IEA Bioenergy

Task 38

Greenhouse Gas Balances of Biomass and Bioenergy Systems

BIOMITRE

Greenhouse Gas Balance of a Forest Management and Bioenergy System in Canada

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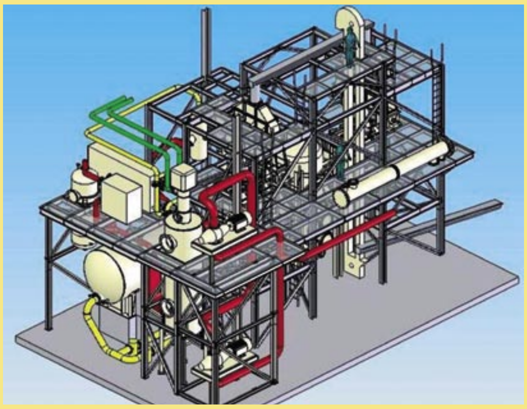
Summary

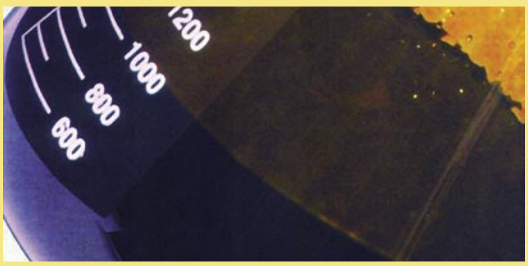
This study quantifies the greenhouse gas (GHG) impact of carbon sequestration as a result of pre-commercial thinning (PCT) on a forest stand, and of building and operating a plant that converts sawmill and forest residues, including thinnings, into bio-oil that will be substituted for fossil fuel. The objective is to determine if GHG emissions (in CO_2 equivalents: CO_2e) resulting from decay of thinnings can be offset by emission reductions by manufacturing bio-oil from forest residues and substituting bio-oil for fossil fuel in industry applications. The study also examines costs per tonne CO_2e (tCO_2e) emissions reduction.

Measurement and modeling results indicate that PCT on good sites (Plonski class 2 or better) results in a long-term increase in carbon stock of approximately 40 tCO_2e per hectare for a Northern Quebec Jack Pine stand. However, net GHG emissions result for several years after PCT due to decay of thinnings. In this case, cumulative emissions from decay of thinnings from PCT operations in 1990–2002 total 128,000 tonnes CO_2e. These emissions are completely offset by emissions reductions achieved over two years operation of a bio-oil plant by substituting bio-oil for fossil fuel.

PCT operation, courtesy of J. D. Irving Ltd., Canada



Bio-oil plant, courtesy of Dynamotive Energy Systems, Canada



Bio-oil sample, courtesy of Dynamotive Energy Systems, Canada

Scope

The case is developed in two parts: sequestration and bioenergy. The first part compares stock changes resulting from carbon sequestration in a natural "reference" stand with a stand that undergoes PCT. PCT is the deliberate removal of excess stems from over-dense stands of young trees. It enhances growth in the remaining stems allowing harvesting and forest renewal to occur earlier, thus shortening the rotation of the stand. Ultimately this allows sufficient wood to be supplied from a smaller land base, leaving some stands treed for other values.

The second part compares an existing "reference" system against a planned "project" that encompasses the construction and operation of a plant that will produce bio-oil. Bio-oil is a dark-brown liquid that is easily transported and can be combusted in boilers, turbines and stationary diesels. Except for minor emissions in manufacture, bio-oil is GHG neutral if the biomass feedstock is from a sustainably managed forest. In the reference system local industry uses diesel for engines, a pulp mill uses fuel oil to run a limekiln, sawmill waste is shipped to landfill where it decays and emits methane, and forest residues from harvest and thinning operations are either burned at roadside or left to decay in the forest. In the project a plant is constructed that uses fast pyrolysis to produce 400 tonnes per day (tpd) bio-oil from sawmill and forest residues. It is built beside a company sawmill. 40 % of the bio-oil is substituted for fossil fuel in a company pulp mill limekiln, and the remainder is sold to nearby industry. Also considered is the option of exporting excess production to Rotterdam. Included are GHG emissions from all transport, including shipping. The system boundary is illustrated in Figure 1.

Outside the system boundary are the GHG impacts resulting from sales of excess char, a byproduct of the manufacture of bio-oil. Char can be used to make charcoal. GHG emissions from the current manufacture and distribution of charcoal in the US are unknown, but they are estimated to be higher than using excess char to make charcoal locally and therefore are ignored.

Method

Sequestration System

In examining the sequestration system, all relevant carbon pools are considered, including above and below ground biomass, litter, soils, harvested wood products, and fossil fuels used to undertake PCT operations. The Graz Oak Ridge Carbon Accounting Model (GORCAM) developed by Dr. B. Schlamadinger, Joanneum Research, and Dr. G. Marland, Oak Ridge National Laboratory, was used to dynamically calculate carbon impacts. Growth and yield curves for Northern Ontario Jack Pine defined the carbon uptake for the reference forest, while 38 years of empirical data from PCT sample plots in Ontario and New Brunswick defined a growth curve for PCT. These curves are shown on Figure 2. Published decay constants were used to determine emissions in soils and litter, and decay from short-lived and long-lived wood products (Environment Canada UNFCCC Submission). Since PCT changes a stand's rotation period, here from 69 to 46 years, the GHG impact was calculated annually over 140 years, or three rotations for a PCT stand.

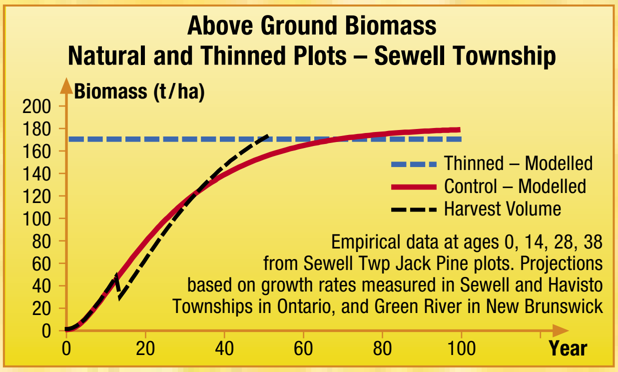


Figure 2. Growth curves for reference and PCT cases

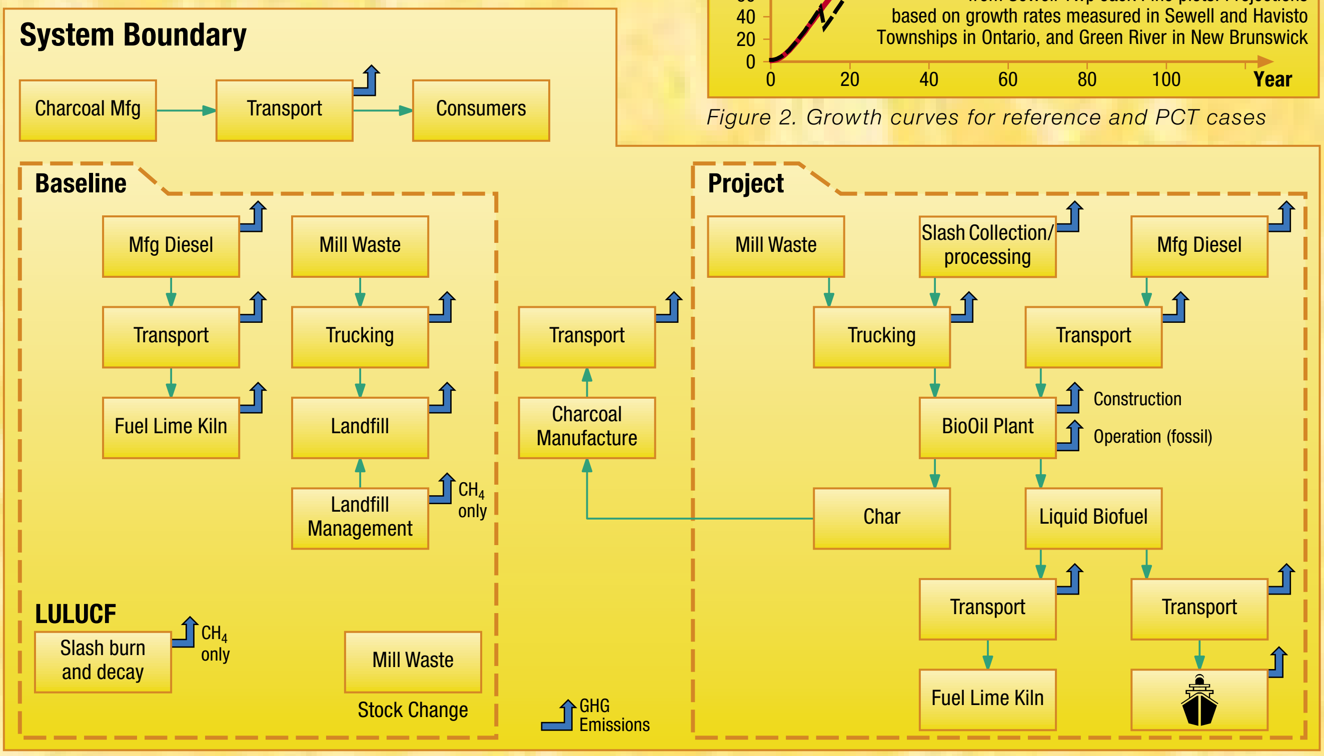


Figure 1. Bioenergy system boundary

Wood chips, courtesy of DOE/NREL, credit Warren Getz

Bioenergy System

The bio-oil plant uses some bio-oil and char for energy in its own process and produces 1,432,274 Gj of excess bio-oil. This defines the amount of fossil fuel that will be displaced in the reference system on a Gj equivalent basis. The limekiln currently requires 567,180 Gj of fuel oil #6, which has a heat value of 41.73 Gj/M3 and GHG emissions of 3.24 kg CO_2e/l. The remainder of displaced fuel is assumed to be third party use of fuel oil #4 in diesel engines, with GHG emissions of 3.1 kg CO_2e/l. The reference system considers upstream emissions resulting from manufacture of these fossil fuels, estimated at 16,314 t CO_2e/PJ production, and emissions from transporting fuel oil from Montreal to the pulp mill by rail and transporting bark to landfill by diesel truck. Feedstock for the plant consists of 35,154 oven-dry tonnes (odt) bark annually from two sawmills (which results in a saving of US$ 8.76/odt by eliminating landfill costs), 60,000 tonnes of harvest residues from roadside (70% of which currently burned), 23,446 odt of forest floor harvest residues, and 12,800 odt of PCT thinnings. Fossil fuel used in landfill management of sawmill residues is included. Important are non-CO_2 emissions from roadside burning of harvest waste (6.2 g CH_4/kg waste, 0.25 g N_2O/kg waste) and from decay in sawmill bark piles, where the Scholl Canyon model is used to calculate annual methane emissions (~1% p.a. of potential emissions of 118 kg CH_4/tonne waste). Forest floor waste is assumed all to decay as CO_2, which can be ignored in a sustainably managed forest. The reference case includes the annual stock increase of 35,154 BDMT bark, equivalent to 64,449 t CO_2e, less the bark which decays as methane, 46.6 tonnes CH_4, or 128 tonnes CO_2e.

Table 1. GHG emissions – first year

Baseline	**[t CO_2e]**	**Project (BioOil Facility)**	**[t CO_2e]**	
Fossil Fuel Emissions		**Fossil Fuel Emissions**		Net CO_2e reduction
Upstream manufacture of fossil fuel	23,352	Upstream mfg & transport of fossil fuel	954	
Fossil fuel transport from Montreal	182	Slash collection & processing	860	
Mill waste transport to Landfill	139	Residue and slash transportation	1,844	
Landfill Management	25	Construction of BioOil Plant	10,507	
Fuel oil use – lime kiln	43,908	BioOil transportation	166	
Fuel oil use – third party	66,970			
CH_4, N_2O Emissions		**CH_4, N_2O Emissions**		
Decay of landfilled residue (non CO_2 only)	980	BioOil production (non CO_2)	2,584	
Roadside waste burning (non CO_2)	17,447	BioOil combustion (non CO_2) kiln	93	
Forest waste decay (non CO_2)	0	BioOil combustion (non CO_2) sold	142	
Total Emissions	153,002	**Total**	17,150	(135,852)
Stock Change				
Landfill	64,321			
Total Emissions and Stock Change	**88,681**		**17,150**	**(71,531)**

In the bioenergy case GHG emissions from building the plant are based on an average Canadian GHG emission rate of 613 g CO_2e/US$ GDP (though this is now considered an overestimate since current modular plant construction concepts use less brick and mortar). The case includes emissions from fossil fuels used in chippers and forwarders to collect and process slash and diesel used to transport slash and sawmill residue to the plant. Emissions from transporting bio-oil to the pulp mill by diesel truck are 2.76 kg CO_2e/l diesel. In the export option, bio-oil surplus to limekiln requirements is transported by rail to Montreal, loaded onto 4,937 tonne capacity ocean tankers, and shipped to Rotterdam. Rail transport emissions are 0.0021 kg CO_2e per km per tonne bio-oil. Tankers use 0.015 t fuel oil/km.

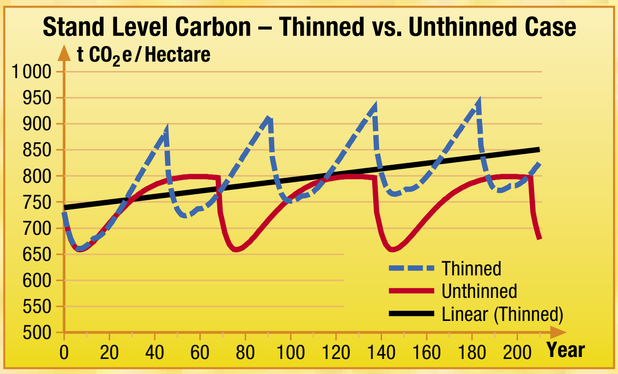


Figure 3. Stand level carbon balances for a thinned (PCT) vs. unthinned stand

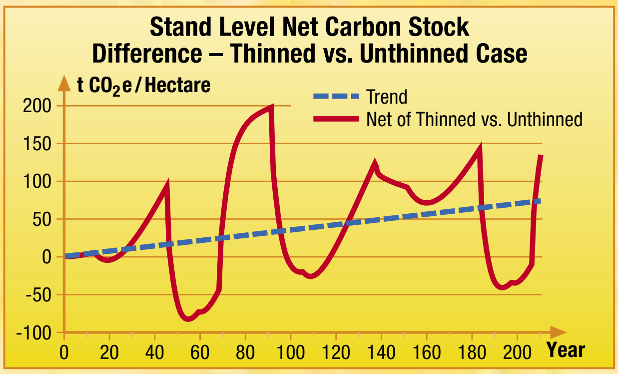


Figure 4. Net sequestration in PCT vs. reference stand

Bundler for slash feedstock, courtesy of Timberjack, Finland

Results

Table 2. Combined sequestration and bioenergy systems

GHG Emissions of Combined Projects / (Sequestration) [kt CO_2e]	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
BioOil Facility (2002+)	(71)	(83)	(83)	(84)	(85)	(86)	(87)	(88)	(89)	(90)	(89)
PCT Programs (1992+)	128	15	12	8	3	(2)	(8)	(15)	(22)	(29)	(37)
Net Emissions / (reductions)	56	(67)	(71)	(76)	(82)	(88)	(95)	(102)	(110)	(118)	(126)

Table 2 combines the net stock changes due to PCT with annual net emission reductions from the bio-oil plant. (Cumulative stock changes from PCT in 1991–2002 are combined into 2002 for simplicity). After two years of operation, emission reductions from bio-oil use of 71 + 83 = 154 kt CO_2e are sufficient to offset all previous emissions from slash decay of 128 + 15 = 143 ktCO_2e. By 2007 both systems are producing net emission reductions.

PCT enhances stand growth, enabling earlier harvest and forest renewal. Figure 3 compares the carbon balances for a reference (unthinned) stand and a PCT stand over several rotations. At the time of harvest of the PCT stand, it contains more biomass than the control stand in the above ground, below ground, litter and soil pools. A trend line shows the trend in sequestration due to PCT. Figure 4 shows net sequestration when the carbon balances in Figure 3 are combined. Despite a long-term gain in carbon stocks, thinning results in net GHG emissions in the early years as a result of decaying slash.

A forestry company thinned 16,000 hectares since 1991 on one of its forest licenses, and plans to continue at 1,950 ha p.a. In stands thinned in 1991–96, sequestration from enhanced growth now exceeds emissions from slash decay, while stands thinned after 1996 are still net GHG emitters as of 2004. For this company, thinning has caused cumulative net emissions of 127,800 tonnes CO_2e 1990–2002. At current levels of PCT activity, net emission is projected to continue until 2006, at which point annual sequestration will exceed emissions.

The annual GHG emissions of the bioenergy system are shown in Table 1. In the reference case, 43,900 t CO_2e are from the limekiln, or 29 % of emissions, and 67,000 t CO_2e are from local diesel engines that will be converted to bio-oil. 15 % of emissions are from the manufacture of fossil fuel. Landfilling sawmill residues increases carbon stocks by 64,300 t CO_2e. In the project case, 10,500 t CO_2e are emitted due to plant construction, however this is a one-time emission. The net emission reduction is 71,500 t CO_2e in the year of construction, and 82,000 t CO_2e in year two, increasing marginally each year due to increasing saving of methane emissions in the base case.

Cost per tonne CO_2e

Thinning, which costs on average US $ 402/ha, results in a long-term higher carbon stock of 40 Mt CO_2e/ha, for a cost / t CO_2e of US $ 10.05. The cost is up front whereas the benefit is achieved over time. However thinning is undertaken to enhance commercial timber yield, not for GHG reasons. Similarly, a bio-oil plant is not built to offset GHG emissions but to make a return on investment. The project results in positive cash flow per tonne (after tax), not a cost. As shown in Table 3, costs of US $ 11.8 million in 2002 (primarily construction costs) and a net emission of 56,000 t CO_2e produce a nonsensical cost per tonne indicator. In 2003, cost per tonne is after-tax revenue of US $ 40 / t CO_2e. Cost per tonne declines over time because emission reductions are increasing more rapidly than revenues.

To address changing cost / benefits over time, especially in the construction year, it is useful to assess lifetime costs per tonne, in this case the 15-year life of the plant (see Table 4). Costs and revenues result in lifetime cash flow of US $ 16 million for emission reductions of 1.47 million t CO_2e, for a revenue / tonne of US $ 10.95. If costs are discounted at a common industry discount rate of 10 %, revenue per tonne is reduced to US $ 1.87.

Table 3. Cost per tonne CO_2e

		2002	2003	2004	2005	2006	2007
Plant costs – cash flow after tax	[1,000 US$]	(11,781)	2,719	2,296	1,953	1,781	1,684
Emission Reduction	[t CO_2e]	(56,436)	67,199	71,349	76,194	81,940	88,278
Plant-$ Revenue / (cost) per t CO_2e	[US$ / t CO_2e]	209	40	32	26	22	19

Table 4. Lifetime cost per tonne CO_2e

Lifetime Cost per tonne CO_2e		**Plant Cost Alone**	
		15 year	NPV @ 10 %
Total Revenue / (Cost)	[1,000 US$]	16,122	2,754
Total Emission Reductions	[kt CO_2e]	1,473	1,473
Revenue / (Cost) per t CO_2e	[US$ / t CO_2e]	10.95	1.87

Uncertainty of results

Sequestration from forest management activity varies widely depending on the species, climate, soil conditions, the type and timing of the activity and other variables. In this case sequestration is not a critical factor in the analysis, however if PCT were done to acquire carbon offsets considerable modeling, measurement and verification would have to take place to have offsets certified.

In the bioenergy system, this bio-oil manufacturing process has been tested successfully in a 15 tpd pilot plant, however the actual feedstock may provide less energy than anticipated. Sensitivity analysis was undertaken on several aspects that were of interest to the company.

Table 5. Sensitivities

(Cost) / Revenue	**[US$ / t CO_2e]**
Base Case	10.95
Reduce char revenue (US$ from 40 to 80 per tonne)	8.45
Increase plant capital cost by 20 %	9.78
Emissions Reduction	**[kt CO_2e p.a.]**
Base Case Bio-oil Plant	82.6
10 % less energy per tonne biomass	69.3
Export 60 % of bio-oil to Rotterdam	78.0

References

Bradley D. 2004. Canada Case Study for Task 38. GHG Balances of forest sequestration and a bioenergy system. www.joanneum.at/iea-bioenergy-task38/projects/task38casestudies/can-fullreport.pdf www.climatechangesolutions.net

Bird N. 2002. Greenhouse Gas Emissions from Bioenergy Systems – A (draft) Case Study – Liquid Fuel from Forest. www.woodrising.com

Bradley D. 2001. Protocol for the Sequestration of GHGs in Forests Through Thinning of Juvenile Aged Stands. www.climatechangesolutions.net

Environment Canada 2000. Canada's Greenhouse Gas Inventory 1990–1998 – Final Submission to the UNFCCC Secretariat.

Discussion

In this bioenergy system over 70 % of the feedstock is either sawmill waste or harvest slash that is burned anyway. 30 % is from the forest floor. As sawmill sources become committed, and more waste is taken from the forest floor for additional plants it will be important to assess the optimum amount taken to ensure forest sustainability. In the sequestration system it is shown that, despite early net emissions, PCT results in net long-term carbon sequestration. To provide incentive for stand-alone PCT activity it may be useful to examine life-cycle accounting systems.

The manufacture and use of bio-liquids and subsequent substitution for fossil fuels present a tremendous opportunity for GHG emission reduction both in Canada and abroad. Although the Canadian forest industry has reduced GHG emissions by 26 % from 1990 levels, opportunities exist for further reductions, both through energy efficiency and conversion from fossil fuel to biomass energy use. For example, many limekilns still use fossil fuel, which results in significant emissions, and bio-oil has been tested and proved in limekilns. The Canadian government is establishing an emissions trading program that will allocate GHG emission reduction targets to industry. To achieve its target, the forest industry is looking at existing sources of biomass including sawmill waste, but is also looking at the potential in forest floor waste, which is currently used as a source of biomass in Finland and Sweden. Bioenergy development in Canada has been slow due to low alternative energy prices and the need for further testing of technologies. The Canadian government has policy measures that enable enhanced write-offs for bioenergy equipment, but with 5 million tonnes excess bark at forest industry mills and considerable potential in forest floor biomass, an enhanced policy package would increase biomass development.

Acknowledgement

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IEA Bioenergy

Task 38

IEA Bioenergy (www.ieabioenergy.com) is an international collaborative agreement, set up in 1978 by the International Energy Agency (IEA) to improve international cooperation and information exchange between national bioenergy research, development and demonstration (RD & D) programs. IEA Bioenergy aims to realize the use of environmentally sound and cost-competitive bioenergy on a sustainable basis, thereby providing a substantial contribution to meeting future energy demands.

IEA Bioenergy Task 38 brings together the work of national programs in 13 participating countries on Greenhouse Gas (GHG) Balances for a wide range of biomass systems, bioenergy technologies and terrestrial carbon sequestration. As one example of work, case studies have been conducted by applying the standard methodology developed by the Task 38. In the case studies GHG balances of different bioenergy and carbon sequestration projects in the participating countries have been assessed and compared, of which that of New Zealand is one example.

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