IEA Bioenergy Task 38

Canada Case Study

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GHG balances of forest sequestration and a bioenergy system

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[Acknowledgement: Ghg emission projections were taken from "Greenhouse Gas Emissions from Bioenergy Systems, A Case Study – Liquid Fuel from Forest Waste" (Draft), Woodrising Consulting, May 25, 2002]

Executive Summary

1. Objectives:

The study quantifies the greenhouse gas (GHG) impact of forest carbon sequestration from juvenile spacing (or pre-commercial thinning- PCT) in a Canadian mixed Jack Pine and Spruce forest, and the ghg impacts of a bioenergy facility that manufactures biooil from forest biomass. It is intended that early net ghg emissions from decaying thinnings from PCT can be offset by emission reductions by substituting biooil for fossil fuel. The study reviews an accounting option for standalone thinning or PCT projects, export potential of biooil, and costs per tonne CO_2e emissions reduction.

2. Description:

PCT is the removal of stems from over-dense young stands, which results in enhanced growth of remaining stems. Thinning shortens the harvest cycle enabling wood products to be supplied from less land, allowing more trees to remain standing. The result is a higher level of carbon stock in trees. However there is a ghg disincentive to PCT since the decay of thinnings causes net ghg emission in the early years. These emissions can be offset if they are used in a bioenergy application.

It is proposed to build a 400 tonne per day biooil plant at a sawmill. The plant will utilize the lowest-cost biomass including sawmill residues, forest residues from local harvest operations, and thinnings from the area PCT program. European collection technology is assumed with Canadian labour rates and haul conditions. The biooil plant uses Canadian technology and is based on pilot operating experience and on projects under development. The study explores the potential for biooil to replace the current use of fuel oil in the limekiln of a nearby pulp mill, and explores options for bio-oil export to Europe. It is assumed that char, a co-product of biooil production, will be utilized as a solid fuel in North American markets. The study examines ghg impacts on all relevant carbon pools including above and below- ground biomass, litter, soils and carbon stock changes in wood products.

3. Results:

PCT operations 1992-2012 result in cumulative GHG **emissions** from decaying thinnings of 128,000 tonnes CO_2e by 2002, peaking at 166,000 tonnes in 2007 before sequestration effects begin to offset emissions. The biooil plant achieves cumulative emission **reductions** of over 150,000 tonnes CO_2e in the second year of operation, offsetting emissions from construction and all emissions from previous thinning activity. Annual plant emission reductions offset all spacing emissions thereafter. Exporting biooil to Europe results in only a minor relative increase in the net emissions.

The biooil plant is an investment that achieves a positive rate of return. Since revenues and savings exceed costs there is no “cost” per tonne CO_2e avoided, but a “revenue” per tonne, $54US in 2003. When examined over the 15-year lifetime of the plant, revenue per tonne is $11US. If costs and returns are discounted at 10%, revenue per tonne is $2US. While a bioenergy project offsets early emissions from thinning, accounting mechanisms should be explored that encourage standalone PCT activity.

1. Pre-commercial Thinning- PCT:

1.1. Project Description:

PCT is the deliberate removal of excess stems from over-dense stands of young trees aged 10-14 years. For a Jack Pine stand thinning reduces stem density from 7,000/ha to around 1,800/ha. Slash (cut stems) is left onsite. Thinning reduces competition for space, light, water and nutrients allowing the live crown area of the remaining trees to expand, thus enhancing growth. Thinning is a common practice in Europe and is increasingly used in North America to enhance merchantable volume. While empirical evidence indicates a higher level of biomass per hectare from PCT in Balsam Fir stands in the Maritime Provinces, results are not consistent across Canada and for all species. Accordingly, this case assumes superior growth in biomass but to levels not exceeding unthinned stands. Wider tree diameters that result from thinning allow harvesting to occur with the same commercial yield at an earlier age, 45-50 years for Northern Ontario and Quebec Jack Pine instead of the normal 65-70 years on unmanaged stands. Early harvesting enables storage of carbon into wood products and earlier stand renewal. In the long term, shorter rotation allows wood products to be supplied from a smaller land base, leaving more trees standing for other environmental values. The result is an increase in carbon stock in the forest as a whole.

1.2. Greenhouse Gas Balances for One Hectare:

To determine the ghg impact of PCT, a baseline (natural growth) is compared with a project case (where a stand undergoes thinning at age 14). Growth and yield curves in Fig.1 illustrate above ground biomass (AGB) for a natural vs a thinned Jack Pine stand. The natural stand reflects a standard "S" growth curve. In the thinned stand the AGB pool initially loses biomass to litter and soil carbon pools, but soon regains lost biomass. As indicated above, this stand is ready for harvest several years earlier than the natural stand.

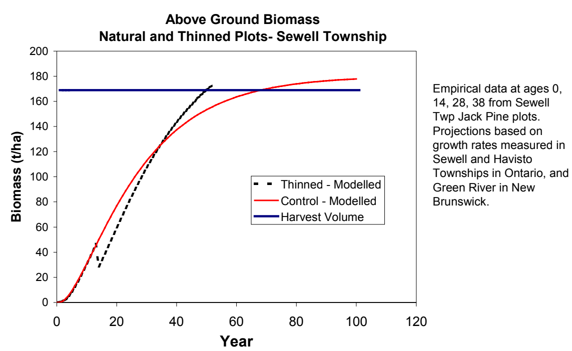


Fig. 1 Above-ground Biomass (AGB) Curves- Unthinned vs Thinned stand

Analysis of AGB is expanded to consider all relevant biomass pools, including above and below ground biomass (BGB), litter, soil, and wood products, and also fossil fuels from harvest and thinning operations. To confirm benefits are not just short term, ghg balances are modelled for several rotations. Ghg impacts are determined by predicting changes in carbon stocks using the GORCAM model[1]. (Appendix 1-Table 1-1 contains baseline (unthinned) and project (thinned) data for a one-ha Jack Pine stand. Table 1-2 summarizes stock changes from Table 1-1. Appendix 1-Illustration 1 depicts biomass tonnes by pool for the baseline and the project, and the difference in tonnes CO_2e).

Fig 2 illustrates the ghg impact on all carbon pools for an unthinned stand over three rotations and a thinned stand over the same time period with more rotations. A trend line has been applied to the thinned case to show the increasing net storage of carbon.

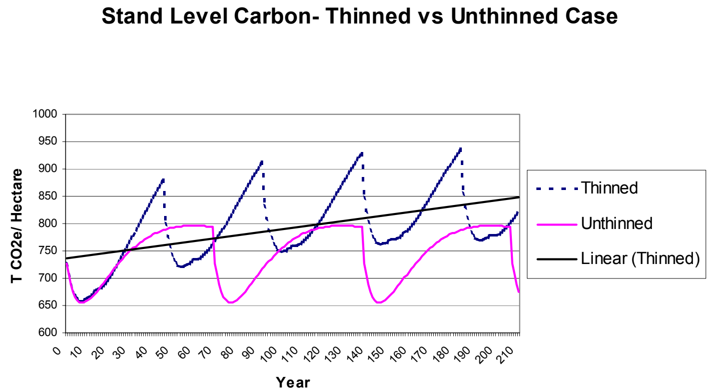


Fig 2- Stand Level Carbon Stocks (including below ground): Thinned vs Unthinned

Fig 3 reflects the difference between the thinned and unthinned stand, i.e. net carbon sequestered from thinning. When the net carbon line is above the x-axis, the carbon stock of the thinned stand exceeds the unthinned stand. Thinning results in a small net emission at ages 14-19 due to decaying slash, and thus has a lower net carbon stock. In years 20-24 the rate of carbon uptake in the fast-growing thinned stand exceeds the unthinned baseline, but its carbon stock is still lower. In years 25-45 the thinned stand achieves increasingly higher net carbon stocks until harvest at age 46, when it loses biomass in the harvesting process while the control stand continues to grow. At age 69 it is the baseline that loses biomass at harvest, while in the project wood products and forest carbon stocks increase relative to the baseline. A trend line has been applied to show trend in sequestration. Despite fluctuations due to altered rotation length, over time thinning has higher carbon stocks than the baseline when all pools are considered.

[1] The Graz Oak Ridge Carbon Accounting Model (GORCAM) was developed by Dr. B. Schlamadinger, Joanneum Institute, Austria, and Dr. G. Marland, Oak Ridge National Laboratory, USA, to dynamically calculate the impact of activities on all carbon pools including trees, roots, other vegetation, litter, soil, and short-lived and long-lived products.

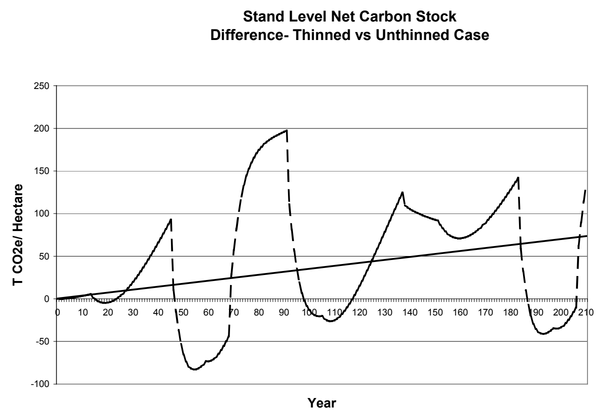


Fig 3. Net Stand-Level Carbon Stock- Thinning vs Baseline (tonnes CO_2e).

Fig 4 shows the forest level impact, or cumulative effect of annual thinning activity in several stands. Initially there is a large increase in carbon stocks in litter and soils as a result of annual thinning. After the first harvest there is an increasing level of carbon stored in trees as a result of stands left unharvested relative to the baseline, which become new forest reserves. There is no impact on harvested wood products since production is the same for the baseline and the project.

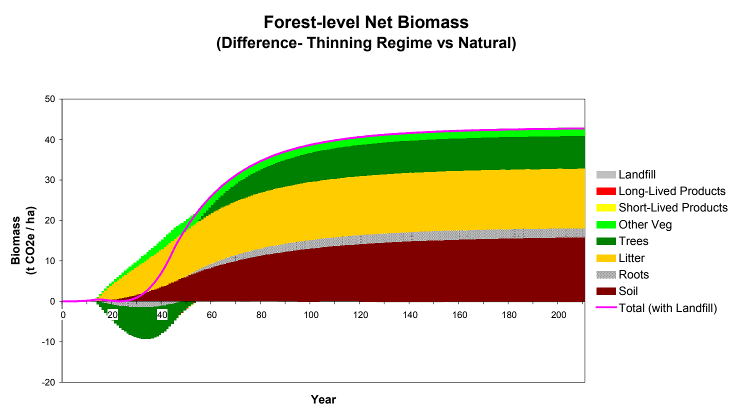


Fig 4. Forest Level Net Biomass- (tonnes CO_2e/ha)

While PCT and setting aside non-harvest land is clearly a good long-term project from a climate change perspective, it results in GHG emissions in the first few years. As shown in Table 1, AGB in the project is 40 tonnes CO_2e per ha less than the baseline in the year of thinning. Thereafter, annual C stock increases are greater in the project, but the cumulative AGB carbon stock is lower than the baseline well into the future. However carbon in the slash is not emitted immediately but merely enters the litter and soil pools, only decaying to atmosphere over time. When BGB, litter and soils pools are considered, the annual stock change is higher than the baseline for the project by year 7 and cumulative net sequestration is greater by year 13.

Table 1

Annual Stock Change- Above and Below Ground Forest Carbon at the Stand Level

Tonnes CO2e/ha

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13
AGB														
Baseline	8.3	8.2	8.1	8	7.9	7.7	7.5	7.3	7.1	6.9	6.7	6.5	6.3	6.1
Project	8.3	-31.7	8.6	8.7	8.8	8.9	8.9	8.9	8.9	8.9	8.8	8.8	8.7	8.7
Net	0	-39.9	0.5	0.7	0.9	1.2	1.4	1.6	1.8	2	2.1	2.3	2.4	2.6
Cumulative		-39.9	-39.4	-38.7	-37.8	-36.6	-35.2	-33.6	-31.8	-29.8	-27.7	-25.4	-23	-20.4
Soils, Litter, BGB:														
Baseline	-0.6	-0.6	-0.3	-0.1	0	0.1	0.2	0.3	0.4	0.4	0.4	0.5	0.5	0.5
Project	-0.6	36.1	-3.6	-2.9	-2.3	-1.7	-1.3	-0.9	-0.5	-0.2	0	0.2	0.4	0.6
Net	0	36.7	-3.3	-2.8	-2.3	-1.8	-1.5	-1.2	-0.9	-0.6	-0.4	-0.3	-0.1	0.1
AGB + Soils, Litter, BGB														
Baseline	7.7	7.6	7.8	7.9	7.9	7.8	7.7	7.6	7.5	7.3	7.1	7	6.8	6.6
Project	7.7	4.4	5	5.8	6.5	7.2	7.6	8	8.4	8.7	8.8	9	9.1	9.3
Net	0	-3.2	-2.8	-2.1	-1.4	-0.6	-0.1	**0.4**	**0.9**	**1.4**	**1.7**	**2**	**2.3**	**2.7**
Cumulative	0	-3.2	-6	-8.1	-9.5	-10.1	-10.2	-9.8	-8.9	-7.5	-5.8	-3.8	-1.5	**1.2**

1.3. Greenhouse Gas Balances for the Thinning Program:

A company began thinning on its Sustainable Forest Licenses in 1992, increasing activity in each year. Appendix 1- Table 1-3 shows actual hectares thinned by the company 1990-2001 and plan 2002-13, and applies a carbon stock change per hectare on Table 1-2 to calculate the overall GHG impact of this thinning activity. Fig 5 below shows the stock change as a result of the individual 1995 and 2002 programs, each beginning with slash emissions, and the impact of all 1992-2012 thinning activity (dotted line). Only in 2007 are carbon stock changes from prior years able to offset emission in the current year.

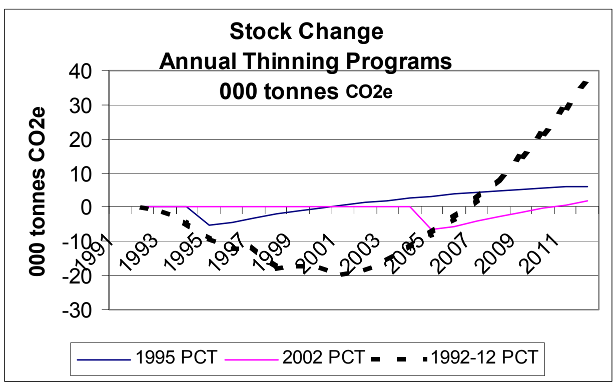


Fig 5. Annual Stock Change- Company Thinning Programs 1992-2012

Table 2 summarizes net annual and cumulative stock changes from Appendix 1-Table 1-2

Table 2- Carbon Stock Changes due to Thinning Program

GHG Impact of Case Thinning Activity

(000 tonnes CO2e)

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Annual	(1)	(5)	(9)	(12)	(11)	(18)	(17)	(17)	(20)	(18)	(15)	(12)	(8)	(3)	2	8
Cumul	(1)	(6)	(15)	(27)	(38)	(56)	(73)	(90)	(110)	(128)	(143)	(155)	(163)	(166)	(163)	(155)

Fig 6 below illustrates the cumulative effect of the above thinning programs. Even though total net positive carbon stock change is anticipated in the future, the impact of the combined thinning activity results in a net negative ghg balance until 2014.

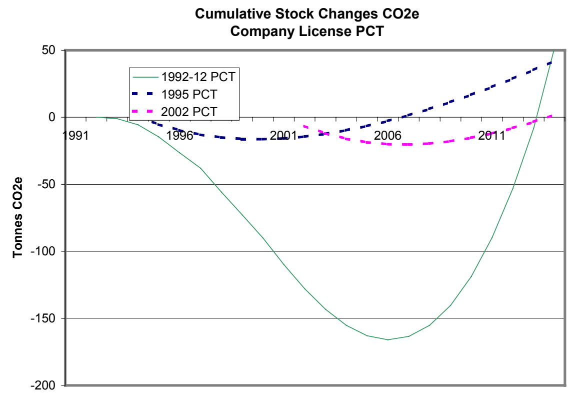


Fig 6-Cumulative Stock Changes- Company Spacing Programs 1992-2012

PCT has many other benefits. It contributes to socio-economic sustainability by maintaining wood supply for forest products industries, and by providing employment in rural areas where unemployment is often high. In Ontario, PCT is increasingly undertaken through contracts with First Nations. For example, Wikwemikong First Nation members are trained and employed by company forestry crews.

1.4. Accounting for Forest Carbon:

Fig 7 below combines net sequestration from PCT and fossil fuel emissions from harvesting and thinning. The cyclical line reflects 'real-time accounting', which accounts for carbon flows when they happen. This accounting of carbon stock change acts as a disincentive to forestry applications such as PCT for many reasons. For example, despite long-term benefits, early emissions are a problem. Real time accounting can require frequent measurement to verify carbon sequestration, yet cost considerations limit stand measurement to 5-year intervals. Cyclic carbon fluxes would result in administrative difficulty and transaction fees because of the frequent buying-selling-buying of credits. Alternative accounting methods are being developed to handle such difficulties, such as the average carbon stocks method proposed by Dr. M Kirschbaum. [i] A long-term average carbon stock level of an activity is estimated, and carbon uptake is credited on an even and annual basis over time until the long-term storage is reached, shown in Fig. 7.

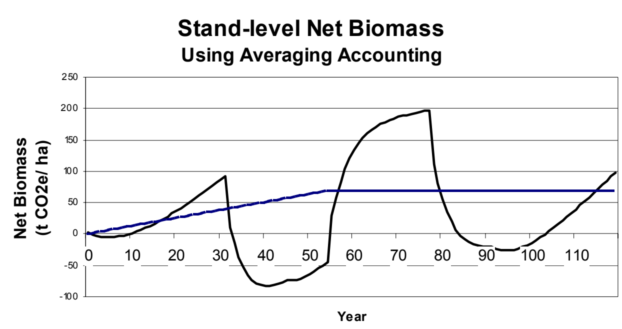


Fig. 7- "Real Time" Carbon Stock Change and "Averaged" Stock Change

Crediting average sequestration is simple, saves on costs for measurement, verification and transaction fees, and eliminates the disincentive from near-term debits. Adjustments to credits can be made periodically if credited sequestration is found to exceed actual. The Kyoto Protocol, confirmed in Marrakech Accords, specifies that forest carbon sequestration will be quantified as the stock change over the first commitment period, therefore crediting in advance of sequestration is disallowed, however averaging may be adopted for domestic implementation. Until innovative accounting mechanisms are developed and accepted, alternative ways must be found to offset initial GHG emissions of projects that reduce long-term emissions. One method is to use thinnings, that would normally decay to atmosphere, to produce biooil to replace fossil fuel, thus providing an offset to near-term emissions.

2. BioOil Plant

2.1. Description-

As in this case, many companies in the forest industry in Canada are integrated, with forest harvest operations, sawmills and pulp mills. The company undertaking thinning operations also consumes internally or sells 60% of the waste bark from its sawmills, and landfills the remaining 40%. Two sawmills are 30 km apart and produce 44,684 oven-dry tonnes (odt) of bark pa, of which just over 35,000 odt pa goes to landfill incurring a charge of $Cdn 4.50/M^3 ($11.25/odt). It is proposed to build a bioenergy facility at one sawmill that would use surplus sawmill residues and other biomass to manufacture biooil. Biooil would be shipped to the companies pulp mill to replace the fuel oil used in the limekiln, with surplus used in local industry operations, or for export to Europe. The following scenario analysis is based on this proposed bioenergy project.

BioOil from pyrolysis of wood is a brown, free-flowing liquid comprised of highly oxygenated compounds and has a density of 1.2 kg/litre. Its heating value is 40% of diesel by weight and 55% by volume. It can be stored, pumped and transported like petroleum products and can be combusted directly in boilers, gas turbines and slow to medium speed diesels for heat and power. The proposed biooil plant will use fast pyrolysis technology (developed by Dynamotive Energy Systems, Vancouver) whereby biomass waste is rapidly heated in the absence of oxygen, vaporized, and then condensed into liquid fuel. Dynamotive has run a successful 15 tonne per day (TPD) biooil pilot, and in 2004 expects to complete construction of a 100 TPD plant in Ontario.

2.2. Biomass Supply and BioOil Production:

To maximize project return a biooil plant should be sized to use about 400 green tonnes of wood waste, or about 125,000odt pa. Currently only 35,000 odt is available from the two sawmills. There are other biomass sources. Roundwood for the sawmills is supplied from three large sustainable forest licenses on Crown land owned by the province of Quebec. On these licenses 1,200,000 m^3 of forest floor biomass is generated annually from harvest operations. About 80% of harvest slash is left at the roadside as a result of full tree harvesting methods. This material is normally either burned under controlled conditions to limit the chance of uncontrolled fire, or is left to decay. About 20% of delimbing occurs at the stump where slash is left to decay. In addition to harvest slash, approximately 2000 hectares in the harvest area undergoes thinning annually, leaving additional forest floor biomass. It is proposed that the facility use a mix from these sources that results in the lowest cost.

Sawmill residues currently incur landfill costs, including transportation and tipping fees, therefore the cost of this biomass supply is negative, shown below as a cost savings of $9US/odt. Slash from the forest is a net cost since it must be chipped and transported to the plant. Waste left at roadside is the least costly forest waste since it has already been forwarded from stump to roadside. In operating the plant the lowest-cost biomass will be used, but for plan purposes the mix and unit costs shown in Table 3 below are used.

Table 3

Biomass Supply- year 1

	M3 pa	Odt per annum Available	Use	Odt/day Use	Cost/odt $Cdn	$US
Sawmill #1		19,856	19,856	60		
Sawmill #2		15,298	15,298	47		
Total Mill Residues		35,154	35,154	107	(13.07)	($8.76)
Harvest waste at roadside	750,000	302,400	60,000	183	44.72	$29.96
Harvest waste at stump	85,000	33,600	23,446	71	60.18	$40.32
Thinnings		12,800	12,800	39	57.48	$38.51
		383,954	131,400	400	33.26	$22.28

Two products will be produced at the plant: liquid biooil fuel and granulated charcoal powder. Some of the biooil will be used in plant operations; some will be shipped to the pulp mill and burned in the limekiln, replacing fuel oil #6. Biomass cannot be burned directly in the limekiln because of the danger of adding carbon to the process. The remainder either will be sold to local industry as a substitute for diesel fuel #4 in stationary diesel engines (Case 1) or shipped to Montreal for export to Europe (Case 2). Annual biooil production, net of that burned in the plant, is summarized in Table 4 below. It is assumed that char is sold locally to a charcoal briquette manufacturer.

Table 4

Annual Production and Use

BioOil:	GJ pa	M3 pa	MT	%
For Pulp Mill Lime Kiln	567,180	27,480	32,976	40%
For External Sale	865,094	41,913	50,296	60%
Production Available	1,432,274	69,393	83,272	
Char:			13,197	

The projected cost structure of the plant is shown in Appendix 2-Table 2-1. Cost savings include the purchase of fuel oil used in the pulp mill, its rail transportation from Montreal, and the cost to landfill sawmill bark. Revenues include sales of biooil to local industry to replace diesel fuel in engines, and sale of char. (Demand for biooil in the vicinity is unknown. At worst, the biooil would be used in a paper mill East of Montreal at a slightly higher transportation charge than shown.) Expenses include waste collection and transport, manufacturing costs, transportation of biooil (rail), and a royalty paid to Dynamotive on sales of char and biooil.

2.3. GHG Balances for the BioOil Plant:

2.3.1. Baseline GHGs:

Annual baseline emissions are shown in Appendix 3-Table 3-1. The first year is shown in Table 5 below. 72% of GHG emissions result from burning fossil fuels: in transport, the pulp mill limekilns, and fuel now used by local industry that will be replaced by biooil from the project (assumed to be diesel for stationary engines). Included are emissions from transporting fossil fuel by rail from Montreal for all fuel that will be substituted by biooil, including third party. Emissions are calculated using published emissions rates for each fuel type, shown in Appendix 5. 15% of emissions, or 23,352 tonnes CO_2e, are from upstream emissions caused in the production of the fossil fuel oil, calculated using published emissions factors for fossil fuel production. Also considered are emissions from transporting sawmill residues to landfill by diesel trucks, and in landfill management by a third party. Methane emissions from sawmill residues in landfill decaying to atmosphere are calculated as 118 kg CH_4/green tonne wood waste [ii]. The stock change from sawmill residues is calculated as the amount of carbon in green biomass (25%) * 44/12 (molecular wt of CO_2 vs C).

2.3.2. Project GHGs for the BioOil Plant:

The project includes emissions from construction of the biooil plant, estimated using a published emission factor per dollar capital spent. Fossil fuel emissions from forwarders and chippers used in slash collection and processing, and truck transport of all residues to the plant, are reflected. The biooil manufacturing process uses energy primarily from biooil and char made on site. All ghg emissions from diesel combustion, and methane emissions from combustion of biooil and char, are included. Fossil fuel emissions transporting biooil by rail to either the limekiln or local industry are included.

Table 5

GHG Emissions- First Year

Tonnes CO2e

Baseline		Project (BioOil Facility)		Net
Fossil Fuel Emissions		***Fossil Fuel Emissions***		
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- Quevillon lime kiln	43,908	BioOil transportation	166	
Fuel oil use- third party	66,970			
CH4, N2O Emissions		***CH4, N2O Emissions***		
Landfill Gas (non CO_2 only)	980	BioOil production (non-CO_2)	2,584	
Roadside Waste Burning (non CO2)	17,447	BioOil combustion (non-CO_2) kiln	93	
Waste Decay (non-CO2)	0	BioOil combustion (non-CO_2) sold	142	
Total Emissions	153,002	**Total**	17,150	(135,852)
Stock Change				
Landfill	64,449			
Total Emissions and Stock Change	88,553		17,150	**(71,403)**

Outside the system boundary are emissions from manufacture and distribution of charcoal, which are unknown. The baseline case assumes 3rd party manufacture of charcoal, while the project scenario assumes the manufacture of charcoal from char at a local briquette plant. Since emissions are estimated to be greater for the baseline, excluding these emissions is a conservative approach to calculating net ghg reductions.

Not part of the analysis (and excluded from the Kyoto Protocol) are CO_2 emissions from burning or decay of biomass in the forest and landfills, and from biooil combustion in the biooil manufacturing process and in the limekiln. In sustainably managed forests emissions as a result of decay or combustion of biomass are offset by growth in forests.

2.3.3. Net GHG Impact- Biooil Plant vs Baseline:

As shown in Table 5, baseline emissions from fossil fuel and landfill gases are 153,002 tonnes CO_2e p.a. Project emissions are 17,150 tonnes in 2002 including construction of the BioOil plant, for a net of 135,852 tonnes CO_2e. When the stock change for landfilled residue is included, net emission reduction is 71,403 MT CO_2e. After the first year, when emissions from plant construction no longer arise, annual reductions are 71,403 + 10,507 = 81,910 MT CO_2e. A system boundary diagram is shown in Appendix 4.

2.3.4. Export Option (Case 2):

Case 2 assumes that 41,913 m^3 of biooil surplus to limekiln requirements is transported to Montreal by rail, loaded onto ocean transports and shipped to Rotterdam for sale into Europe[iii]. Transports are small chemical tankers suitable for pyrolysis oil with capacity of 4,927 M^3. Nine shiploads are required annually. To maintain tank integrity, ships are dedicated to biooil and return to Montreal empty, adding to costs. Assumptions are in Appendix 5. As shown in Table 6, emissions increase by 4,300 tonnes CO_2e for the export option. Costs and emissions can be reduced with larger ships with return cargos.

Table 6- Annual Net Emission Reductions- MT CO_2e

Annual net emission reductions from Case 1 (2.3.3)	81,910
Emission savings by not trucking biooil locally	200
Emissions transporting biooil to Europe	(4,500)
Net emissions reductions- export option	77,610

3. Combined Spacing and Biooil Projects:

Shown in Table 7 below is the combined GHG impact of the biooil facility and PCT programs. (For simplicity, 1992-2002 net emissions from thinning of 128,000 tonnes are combined into 2002.) PCT results in net annual emissions until 2006. In each year emissions reductions as a result of the biooil plant offset emissions from PCT, except for 2002. Therefore, the biooil plant will offset early emissions from all company PCT activity 1992-2012. Details are shown in Table 3.2-Appendix 3.

Table 7

Combined Projects GHG Emissions/(Sequestration)

000 Tonnes CO2e

	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)

A company may wish to know only if a plant will offset new thinning activity, not historic activity. In Table 8, though new thinning activity has net emissions until 2013, these emissions are offset by emission reductions from the plant in each year.

Table 8

Combined Projects GHG Emissions/(New Sequestration)

000 Tonnes CO2e

	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)
New PCT Programs (2002+)	7	12	16	19	20	20	20	18	15	12	8
Net Emissions/ (reductions)	(65)	(71)	(67)	(65)	(65)	(66)	(67)	(70)	(73)	(77)	(81)

4. Cost per tonne CO_2e avoided emission:

All costs are compared on an after-tax basis. The cost of PCT varies widely depending on species, stem density and terrain, and ranges from $Cdn500/ha for Ontario Jack Pine to $Cdn800/ha for very dense Black Spruce stands in Quebec. An average is approximately $Cdn600/ha ($US444). Planned activity of 1,950 ha p.a. would result in annual costs of $Cdn1,170,000 before tax, or $Cdn644,000 ($US477,000) after tax as shown in Table 9. If this activity were undertaken specifically to supply the biooil plant it would be appropriate to include it in the cost per tonne, however in this case the activity is done anyway and therefore costs should not be included.

The biooil plant will be a commercial operation, which must make an acceptable rate of return to proceed. Shown in Table 9, plant cash flow is $Cdn(15.7) million in the first year owing to construction. In 2003-10 annual cash flow is positive $Cdn3.6 million, declining each year, due to reduced tax depreciation, to $2.3 million in 2010. The result is not a cost/tonne but revenue/tonne CO_2e, $Cdn54/t in 2003. Even if the cost of thinning were included, the combined projects would result in a revenue/tonne of $Cdn44 ($US33) in 2003.

Table 9

Cost per Tonne CO2e

$Cdn

	2002	2003	2004	2005	2006	2007	2008	2009	2010
Plant costs- cash flow after tax($000)	(15,707)	3,625	3,061	2,604	2,374	2,246	2,193	2,198	2,252
Emission Reduction (MT CO2e)	-56,436	67,199	71,349	76,194	81,940	88,278	95,129	102,496	110,321
Plant- $Revenue/(cost) per MT CO2e	**$278**	**$54**	**$43**	**$34**	**$29**	**$25**	**$23**	**$21**	**$20**
If Spacing costs included:									
Cost 2002-16 (1,950 ha pa) ($000)	(644)	(660)	(676)	(693)	(710)	(728)	(746)	(765)	(784)
Total Plant + Spacing Cost ($000)	(16,351)	2,966	2,385	1,911	1,664	1,518	1,447	1,433	1,468
Total- $Revenue/(cost) per MT CO2e)	**$290**	**$44**	**$33**	**$25**	**$20**	**$17**	**$15**	**$14**	**$13**
$US/MT	$214	$33	$25	$19	$15	$13	$11	$10	$10

To accommodate the peculiar result in the construction year and changing annual costs, another way to reflect cost/tonne is over the lifetime of the project, in this case 15 years. Table 10 below compares lifetime project cash flow of $21 million with emission reductions of 1.47 million tonnes CO_2e. The result is positive at $Cdn14.60/tonne ($US10.80). If the cash flow stream is discounted at a common industry discount rate of 10%, the result is still positive at $US1.80/tonne. If thinning costs are included, the revenue per tonne CO_2e is $US5.

Table 10

Lifetime Cost per MT CO2e

	Plant Cost Alone		Plant + Spacing Costs	
	15 year	NPV @10%	15 year	NPV @10%
Total Revenue/(Cost) ($000)	21,496	3,672	9,957	410
Total Emission Reductions (000MT)	1,473	1,473	1,473	1,473
Revenue/(Cost) per MT ($Cdn)	$14.60	$2.49	$6.76	$0.28
Revenue/(Cost) per MT ($US)	$10.80	$1.84	$5.00	$0.21

5. Sensitivities:

The following sensitivities represent the average (cost)/revenue per tonne GHG reduction over a 15 year period. They do not include the tradable carbon value, which is projected to be in the $5-10US/tonne range.

	(Cost)/Revenue \$US/tonne CO_2e
Base Case	10.80
Reduce char revenue to \$40/tonne from \$80	8.45
Increase capital cost by 20%	9.78

	Emissions Reduction (000 tonnes CO_2e p.a.)
Base Case Biooil Plant	82.6
10% less energy per tonne biomass	69.3
Export 60% of biooil to Rotterdam	78.0

6. Ownership of Emission Reductions:

To properly evaluate the GHG impact of a project, all emission reductions and sequestration impacts caused by the project within the system boundary are included. This approach prevents or minimizes leakage. However, the investor may not necessarily own all the emission reductions, including:

- Emission reductions from third parties that buy the biooil and use it in their operations instead of fossil fuel
- Emission reductions from reduced upstream manufacture of fuel oil
- Emission reductions due to reduced landfill management

The investor <u>may</u> be able to secure carbon value in the price of the biooil sold.

Canada is assessing different sequestration ownership options. The Federal government has proposed that business-as-usual sinks be considered a national treasure and not be available as offsets, with only those sinks resulting from above business-as-usual activity available to be sold as offsets. The Provinces, which own most of Canada's forests, consider that any carbon sink on Crown land is the property of the Provinces. The forest industry has an equal call on ownership as it pays for the forest management activity that results in the sink. These issues will be resolved in upcoming negotiations.

7. **Conclusion:**

Thinning of stands destined for harvest can have a positive long term impact on carbon storage due to reduced rotation length, which ultimately leads to supplying wood products from a smaller land base and the ability to set aside forests for other values. However, early emissions from thinning cause a disincentive to this activity, which must be addressed, potentially through accounting techniques such as averaging. In the absence of such mechanisms, developing bioenergy facilities that utilize slash from anthropogenic thinning activity can offset early emissions from decay.

TABLE 1

Net Emission- Above Ground Biomass and Other C Pools

(-)ve = emission from pool/ (+)ve =sequestration into pool

Tonnes CO2e/hectare

Year	Age	Baseline			Spacing Project			Net			Cumulative					
		AGB	Soil-Ltr-BGB	Wood Prod	AGB	Soil-Ltr-BGB	Wood Prod	AGB	Soil-Ltr-BGB	Wood Prod	AGB	Soil-Ltr-BGB	Wood Prod	Sum	Stock Ch	
-2	12	-8.3	1.1	3.6	-8.5	0.7	3.6	-0.2	-0.4	0.0						
-1	13	-8.3	0.8	3.4	-8.5	0.4	3.4	-0.2	-0.5	0.0						
1	14	-8.2	0.6	3.2	31.7	-36.1	3.2	39.9	-36.6	0.0	39.9	-36.6	0.0	3.3	-3.3	
2	15	-8.1	0.3	3.1	-8.6	3.6	3.1	-0.4	3.3	0.0	39.5	-33.4	0.0	6.1	-2.8	
3	16	-8.0	0.1	2.9	-8.7	2.9	2.9	-0.7	2.7	0.0	38.8	-30.6	0.0	8.2	-2.0	
4	17	-7.9	0.0	2.8	-8.8	2.3	2.8	-0.9	2.3	0.0	37.8	-28.3	0.0	9.5	-1.3	
5	18	-7.7	-0.1	2.7	-8.9	1.7	2.7	-1.2	1.9	0.0	36.7	-26.5	0.0	10.2	-0.7	
6	19	-7.5	-0.2	2.6	-8.9	1.3	2.6	-1.4	1.5	0.0	35.3	-25.0	0.0	10.3	-0.1	
7	20	-7.3	-0.3	2.4	-8.9	0.9	2.4	-1.6	1.2	0.0	33.7	-23.8	0.0	9.9	0.4	
8	21	-7.1	-0.4	2.3	-8.9	0.5	2.3	-1.8	0.9	0.0	32.0	-22.9	0.0	9.1	0.9	
9	22	-6.9	-0.4	2.3	-8.9	0.2	2.3	-1.9	0.7	0.0	30.0	-22.3	0.0	7.8	1.3	
10	23	-6.7	-0.4	2.2	-8.8	0.0	2.2	-2.1	0.4	0.0	27.9	-21.8	0.0	6.1	1.7	
11	24	-6.5	-0.5	2.1	-8.8	-0.2	2.1	-2.3	0.2	0.0	25.6	-21.6	0.0	4.0	2.1	
12	25	-6.3	-0.5	2.0	-8.7	-0.4	2.0	-2.4	0.0	0.0	23.2	-21.6	0.0	1.6	2.4	
13	26	-6.1	-0.5	2.0	-8.7	-0.6	2.0	-2.6	-0.1	0.0	20.6	-21.7	0.0	-1.0	2.7	
14	27	-5.9	-0.5	1.9	-8.6	-0.8	1.9	-2.7	-0.3	0.0	17.9	-22.0	0.0	-4.0	3.0	
15	28	-5.7	-0.5	1.8	-8.5	-0.9	1.8	-2.8	-0.4	0.0	15.1	-22.4	0.0	-7.3	3.2	
16	29	-5.5	-0.4	1.8	-8.4	-1.0	1.8	-2.9	-0.5	0.0	12.2	-22.9	0.0	-10.8	3.5	
17	30	-5.3	-0.4	1.7	-8.3	-1.1	1.7	-3.1	-0.7	0.0	9.1	-23.6	0.0	-14.5	3.7	
18	31	-5.1	-0.4	1.7	-8.2	-1.2	1.7	-3.2	-0.8	0.0	6.0	-24.4	0.0	-18.4	3.9	
19	32	-4.9	-0.4	1.6	-8.1	-1.2	1.6	-3.2	-0.9	0.0	2.7	-25.2	0.0	-22.5	4.1	
20	33	-4.7	-0.3	1.6	-8.0	-1.3	1.6	-3.3	-1.0	0.0	-0.6	-26.2	0.0	-26.8	4.3	
21	34	-4.5	-0.3	1.6	-7.9	-1.4	1.6	-3.4	-1.0	0.0	-4.0	-27.3	0.0	-31.3	4.5	
22	35	-4.3	-0.3	1.5	-7.8	-1.4	1.5	-3.5	-1.1	0.0	-7.5	-28.4	0.0	-35.9	4.6	
23	36	-4.2	-0.3	1.5	-7.7	-1.4	1.5	-3.5	-1.2	0.0	-11.1	-29.6	0.0	-40.6	4.7	
24	37	-4.0	-0.2	1.5	-7.6	-1.5	1.5	-3.6	-1.2	0.0	-14.7	-30.8	0.0	-45.5	4.9	
25	38	-3.8	-0.2	1.4	-7.5	-1.5	1.4	-3.7	-1.3	0.0	-18.3	-32.1	0.0	-50.4	5.0	
26	39	-3.7	-0.2	1.4	-7.4	-1.5	1.4	-3.7	-1.4	0.0	-22.0	-33.5	0.0	-55.5	5.1	
27	40	-3.5	-0.1	1.4	-7.2	-1.5	1.4	-3.7	-1.4	0.0	-25.8	-34.9	0.0	-60.6	5.1	
28	41	-3.4	-0.1	1.3	-7.1	-1.6	1.3	-3.8	-1.4	0.0	-29.5	-36.3	0.0	-65.9	5.2	
29	42	-3.2	-0.1	1.3	-7.0	-1.6	1.3	-3.8	-1.5	0.0	-33.3	-37.8	0.0	-71.1	5.3	
30	43	-3.1	-0.1	1.3	-6.9	-1.6	1.3	-3.8	-1.5	0.0	-37.2	-39.3	0.0	-76.5	5.3	
31	44	-2.9	0.0	1.3	-6.8	-1.6	1.3	-3.8	-1.5	0.0	-41.0	-40.9	0.0	-81.9	5.4	
32	45	-2.8	0.0	1.2	-6.7	-1.6	1.2	-3.9	-1.6	0.0	-44.9	-42.4	0.0	-87.3	5.4	
33	46	-2.7	0.0	1.2	300.3	-68.3	-151.0	303.0	-68.3	-152.3	258.1	-110.7	-152.3	-4.8	-82.4	H1
34	47	-2.6	0.0	1.2	-0.3	16.7	7.7	2.3	16.7	6.5	260.4	-94.1	-145.8	20.6	-25.5	
35	48	-2.5	0.1	1.2	-1.7	14.7	7.2	0.7	14.6	6.0	261.2	-79.5	-139.8	41.9	-21.3	
36	49	-2.4	0.1	1.2	-3.5	12.3	6.7	-1.2	12.2	5.5	260.0	-67.3	-134.2	58.5	-16.6	
37	50	-2.3	0.1	1.1	-5.0	10.0	6.3	-2.7	9.9	5.1	257.3	-57.4	-129.1	70.8	-12.3	
38	51	-2.2	0.1	1.1	-6.0	7.8	5.9	-3.9	7.7	4.7	253.4	-49.7	-124.4	79.3	-8.5	
39	52	-2.1	0.1	1.1	-6.8	5.8	5.5	-4.8	5.7	4.4	248.6	-44.1	-120.0	84.6	-5.3	
40	53	-2.0	0.2	1.1	-7.4	4.2	5.2	-5.4	4.0	4.1	243.2	-40.0	-115.9	87.2	-2.7	
41	54	-1.9	0.2	1.1	-7.8	3.5	4.9	-6.0	3.3	3.8	237.2	-36.7	-112.2	88.4	-1.2	
42	55	-1.8	0.2	1.1	-8.1	2.9	4.6	-6.4	2.7	3.5	230.9	-34.0	-108.7	88.3	0.1	
43	56	-1.7	0.2	1.1	-8.3	2.4	4.3	-6.6	2.2	3.3	224.2	-31.8	-105.4	87.1	1.2	
44	57	-1.6	0.2	1.0	-8.5	1.9	4.1	-6.8	1.7	3.0	217.4	-30.1	-102.3	85.0	2.1	
45	58	-1.6	0.2	1.0	-8.5	1.5	3.9	-6.9	1.3	2.8	210.5	-28.8	-99.5	82.2	2.8	
46	59	-1.5	0.3	1.0	-8.5	1.2	3.7	-7.0	0.9	2.7	203.5	-27.9	-96.8	78.7	3.4	
47	60	-1.4	0.3	1.0	31.7	-35.3	3.5	33.1	-35.6	2.5	236.6	-63.5	-94.4	78.8	-0.1	
48	61	-1.4	0.3	1.0	-8.6	4.4	3.3	-7.2	4.1	2.3	229.4	-59.4	-92.0	78.0	0.8	
49	62	-1.3	0.3	1.0	-8.7	3.6	3.2	-7.4	3.4	2.2	222.0	-56.0	-89.8	76.2	1.9	
50	63	-1.2	0.3	1.0	-8.8	3.0	3.0	-7.6	2.7	2.1	214.4	-53.3	-87.7	73.4	2.8	
51	64	-1.2	0.3	0.9	-8.9	2.4	2.9	-7.7	2.1	2.0	206.7	-51.2	-85.8	69.8	3.6	
52	65	-1.1	0.3	0.9	-8.9	2.0	2.8	-7.8	1.7	1.8	199.0	-49.5	-83.9	65.5	4.3	

H1- harvest spaced stand

Year	Age	Baseline			Spacing Project			Net			Cumulative					
		AGB	Soil-Ltr-BGB	Wood Prod	AGB	Soil-Ltr-BGB	Wood Prod	AGB	Soil-Ltr-BGB	Wood Prod	AGB	Soil-Ltr-BGB	Wood Prod	Sum	Stock Ch	
53	66	-1.1	0.3	0.9	-8.9	1.6	2.7	-7.8	1.2	1.7	191.1	-48.2	-82.2	60.7	4.9	
54	67	-1.0	0.3	0.9	-8.9	1.2	2.6	-7.9	0.9	1.7	183.2	-47.4	-80.6	55.3	5.3	
55	68	-1.0	0.3	0.9	-8.9	0.9	2.5	-7.9	0.6	1.6	175.3	-46.8	-79.0	49.5	5.8	
56	69	292.5	-73.7	-151.6	-8.8	0.6	2.4	-301.3	74.4	154.0	-126.0	27.6	75.0	-23.4	72.9	H2
57	70	-0.3	14.9	7.4	-8.8	0.4	2.3	-8.5	-14.6	-5.1	-134.5	13.0	70.0	-51.6	28.2	
58	71	-1.7	13.6	6.9	-8.7	0.2	2.2	-7.0	-13.4	-4.6	-141.6	-0.4	65.3	-76.7	25.1	
59	72	-3.4	11.5	6.4	-8.7	0.0	2.2	-5.2	-11.5	-4.2	-146.8	-11.9	61.1	-97.7	21.0	
60	73	-4.8	9.3	6.0	-8.6	-0.2	2.1	-3.8	-9.5	-3.9	-150.6	-21.4	57.2	-114.8	17.1	
61	74	-5.9	7.2	5.6	-8.5	-0.3	2.0	-2.6	-7.5	-3.5	-153.2	-28.9	53.6	-128.4	13.7	
62	75	-6.6	5.2	5.2	-8.4	-0.4	2.0	-1.8	-5.7	-3.2	-155.0	-34.5	50.4	-139.1	10.7	
63	76	-7.2	3.6	4.9	-8.3	-0.6	1.9	-1.1	-4.2	-3.0	-156.1	-38.7	47.4	-147.4	8.3	
64	77	-7.6	3.0	4.6	-8.2	-0.7	1.9	-0.6	-3.7	-2.7	-156.7	-42.4	44.7	-154.4	7.0	
65	78	-7.9	2.4	4.3	-8.1	-0.7	1.8	-0.2	-3.2	-2.5	-156.9	-45.6	42.2	-160.3	5.9	
66	79	-8.1	1.9	4.1	-8.0	-0.8	1.8	0.1	-2.8	-2.3	-156.8	-48.3	39.9	-165.2	5.0	
67	80	-8.2	1.5	3.8	-7.9	-0.9	1.7	0.3	-2.4	-2.1	-156.5	-50.7	37.9	-169.4	4.2	
68	81	-8.3	1.1	3.6	-7.8	-0.9	1.7	0.5	-2.1	-1.9	-156.1	-52.8	35.9	-173.0	3.5	
69	82	-8.3	0.8	3.4	-7.7	-1.0	1.7	0.6	-1.8	-1.8	-155.5	-54.6	34.2	-176.0	3.0	
70	83	-8.2	0.6	3.2	-7.6	-1.0	1.6	0.6	-1.6	-1.6	-154.9	-56.2	32.5	-178.6	2.6	
71	84	-8.1	0.3	3.1	-7.5	-1.1	1.6	0.6	-1.4	-1.5	-154.3	-57.6	31.1	-180.8	2.3	
72	85	-8.0	0.1	2.9	-7.4	-1.1	1.6	0.6	-1.3	-1.4	-153.6	-58.9	29.7	-182.8	2.0	
73	86	-7.9	0.0	2.8	-7.2	-1.1	1.5	0.6	-1.1	-1.3	-153.0	-60.0	28.4	-184.6	1.8	
74	87	-7.7	-0.1	2.7	-7.1	-1.2	1.5	0.6	-1.0	-1.2	-152.4	-61.0	27.3	-186.2	1.6	
75	88	-7.5	-0.2	2.6	-7.0	-1.2	1.5	0.5	-0.9	-1.1	-151.9	-62.0	26.2	-187.7	1.5	
76	89	-7.3	-0.3	2.4	-6.9	-1.2	1.5	0.4	-0.9	-1.0	-151.5	-62.9	25.2	-189.2	1.4	
77	90	-7.1	-0.4	2.3	-6.8	-1.2	1.4	0.4	-0.8	-0.9	-151.1	-63.7	24.3	-190.6	1.4	
78	91	-6.9	-0.4	2.3	-6.7	-1.2	1.4	0.3	-0.8	-0.9	-150.9	-64.5	23.4	-192.0	1.4	
79	92	-6.7	-0.4	2.2	300.3	-67.9	-150.9	307.0	-67.5	-153.0	156.1	-132.0	-129.6	-105.5	-86.5	
80	93	-6.5	-0.5	2.1	-0.3	17.0	7.9	6.2	17.5	5.8	162.4	-114.5	-123.9	-75.9	-29.5	
81	94	-6.3	-0.5	2.0	-1.7	15.0	7.3	4.6	15.5	5.3	167.0	-99.0	-118.6	-50.6	-25.4	
82	95	-6.1	-0.5	2.0	-3.5	12.6	6.9	2.6	13.1	4.9	169.5	-85.9	-113.7	-30.0	-20.6	
83	96	-5.9	-0.5	1.9	-5.0	10.3	6.4	0.9	10.8	4.5	170.4	-75.1	-109.2	-13.8	-16.2	
84	97	-5.7	-0.5	1.8	-6.0	8.1	6.0	-0.4	8.6	4.2	170.1	-66.5	-105.0	-1.4	-12.4	
85	98	-5.5	-0.4	1.8	-6.8	6.1	5.6	-1.4	6.5	3.9	168.7	-60.0	-101.1	7.7	-9.1	
86	99	-5.3	-0.4	1.7	-7.4	4.5	5.3	-2.1	4.9	3.6	166.6	-55.1	-97.5	14.0	-6.4	
87	100	-5.1	-0.4	1.7	-7.8	3.8	5.0	-2.8	4.2	3.3	163.8	-50.8	-94.2	18.8	-4.8	
88	101	-4.9	-0.4	1.6	-8.1	3.2	4.7	-3.3	3.6	3.1	160.6	-47.2	-91.1	22.2	-3.4	
89	102	-4.7	-0.4	1.6	-8.3	2.7	4.5	-3.6	3.0	2.9	156.9	-44.2	-88.3	24.4	-2.2	
90	103	-4.5	-0.3	1.6	-8.5	2.2	4.2	-3.9	2.5	2.7	153.0	-41.7	-85.6	25.6	-1.2	

Soil-Ltr-BGB= soil, litter and below ground biomass

H1- Age 46 Harvest Spaced stand
H2- Age 69 Harvest Reference stand

Thinning (Spacing) project:

- Thinned in year 1 (age14)
- Harvested in year 33 (age 46), new stand planted
- Second stand thinned in year 47 (age 14)
- Second stand harvested year 79 (age 46)

Baseline:
- Harvested year 56 (age 69)

TABLE 1-2

Stock Change- AGB Vs Other C Pools

(-)ve = reduction in stock / (+) = stock increase

Tonnes CO2e/hectare

Year	AGB Stock Baseline	AGB Stock Project	Diff Stock	AGB Stock Ch.	Soil Stock Ch.	Wood P Stock Ch.	Total Stock Ch.
-2	8.3	8.3	0.0				
-1	16.5	16.5	0.0	0.0			
1	24.7	-15.2	-39.9	-39.9	36.6		-3.3
2	32.9	-6.6	-39.5	0.4	-3.3		-2.8
3	40.9	2.1	-38.8	0.7	-2.7		-2.0
4	48.7	10.9	-37.8	0.9	-2.3		-1.3
5	56.4	19.7	-36.7	1.2	-1.9		-0.7
6	63.9	28.6	-35.3	1.4	-1.5		-0.1
7	71.3	37.6	-33.7	1.6	-1.2		0.4
8	78.4	46.5	-32.0	1.8	-0.9		0.9
9	85.4	55.3	-30.0	1.9	-0.7		1.3
10	92.1	64.2	-27.9	2.1	-0.4		1.7
11	98.6	73.0	-25.6	2.3	-0.2		2.1
12	104.9	81.7	-23.2	2.4	0.0		2.4
13	111.0	90.4	-20.6	2.6	0.1		2.7
14	116.9	99.0	-17.9	2.7	0.3		3.0
15	122.6	107.5	-15.1	2.8	0.4		3.2
16	128.1	115.9	-12.2	2.9	0.5		3.5
17	133.3	124.2	-9.1	3.1	0.7		3.7
18	138.4	132.5	-6.0	3.2	0.8		3.9
19	143.3	140.6	-2.7	3.2	0.9		4.1
20	148.0	148.6	0.6	3.3	1.0		4.3
21	152.5	156.5	4.0	3.4	1.0		4.5
22	156.8	164.4	7.5	3.5	1.1		4.6
23	161.0	172.1	11.1	3.5	1.2		4.7
24	165.0	179.6	14.7	3.6	1.2		4.9
25	168.8	187.1	18.3	3.7	1.3		5.0
26	172.4	194.5	22.0	3.7	1.4		5.1
27	176.0	201.7	25.8	3.7	1.4		5.1
28	179.3	208.9	29.5	3.8	1.4		5.2
29	182.5	215.9	33.3	3.8	1.5		5.3
30	185.6	222.8	37.2	3.8	1.5		5.3
31	188.6	229.6	41.0	3.8	1.5		5.4
32	191.4	236.3	44.9	3.9	1.6		5.4
33	194.1	-64.0	-258.1	-303.0	68.3	152.3	-82.4
34	196.7	-63.8	-260.4	-2.3	-16.7	-6.5	-25.5
35	199.1	-62.0	-261.2	-0.7	-14.6	-6.0	-21.3
36	201.5	-58.5	-260.0	1.2	-12.2	-5.5	-16.6
37	203.7	-53.5	-257.3	2.7	-9.9	-5.1	-12.3
38	205.9	-47.5	-253.4	3.9	-7.7	-4.7	-8.5
39	208.0	-40.7	-248.6	4.8	-5.7	-4.4	-5.3
40	209.9	-33.3	-243.2	5.4	-4.0	-4.1	-2.7
41	211.8	-25.4	-237.2	6.0	-3.3	-3.8	-1.2
42	213.6	-17.3	-230.9	6.4	-2.7	-3.5	0.1
43	215.3	-8.9	-224.2	6.6	-2.2	-3.3	1.2
44	216.9	-0.5	-217.4	6.8	-1.7	-3.0	2.1
45	218.5	8.0	-210.5	6.9	-1.3	-2.8	2.8
46	220.0	16.5	-203.5	7.0	-0.9	-2.7	3.4
47	221.4	-15.2	-236.6	-33.1	35.6	-2.5	-0.1
48	222.8	-6.6	-229.4	7.2	-4.1	-2.3	0.8
49	224.1	2.1	-222.0	7.4	-3.4	-2.2	1.9
50	225.3	10.9	-214.4	7.6	-2.7	-2.1	2.8
51	226.5	19.7	-206.7	7.7	-2.1	-2.0	3.6
52	227.6	28.6	-199.0	7.8	-1.7	-1.8	4.3

Year	AGB Stock			AGB	Soil	Wood P	Total	
	Baseline	Project	Diff Stock	Stock Ch.	Stock Ch.	Stock Ch.	Stock Ch.	
53	228.7	37.6	-191.1	7.8	-1.2	-1.7	4.9	
54	229.7	46.5	-183.2	7.9	-0.9	-1.7	5.3	
55	230.7	55.3	-175.3	7.9	-0.6	-1.6	5.8	
56	-61.8	64.2	126.0	301.3	-74.4	-154.0	72.9	H2
57	-61.5	73.0	134.5	8.5	14.6	5.1	28.2	
58	-59.9	81.7	141.6	7.0	13.4	4.6	25.1	
59	-56.4	90.4	146.8	5.2	11.5	4.2	21.0	
60	-51.6	99.0	150.6	3.8	9.5	3.9	17.1	
61	-45.7	107.5	153.2	2.6	7.5	3.5	13.7	
62	-39.1	115.9	155.0	1.8	5.7	3.2	10.7	
63	-31.9	124.2	156.1	1.1	4.2	3.0	8.3	
64	-24.2	132.5	156.7	0.6	3.7	2.7	7.0	
65	-16.3	140.6	156.9	0.2	3.2	2.5	5.9	
66	-8.2	148.6	156.8	-0.1	2.8	2.3	5.0	
67	0.0	156.5	156.5	-0.3	2.4	2.1	4.2	
68	8.3	164.4	156.1	-0.5	2.1	1.9	3.5	
69	16.5	172.1	155.5	-0.6	1.8	1.8	3.0	
70	24.7	179.6	154.9	-0.6	1.6	1.6	2.6	
71	32.9	187.1	154.3	-0.6	1.4	1.5	2.3	
72	40.9	194.5	153.6	-0.6	1.3	1.4	2.0	
73	48.7	201.7	153.0	-0.6	1.1	1.3	1.8	
74	56.4	208.9	152.4	-0.6	1.0	1.2	1.6	
75	64.0	215.9	151.9	-0.5	0.9	1.1	1.5	
76	71.3	222.8	151.5	-0.4	0.9	1.0	1.4	
77	78.4	229.6	151.1	-0.4	0.8	0.9	1.4	
78	85.4	236.3	150.9	-0.3	0.8	0.9	1.4	
79	92.1	-64.0	-156.1	-307.0	67.5	153.0	-86.5	
80	98.6	-63.8	-162.4	-6.2	-17.5	-5.8	-29.5	
81	104.9	-62.0	-167.0	-4.6	-15.5	-5.3	-25.4	
82	111.0	-58.5	-169.5	-2.6	-13.1	-4.9	-20.6	
83	116.9	-53.5	-170.4	-0.9	-10.8	-4.5	-16.2	
84	122.6	-47.5	-170.1	0.4	-8.6	-4.2	-12.4	
85	128.1	-40.7	-168.7	1.4	-6.5	-3.9	-9.1	
86	133.3	-33.3	-166.6	2.1	-4.9	-3.6	-6.4	
87	138.4	-25.4	-163.8	2.8	-4.2	-3.3	-4.8	
88	143.3	-17.3	-160.6	3.3	-3.6	-3.1	-3.4	
89	148.0	-8.9	-156.9	3.6	-3.0	-2.9	-2.2	
90	152.5	-0.5	-153.0	3.9	-2.5	-2.7	-1.2	

Appendix 1 (cont'd)

Illustration 1-Baseline vs Project Stands

Net biomass in tonnes for all relevant carbon pools over 210 years; trees, roots, litter, other vegetation, soil, short-lived products (SLP) and long-lived products (LLP).

Fig i. Baseline- Natural Northern Ontario Jack Pine Forest (3 rotations)- tonnes biomass

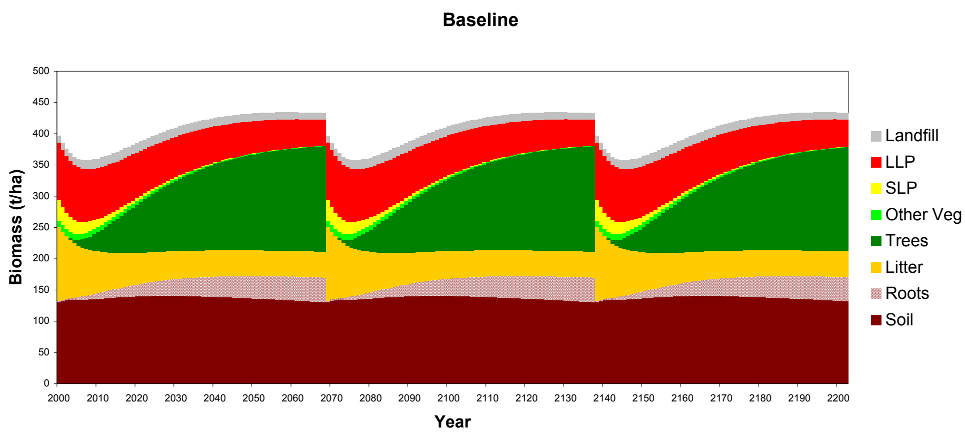


Fig ii Spaced Stand- (4.6 rotations)- tonnes biomass

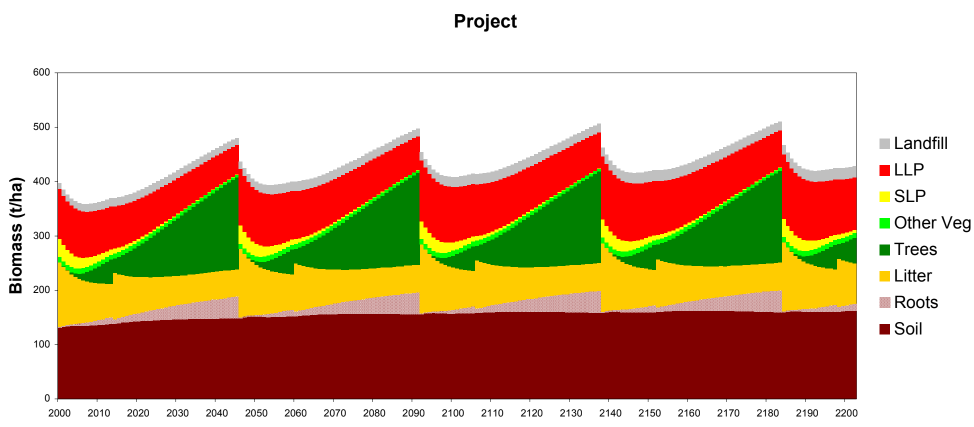


Fig. iii Difference between natural and spaced stands (converted to tonnes CO2e).

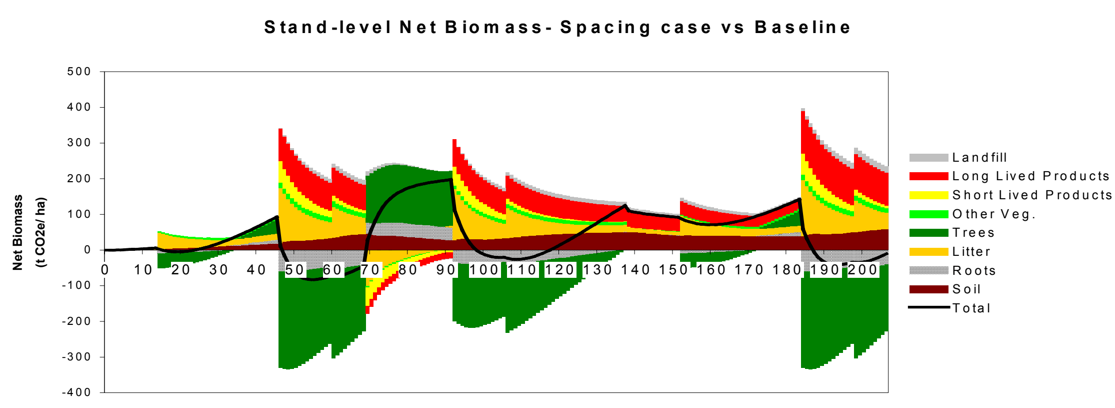


Table 1-3
Annual GHG Impact of Project Spacing Program

Val D'Or Spacing

	Spacing	Tonnes C02 Sequestered													
	Ha.	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Actual															
		3.36	2.82	2.05	1.34	0.70	0.13	-0.39	-0.86	-1.29	-1.69	-2.05	-2.39	-2.70	-2.98
1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	111		373	313	228	149	78	14	(43)	(95)	(143)	(188)	(228)	(265)	(300)
1993	300			1,008	846	615	402	210	39	(117)	(258)	(387)	(507)	(615)	(717)
1994	1,123				3,773	3,167	2,302	1,505	786	146	(438)	(966)	(1,449)	(1,898)	(2,302)
1995	1,575					5,292	4,442	3,229	2,111	1,103	205	(614)	(1,355)	(2,032)	(2,662)
1996	1,393						4,680	3,928	2,856	1,867	975	181	(543)	(1,198)	(1,797)
1997	755							2,537	2,129	1,548	1,012	529	98	(294)	(649)
1998	2,950								9,912	8,319	6,048	3,953	2,065	384	(1,151)
1999	1,208									4,059	3,407	2,476	1,619	846	157
2000	1,912										6,424	5,392	3,920	2,562	1,338
2001	2,720											9,139	7,670	5,576	3,645
2002	1,950												6,552	5,499	3,998
2003	1,950													6,552	5,499
2004	1,950														6,552
2005	1,950														
2006	1,950														
2007	1,950														
2008	1,950														
2009	1,950														
2010	1,950														
2011	1,950														
2012	1,950														
2013	1,950														
Total		0	0	1,008	4,619	9,074	11,826	11,409	17,832	16,924	17,374	19,703	18,070	15,381	11,911
Cumulative		0	0	1,008	5,627	14,701	26,527	37,936	55,768	72,692	90,066	109,769	127,839	143,221	155,132

Table 2-1
BioOil Plant Cost Structure

Annual Costs- Revenues

	$000	Units		$Cdn/Unit	$US/Unit
Cost Savings:					
Waste transportation to landfill	210	35,154	BDMT bark	5.97	4.00
Tipping fees	395	35,154	BDMT bark	11.25	7.54
Fuel Oil transportation	605				
Fuel Oil	3,403				
	4,614				
Revenues:					
BioOil Sales	8,917	865,094	GJ	10.31	6.91
Charcoal sales	1,056	13,197	MT	80.00	53.60
	9,972				
Expenses:					
Royalty	1,338				
Waste Collection	2,189	96,247	BDMT slash	22.74	15.24
Waste transportation	2,787	167,649	BDMT slash	16.62	11.14
Operating Costs					
Power	966	83,272	MT BioOil	11.60	7.78
Natural Gas	37	83,272	MT BioOil	0.45	0.30
Non-energy operating costs	2,105	83,272	MT BioOil	25.28	16.94
Total operating costs	3,109				
BioOil transportation	650	83,272	MT BioOil	7.80	5.23
Char transportation	0	13,197	MT	0.00	
Total Expenses	10,072				
Operating Income	4,514				

BDMT= Bone dry metric tonnes = oven dry tonnes= odt

Appendix 3

Table 3-1

Net GHG Emissions- BioOil Facility

Tonnes CO2e

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Baseline											
Fossil Fuel Emissions											
Transport fuel from Montreal	182	182	182	182	182	182	182	182	182	182	182
Upstream manufacture of fuel oil	23,352	23,039	22,746	22,473	22,491	22,509	22,527	22,544	22,561	22,523	22,523
Mill waste transport to Landfill	139	139	139	139	139	139	139	139	139	139	139
Landfill Management	25	25	25	25	25	25	25	25	25	25	25
Fuel oil use (GJ equivalent of prodn)	110,878	110,878	110,878	110,878	110,878	110,878	110,878	110,878	110,878	110,878	110,878
Total Fossil Fuel	134,575	134,262	133,970	133,696	133,714	133,732	133,750	133,767	133,784	133,746	133,746
Landfill Gas (CH4,N2O)	980	1,950	2,911	3,862	4,803	5,736	6,659	7,572	8,477	9,373	9,279
Roadside waste burning (non-CO2)	17,447	17,447	17,447	17,447	17,447	17,447	17,447	17,447	17,447	17,447	17,447
Waste decomposition (non-CO2)	0	0	0	0	0	0	0	0	0	0	0
Total Emissions	153,002	153,659	154,327	155,005	155,965	156,915	157,855	158,786	159,708	160,566	160,472
Landfill Stock Change	64,449	64,449	64,449	64,449	64,449	64,449	64,449	64,449	64,449	64,449	64,449
Total Baseline Emissions	88,553	198,711	198,419	198,145	198,163	198,181	198,199	198,216	198,233	198,195	198,195
Outside System Boundary:											
Charcoal transport 3rd pty- Ky-Torontc	2,522	2,522	2,522	2,522	2,522	2,522	2,522	2,522	2,522	2,522	2,522
Non-IPCC ghgs (possibly relevant in the event of full carbon accounting):											
Roadside waste burning (CO2)	77,000	77,000	77,000	77,000	77,000	77,000	77,000	77,000	77,000	77,000	77,000
Slash decomposition (CO2)	4,222	8,260	12,121	15,814	19,345	22,723	25,954	29,044	31,999	34,826	33,309
Landfill Gas (CO2)	128	255	381	506	629	751	872	992	1,110	1,227	1,215
Project											
Fossil Fuel											
Upstream fuel oil production	954	941	929	918	919	919	920	921	921	920	920
Slash collection & processing	860	860	860	860	860	860	860	860	860	860	860
Residue and slash transportation	1,844	1,844	1,844	1,844	1,844	1,844	1,844	1,844	1,844	1,844	1,844
Build bioOil facility	10,507	0	0	0	0	0	0	0	0	0	0
Biooil Transportation	166	166	166	166	166	166	166	166	166	166	166
Landfill Gas (CH4,N2O)											
BioOil prodn (ngas, non-CO2 char)	2,584	2,584	2,584	2,584	2,584	2,584	2,584	2,584	2,584	2,584	2,584
BioOil combustion (non-CO2) at kiln	235	235	235	235	235	235	235	235	235	235	235
Total Project	17,150	6,630	6,618	6,607	6,607	6,608	6,609	6,610	6,610	6,609	6,609
Outside System Boundary:											
Charcoal transportation	938	938	938	938	938	938	938	938	938	938	938
Char transportation ?											
Non-IPCC ghgs (possibly relevant in the event of full carbon accounting):											
BioOil production (CO2)	51,334	51,334	51,334	51,334	51,334	51,334	51,334	51,334	51,334	51,334	51,334
BioOil combustion (CO2)	110,643	110,643	110,643	110,643	110,643	110,643	110,643	110,643	110,643	110,643	110,643
Total (including CO2)	161,977	161,977	161,977	161,977	161,977	161,977	161,977	161,977	161,977	161,977	161,977
Net Impact (Project -Baseline)											
Emissions	(135,852)	(147,029)	(147,710)	(148,398)	(149,357)	(150,307)	(151,247)	(152,177)	(153,098)	(153,957)	(153,864)
Stock Changes	64,449	64,449	64,449	64,449	64,449	64,449	64,449	64,449	64,449	64,449	64,449
Total	**(71,403)**	**(82,580)**	**(83,261)**	**(83,949)**	**(84,908)**	**(85,858)**	**(86,798)**	**(87,728)**	**(88,649)**	**(89,508)**	**(89,415)**

Appendix 3

Table 3.2

Combined Projects GHG Emissions/(Sequestration)

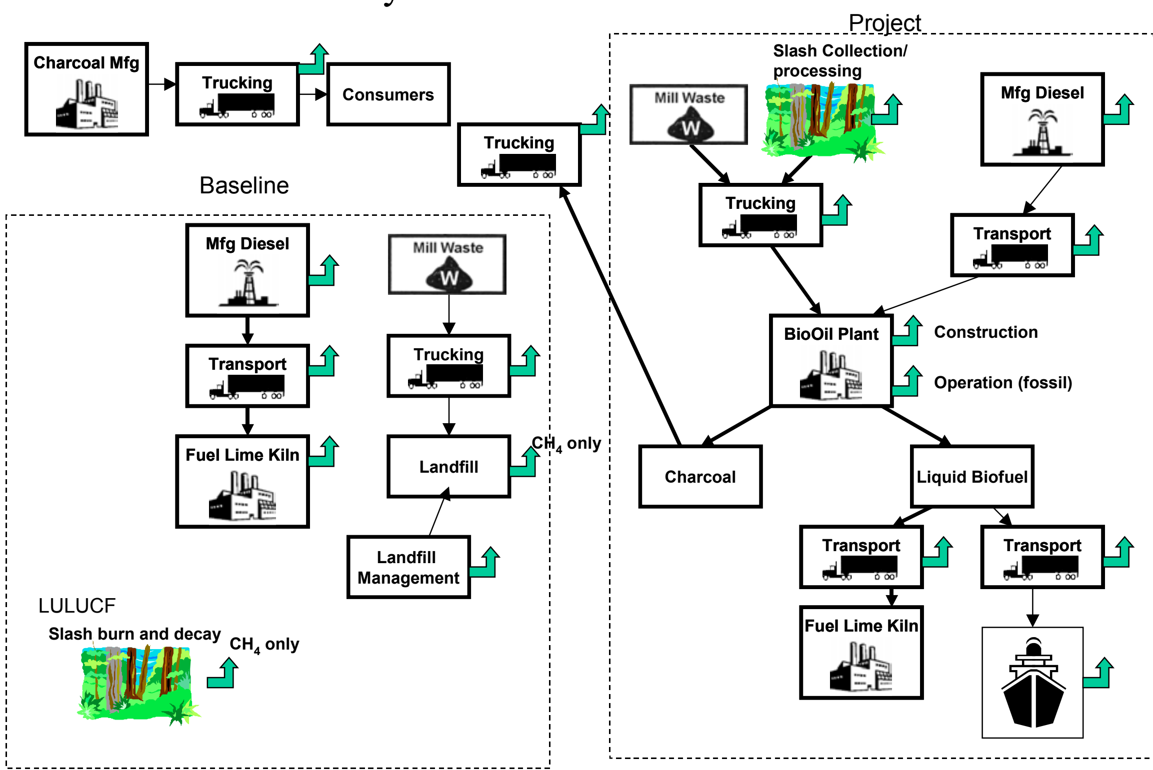
Tonnes CO2e

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
BioOil Plant:										
Baseline Emissions										
Fossil Fuel + landfill CH4	153,002	153,659	154,327	155,005	155,965	156,915	157,855	158,786	159,708	160,566
Stock Change	(64,449)	(64,449)	(64,449)	(64,449)	(64,449)	(64,449)	(64,449)	(64,449)	(64,449)	(64,449)
Total	88,553	89,210	89,878	90,556	91,516	92,466	93,406	94,337	95,259	96,117
Project Emissions										
Fossil Fuel	17,150	6,630	6,618	6,607	6,607	6,608	6,609	6,610	6,610	6,609
Net Emissions/(Sequestration)										
Fossil Fuel + landfill CH4	(135,852)	(147,029)	(147,710)	(148,398)	(149,357)	(150,307)	(151,247)	(152,177)	(153,098)	(153,957)
Stock Change	64,449	64,449	64,449	64,449	64,449	64,449	64,449	64,449	64,449	64,449
Total BioOil Facility	(71,403)	(82,580)	(83,261)	(83,949)	(84,908)	(85,858)	(86,798)	(87,728)	(88,649)	(89,508)
Forestry Project: *										
Juvenile Spacing Stock Change	(127,839)	(15,381)	(11,911)	(7,755)	(2,968)	2,420	8,331	14,768	21,672	28,990
Forestry + BioOil Plant:										
Net Combined Emissions/(Seq)	56,436	(67,199)	(71,349)	(76,194)	(81,940)	(88,278)	(95,129)	(102,496)	(110,321)	(118,498)

* 1992-2002 juvenile spacing emissions combined into 2002

Appendix 4

System Boundaries



Appendix 5 -Assumptions ("GHG Emissions from Bioenergy Systems- A Case Study- Liquid Fuels from Forest Waste"- Woodrising Consulting, Ontario, Canada)

Densities, Emission and Energy Factors

Densities (kg/m^3)			Emissions ($kgCO_2e/GJ$)	Energy	
Dry waste[iv]	400	BioOil[viii]	150.0	20.64	GJ/m^3
Green waste [v]	750	Charcoal[vi vii viii]	115.1	23.20	GJ/tonne
BioOil[viii]	1,200	Diesel – combustion[ix]	150.0	41.73	GJ/m^3
Diesel[x]	840	Diesel – vehicles[ix]	133.9	41.73	GJ/m^3
		Natural Gas[ix]	50.7	0.03723	GJ/m^3
		Wood waste[vi]	125.8	15.5	GJ/tonne

Note: BioOil emissions assumed to be the same on as diesel on a per unit energy basis.

Facility Information[viii]

Production			Consumption		
Capacity	124,830	bdmt/yr	BioOil	0.686	GJ/bdmt
			Charcoal	3.1	GJ/bdmt
BioOil	10.9	GJ/bdmt	Electricity	189.0	kWh/bdmt
Charcoal	2.33	GJ/bdmt	Natural Gas	0.05	GJ/bdmt

Financial Information

Capital cost	$18.1Cdn million
Tax Rate	45%
Tax Depreciation Rate	30% Declining Balance
Royalty rate	10% of gross revenues

Variable prices and costs

	2002	2003	2004	2005	2006	2007	2008	2009
Trucking ($/tkm)[xi]	0.212	0.216	0.220	0.224	0.229	0.233	0.238	0.242
Rail ($/MTkm)	0.051	0.052	0.053	0.055	0.056	0.057	0.059	0.060
Tanker Loading ($/MT)	2.61	2.68	2.75	2.81	2.89	2.96	3.03	3.11
Shipping ($/MT)	73.52	75.36	77.24	79.17	81.15	83.18	85.26	87.39
Electricity ($/MWh)	38.91	39.63	40.35	41.08	41.91	42.75	43.59	44.43
Natural gas ($/m3)	0.21	0.22	0.22	0.22	0.23	0.23	0.24	0.24
Non-road Diesel ($/l)	0.52	0.53	0.54	0.56	0.57	0.59	0.60	0.62
Fuel Oil #4 ($/l)	0.41	0.42	0.43	0.44	0.46	0.47	0.48	0.49
Fuel Oil #6 (Bunker C) ($/l)	0.24	0.25	0.25	0.26	0.26	0.27	0.28	0.29
Charcoal ($/GJ)[xii]	4.30	4.38	4.54	4.79	5.16	5.67	6.36	7.26
Char Price @ Plant Gate $/BDMT	80.00	82.00	84.05	86.15	88.31	90.51	92.78	95.09
Tippage fee ($/m3)[xiii]	4.50	4.58	4.75	5.02	5.40	5.94	6.65	7.60
Non-energy Plant Op.costs ($/bdt)	16.02	16.32	16.62	16.91	17.26	17.60	17.95	18.29

Additional assumptions

Values have been adjusted to nearest available year using price indexes from CANSIM[xiv]. Non-road diesel price has been calculated from road diesel price removing road diesel taxes in Quebec[xv].

Forest Machinery Information

	Processing Rates	Fuel Consumption Rates
Chippers[xvi xvii]	33 m^3/hr.	35 L/hr
Forwarders[xvi xvii]	12 m^3/hr.	8 L/hr
Tankers[xviii xix]	40 m^3 BioOil/load	40 L/100 km
	57 m^3 diesel/load	40 L/100 km
Trucks [xix]	35 m^3/load	40 L/100 km

Operational costs[xvi]

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Chippers (C$/hr)	228.05	232.41	236.76	241.12	246.19	251.26	256.33	261.40	266.47	271.91
Forwarder (C$/hr)	74.21	75.61	77.02	78.42	80.06	81.69	83.33	84.96	86.60	88.35

Note: Operational costs have been modified from 2001 by assuming current diesel costs, and adjusting the non-diesel portion by the consumer price index[xiv]. Gingras et al (1996) have significantly different processing and fuel consumption rates. We used the values from Asikainen (2001)[xvi] because it was felt that they better represented conditions if waste collection becomes commonplace.

Forest Management Information[xx]

Juvenile spacing waste	29,400	m^3/yr
Roadside waste	756,000	m^3/yr
Stumpside waste	84,000	m^3/yr

Additional assumptions

Juvenile spacing waste assumes 1,950 hectares are spaced annually. These lands are 80% Black Spruce and 20% Jack Pine. Spacing occurs at age 15 and 45% of the aboveground biomass is removed.

70% of roadside waste is normally burnt

20% of forest waste is distributed uniformly within 70 km of the facility. The remainder is distributed uniformly between 70 and 200 km of the facility.

Other Constants

Mill waste decomposition

Lo[xxi]- (Canada GHG Inventory- 1990-99- pg 54)	118 kg CH_4/odt
K[xxi] - (Canada GHG Inventory- 1990-99- pg 54)	0.01 year^{-1}
Processing emissions[xxii]	700 g CO_2e / t
Ratio CO_2/CH_4 Emissions by wt. CO_2e	.131

Coarse forest floor waste decomposition

K[xxiii]	0.0457 year^{-1}
Portion transferred to soil	5%
K_{soil}[xxiii]	0.0186 year^{-1}

Upstream emissions from fossil fuel consumption

Upstream emissions are estimated from industry emissions and production. In 2000, the upstream emissions were ~ 16,314 t CO_2e/PJ of production[xix].

Indirect emissions from electricity consumption

Indirect emissions from electricity consumption in Quebec are interpolated from Environment Canada data[xix]. In 2000, there was 0.0014 t CO_2e/MWh produced in Quebec.

Emissions from building the BioOil facility

Direct and indirect emissions from building the BioOil facility have been estimated using Canada's average emission rate of 612.7 g CO_2e/$GDP and the cost of the facility.

Juvenile Spacing Model Parameters

Tree growth, spacing and harvest

	Black Spruce	**Jack Pine**
Yield Curve	Pothier, David and F. Savard[xxiv]	Pothier, David and F. Savard.
Site Index	18	18
Density (t/m^3)[xxv]	0.442	0.412
Expansion factor	238%	182%
Harvest age	50	50
GTV at harvest (m^3/ha)	141	151
Harvest age – after spacing	40	40
GTV – at harvest (m^3/ha)	141	151

GTV= gross total volume = roots, bole, branches, needles

Export Parameters (Reference ii)

Chemical tankers of capacity 4,927M^3, suitable for pyro-oil, need .015 MT/km of heavy fuel oil to run full, 65% of that to run empty. Montreal to Rotterdam is approximately 6160 km. Loading pyro-oil costs 1.6 Euros/tonne.

Other Parameters

The below ground biomass (roots) is linked to the above ground biomass using empirical formula developed by Kurz et al[xxvi].

Four litter pools (fine above ground, coarse above ground, fine below ground, coarse below ground) are linked dynamically to the above/below ground biomass. Each pool decays exponentially, with its own decay constant, and the material lost through decay is transferred to the atmosphere or soil pool (each litter pool has its own transfer constants). The model describing the litter and soil dynamics has been tailored to fit regional forest conditions. This is accomplished by modelling specific stand types assuming no harvest and choosing parameters so that the carbon stored in the soil and litter pools match measurements made by Siltanen et al[xxvii] in Ontario. These are adjusted for temperature and precipitation affects using relationships on foliage decay by Moore et al[xxviii].

Two wood product pools, short-lived (paper) and long-lived (lumber) are included. These pools also decay exponentially, each pool with a different decay constant, and the material lost through decay is transferred to the atmosphere (by burning), recycled or transferred to the landfill pool. Each wood product pool has a unique transfer constant. When product is burnt, a portion is used a fuel that may displace other fossil fuels. Values are taken from Canadian waste and recycling data[xxii].

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