this biological CCS strategy. There may be some environmental benefits to reducing the regeneration delay following clearcutting in terms of soil erosion and dispersal. Forested land tends to erode less and be less dusty than exposed ground.

6.5.6 Economics and practicality of implementation

The economics of establishing aggressive silviculture practices for the purposes of biological CCS seem dubious at best. Forestry in and of itself has a low return on investment. Investing in rather expensive stand tending exercises over a vast area may not be cost effective.[56] There may be better ways to invest in terms of biological CCS strategies.

6.5.7 Key gaps that need to be address for success

The major gap needed to promote the use of intensive silviculture as a biological CCS strategy is the availability of empirical data on the actual C gains from further investments in silviculture.

More specifically, data from established permanent sample plots on the actual volume gain or systematic development of wood quality improvements associated with undertaking intensive silviculture management practices in Alberta are required to adequately verify the opportunity that this strategy holds.

6.6 Purpose selected cultivars

By selecting cultivars specifically for increased biomass production over the current business as usual approach in Alberta there exists an opportunity for a biological CCS. However, determining whether this makes economic sense is a difficult question to answer. Also, there is conflicting evidence on whether a cultivar which produces more biomass than a counterpart is actually producing a better final end-product.

This strategy meets the following evaluation criteria:

[56] MacKenney, D. 2000. What's the economics of intensive silviculture? Forestry Chronicle, 76, 275 – 281.

- Additionality – Purpose selected cultivars would only meet this criteria if it is able to be shown that the cultivars chosen were chosen specifically for biomass increases. Currently the cultivars in place in Alberta have already gone through rigorous selection criteria for improved profitability, disease and pest resistance and overall growth. This may be a difficult evaluation criteria to meet

- Leakage – Assuming that by selecting increased biomass cultivars does not decrease the overall crop production, there should be little reason for leakage to occur.

6.6.1 Scale of tonnage

Given the complete lack of data available to estimate this, it is not clear as to the scale of tonnage which would be realized by this biological CCS.

6.6.2 Ability to measure

The ability to measure would most likely be fairly easy. Crops are already measured extensively en route to markets. Determining the biomass would be an extra calculation which could most likely be determined by a relationship from the bulk weight of the harvested crops.

6.6.3 Maturity of the scientific and technical knowledge

The scientific and technical knowledge with respect to the agricultural cultivars in Alberta is quite mature. There have been a plethora of field studies around the productivity, habitat suitability, biomass produces and profitability of most commercial agricultural crops in Alberta and the Canadian prairies[57]. It would most likely be reasonably easy to optimize the cultivars in use for optimal biomass production, while minimizing the losses to profitability. This, however, would take an analytical exercise with some verification methods as well.

6.6.4 Readiness of the marketplace

Given that the end product of the agricultural cultivars is chiefly designed for the marketplace, this strategy is ready for the marketplace. An assumption however, is that the optimal blend of cultivars in use would not sacrifice the quality of the products produced.

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[57] Nagy, J.G. 2003. .Economic returs to feed barley yield-increasing and disease resistance research at the Alberta field crop development centre. Canadian Journal of Agricultural Economics. 51. 281-298.

6.6.5 Co-benefits

The co-benefits for purpose selected cultivars may be difficult to distinguish from the business as usual. The agricultural sector of Alberta is likely already optimized for sustainability, profitability and socio-economic benefits. By implementing a purpose selected cultivar CCS in Alberta effectively the co-benefits would be reduced GHG emissions for the province.

6.6.6 Economics and practicality of the implementation

The economics of this strategy will prove whether it is a successful biological CCS. Agricultural practices are already working with thin profitability margins[58]. Instilling a protocol to increase the C capture and storage through an optimal cultivar blend could be possible with careful consideration of the profitability of the implementation. Simply optimizing for biomass accumulation would likely not be the most economically viable result. A careful optimization of both biomass CCS, profitability and socio-economic benefits would likely be the best course of action.

6.6.7 Key gaps needed to address for success

In order to address the key gaps for success with this strategy, it would seem necessary for a least a cursory examination of alternative strategies for cultivar selection through the agricultural sector of Alberta. An analysis dealing strictly with optimizing the desired results, in this case a biological CCS activity, socio-economic impacts and profitability would advise whether purpose selected cultivars would be an adequate biological CCS.

6.7 Maintain C stores through disturbance mitigation

Protecting important C reservoirs on public and private land is relatively easy to achieve with the proper information available for decision makers. With detailed maps of areas where there are significant C reservoirs, decisions to avoid such areas for development could be easily implemented. The difficulty begins when the reservoirs conflict with other industrial interests that do not necessarily consider the impact of disturbing the reservoirs.

This strategy meets the following evaluation criteria:

[58] Smith, G.,E., McKenzie, R.H., Grant, C.A. 2003. Optimal input use when inputs affect price and yield. Canadian Journal of Agricultural Economics. 51. 1-13.

- Additionality – meeting this requirement may be difficult as it is often difficult to prove that an action that was going to be taken wasn't (in other words, it is difficult to demonstrate that you were in fact going to disturb something, but decide not to). If projects which would otherwise disturb C stores on public land simply do not occur, then the additionality requirement is likely not met. It will be up to the project developers to show how they are indeed not disturbing C stores.
- Co-benefits – protecting peatlands or wetlands would have positive impacts on the habitat of certain migratory bird species as well as protect water quality. This has an economic spin-off in terms of duck hunting markets as well as improved water quality when considering wetlands.
- Effectiveness – leaving peatlands and other C dense areas is an effective strategy to reduce the overall GHG emissions.

Protecting C stores through avoided land disturbance may not address the following evaluation criteria:

- Leakage – if avoiding high C value areas leads to more area being disturbed elsewhere than leakage will be an issue. It does not necessarily make sense to build roads around certain areas if it is likely to cause more overall damage than simply building through a C dense area.

6.7.1 Scale of GHG emission reductions

Total emissions from deforestation in Alberta are from 3.5 to 5 Mt CO_2e / yr. This figure does not include linear disturbances so the actual number will be even higher. There are opportunities to reduce the overall footprint of deforestation activities by carefully selecting areas for deforestation. Currently, the majority of the deforestation is for either oil and gas development or exploration. It is clear that these activities will take priority over most other environmental and social issues, however there are opportunities to either buffer certain C dense areas, or re-establish wetlands and peatlands following resource extraction.

It is not outside the realm of possibility to expect close to 1 M t CO_2e / yr reductions if deforestation rates are reduced, or at least done with some optimization of areas deforested. If at all possible, negative impact on peatlands and wetlands should be minimized as they have many benefits related to habitat or water quality.

6.7.2 Ability to measure (verify and validate)

There remain difficulties in measuring and validating the area not deforested or protected without remote sensing or modeling exercises. This is an area that could be addressed with Alberta's new monitoring program. There are currently no comprehensive spatial datasets available for Alberta which could be used to pinpoint C dense areas worth protecting. However, the Alberta Biodiversity Monitoring Institute (ABMI) is currently developing an updated dataset that outlines the linear disturbance in Alberta.

6.7.3 Maturity of the scientific and technical knowledge

There is little doubt in the scientific community that C dense areas such as peatlands, old growth forests of considerable size and structure, and other C reservoirs have higher C amounts than do deforested, or scrub lands. Protecting these reservoirs as a biological CCS strategy is still under investigation; however sufficient scientific and technical knowledge is garnered to recognize the value of protecting these stores.

6.7.4 Readiness of the marketplace of policy environment

Small-scale reductions in deforestation would probably be justifiable from a market sense. Reducing the widths of linear features in the oil and gas industry, or eliminating deforestation activities in high C value areas could be adopted so long as the opportunity costs of using the land in question in this way is not too high. Although traditionally the opportunity cost of using development land for some other purpose (e.g. as a store of C) has been too high to justify avoiding the disturbance, the evolution of ecosystem service markets such as conservation offsets may increase this type of biological CCS strategy to realize a high tonnage of GHG emission reductions.

6.7.5 Co-benefits

There are significant co-benefits to protecting C stores on public land. Old-growth forests provide many intrinsic values, peatlands and wetlands provide numerous habitat and water quality benefits, and recreational values are generally higher with closed canopy, old-growth forests.

There are economic ramifications to removing recreational use areas for hunters, hikers, or other outdoor activities. Recreation remains a growing industry in Canada and Alberta. By creating reserves of C, a co-benefit of this strategy would be to allow for potentially more area for recreation purposes.

6.7.6 Economics and practicality of implementation

The economics and practicality of implementing disturbance mitigation is challenging in Alberta as the pressures associated with urban development and oil & gas development are growing as the price oil rises. However, small-scale reductions in deforestation may result in suitable reductions in disturbance while not entirely prohibiting development. A delicate balance must be struck between the value of oil and gas production and the need for reduced GHG emissions. From this perspective, peat lands, wetlands and old-growth forest stands should be prioritized for avoidance or as offsets given the large amount of organic C stored by these ecosystem attributes.

6.7.7 Key gaps that need to be addressed for success

There are a number of key gaps that need to be addressed to deliver the potential GHG emission reductions from avoided disturbance strategies. These gaps include:

- Data sets to support a provincial spatial identification of important C reservoirs in Alberta. The creation of a spatial dataset which outlines the important C reservoirs could help provincial land managers to identify where and what would be impacted by deforestation or other land disturbances for development. Work is underway in this area at Green Analytics, the Land Use Secretariat and the University of Alberta.
- There are no specific C related conservation targets for Alberta. Collaboration between SRD, ARD and the Land Use Secretariat to develop a framework for including strategic C stores in land use planning could begin to address this gap.
- A key practice gap that needs to be addressed to thwart the pace and scale of land disturbance in the province is the introduction of a pilot market-based instrument, such as conservation offsets, to validate the proposition that the environmental externalities associated with land disturbance can be internalized in existing land and resource use markets.

7. Summary of Promising Options and Key Gaps for Biological CCS

This report describes, assesses and evaluates the range of strategies the province of Alberta could consider deploying to realize substantial GHG emissions reductions through biological CCS. While there are a large variety of opportunities outlined Section 2 that can lead to more than 12.25 Mt of CO_2e reductions per year (Table 2), the most viable options will most definitely result in more modest tonnages of emission reductions.

Through the gap analysis conducted for this project, the following strategies are recommended for further exploration as viable means for CCEMC to invest in strategies that promote biological CCS:

- Extended forest rotations
- Reduced pile burning
- Afforestation
- Intensive silviculture
- Avoided land disturbance

The strategies recommended for further exploration are chosen based on their ability to qualitatively and quantitatively address the evaluation criteria outlined in Section 3. To ensure that these strategies realize the potential for biological CCS as outlined in Section 4, the key gaps described below need to be addressed.

7.1 Key Gaps Related to Extending Forest Rotations

There exists data and policy gaps that must be addressed in order for this strategy to be implemented as a biological CCS strategy. This strategy ultimately becomes an exercise in forecasting growth and yield on selected areas.

The main gap that needs to be addressed with extending forest rotations is to develop a forest inventory system that is annually updated and automated to reduce long-term verification and validation costs. Currently, there are initiatives underway to develop automated inventory processes for forest management using 4-band multi-spectral imagery and lidar remote sensing.

7.2 Key Gaps Related to Afforestation

There are two types of gaps that need to be addressed for afforestation to gain considerable uptake. First, there is a policy gap surrounding the ownership of the C in afforestation projects, especially on Crown Land. The development of new property right legislation to allow for co-ownership of any emission reductions generated from afforestation would be a critical market driver. Secondly, there is a lack of data on the amount of land area that would be eligible for afforestation in the province. Using afforestation protocol information and geo-spatial data analysis a detailed inventory of eligible lands in Alberta could be approximated and serve as a market enabler.

7.3 Key Gaps Related to Intensive Silviculture Use

The major gap that needs to be addressed to promote the use of intensive silviculture as a biological CCS strategy relates to empirical data on the actual C gains from further investments in silviculture.

More specifically, data from established permanent sample plots that capture the actual volume gain, or systematic development of wood quality improvements associated with undertaking intensive silviculture management practices in Alberta are required to adequately verify the opportunity that this strategy holds.

7.4 Key Gaps Related to Avoided Land Disturbance

There are a number of key gaps that need to be addressed to deliver the potential GHG emission reductions from avoided disturbance strategies. These gaps include:

- Data sets to support a provincial spatial identification of important C reservoirs in Alberta. The creation of a spatial dataset which outlines the important C reservoirs could help provincial land managers to identify where and what would be impacted by deforestation or other land disturbances from development. Work is underway in this area at Green Analytics, the Land Use Secretariat and the University of Alberta.
- The lack of C related conservation targets for Alberta. Collaboration between SRD, ARD and the Land Use Secretariat to develop a framework for including strategic C stores in land use planning could begin to address this gap.

- A key practice gap that needs to be addressed to thwart the pace and scale of land disturbance in the province is the piloting of a new market-based instrument, such as conservation offsets, to validate the proposition that the environmental externalities associated with land disturbance can be internalized in existing land and resource use markets.