Enterprise Budget: Biochar Production at Muskrat Falls

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Introduction

This report accompanies an Excel-based enterprise budget for a prospective biochar production project co-located at the Muskrat Falls hydro-electric mega-project under construction by Nalcor Energy (Nalcor Energy, 2018) in Newfoundland and Labrador, Canada. The main construction site is approximately 25 kilometres west of Happy Valley-Goose Bay, a town with a population of 8,109 located in central Labrador – a remote location of Northeastern Canada (Statistics Canada, 2017; Town of Happy Valley-Goose Bay, 2018). See Figure 1 (sotto) for a map of the area.

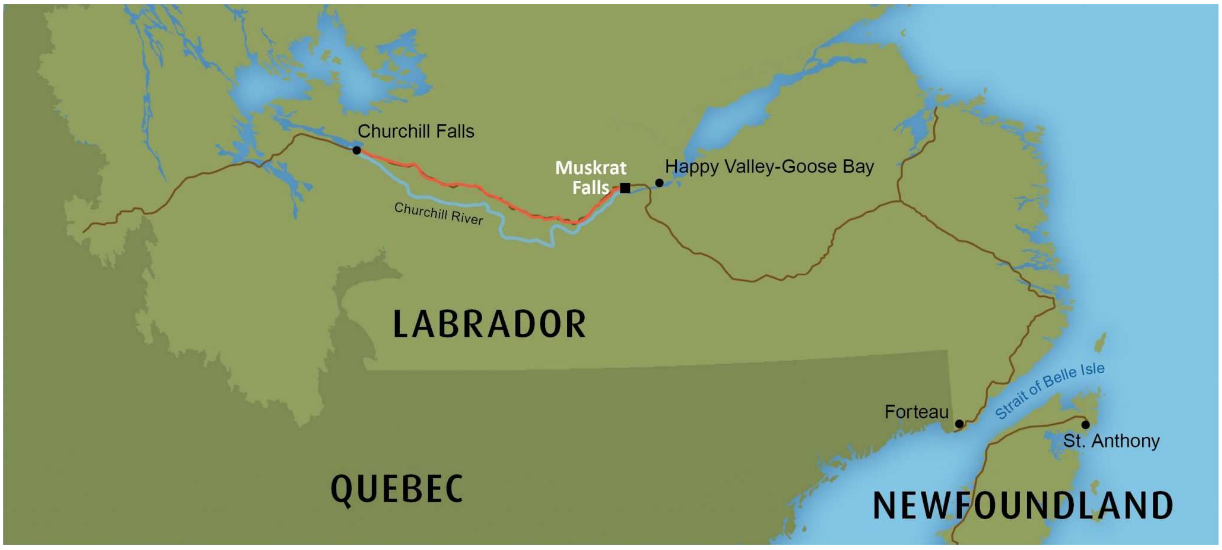

Figure 1: Map of Muskrat Falls Mega-Project Site Location
Map from Nalcor Energy. URL: https://muskratfalls.nalcorenergy.com/construction-activities/labrador-transmission-assets-construction-progress/

The enterprise budget serves as a pilot study to assess the economic and technical feasibility of producing biochar from biomass feedstock (primarily black spruce and balsam fir) cleared after forest clearance for transmission lines running to the new generating station at Muskrat Falls. It is anticipated that the project will focus on the use of a mobile pyrolysis unit to reduce capital costs and take advantage of the log piles (pits) left after forest clearance. The largest of these pits is located right next to the Muskrat Falls site. For the operation described in this report, biochar production would take place at the pit nearest Muskrat Falls, while Happy Valley-Goose Bay would be the business headquarters.

The enterprise budget has been developed in an accessible spreadsheet format to facilitate adaptation to other project contexts. Therefore the results of this project to some extent represent an exploration of the potential for biochar production operations to derive value from resource development project waste in remote regions across the North.

The enterprise budget provides options for the user to choose between using slow and fast pyrolysis units. However, the default for the budget is slow pyrolysis. This is because slow pyrolysis usually produces more biochar than fast pyrolysis (Pratt & Moran, 2010; Kung, McCarl, & Cao, 2013; Ahmed, Zhou, Ngo, & Guo, 2016; Ronsse, Van Hecke, Dickinson, & Prins, 2013), and this project is mainly focused on biochar as an output. Slow pyrolysis also has lower pre-treatment costs (Ahmed, Zhou, Ngo, & Guo, 2016; Wrobel-Tobiszewska, Boersma, Sargison, Adams, & Jarick, 2015), which is favourable for a small scale operation.

The Production Process

The biochar production process includes 5 stages – transportation to production site, pre-processing, pyrolysis, biochar bagging, and biochar transportation and storage. Due to the remote location of Muskrat Falls, both slow and fast pyrolysis process options will begin with transportation to the worksite from Happy Valley-Goose Bay. The activities in pre-processing, pyrolysis, and biochar bagging will differ between slow and fast pyrolysis, but then both processes will end with the transportation of bagged biochar back to Happy Valley-Goose Bay for storage.

Pre-processing for slow pyrolysis will simply consist of cutting logs with a chainsaw to a maximum of two metres for the pyrolysis unit. A utility tractor with a grapple bucket will be used to move logs from the pit for cutting and then into metal cages built specifically for the pyrolysis unit. These cut logs will be loaded directly into the pyrolysis unit without any additional drying using a utility tractor with pallet forks to the lift the cages. Pre-processing for fast pyrolysis will require grinding whole logs with a horizontal grinder and then screening material using a rotary screener to ensure it meets the required size. A utility tractor with a grapple bucket will also be used to move logs, and a regular bucket will be used to move material after grinding and screening are complete.

The process of slow pyrolysis takes approximately four hours. This includes a highest temperature treatment of about 480 degrees Celsius and a residence time of about 180 minutes (Wrobel-Tobiszewska, Boersma, Sargison, Adams, & Jarick, 2015). After pyrolysis the biochar is quenched by water inside the unit. For fast pyrolysis the preprocessed feedstock is first loaded into a hopper using the utility tractor with a regular bucket. The feedstock is dried by heat generated from the thermal oxidizer exhaust stack as it slowly moves into the reactor using a conveyor system. The reactor has two stages. In the first stage the feedstock is carbonized in a controlled environment with limited oxygen at a temperature around 700-750 degrees Celsius for less than a minute. The carbonized feedstock is then held in a second reactor for 10 to 15 minutes at a temperature around 400-550 degrees Celsius. After these two stages are complete the carbonized feedstock leaves the pyrolysis machine via a liquid-cooled auger with an air lock (Kim, Anderson, & Chung, 2015).

Once the charcoal is removed from the pyrolysis unit and has time to sufficiently cool, it must be bagged using a bagging machine. Prior to being bagged the charcoal logs from slow pyrolysis must be ground using a horizontal grinder. Charcoal logs must be moved using a utility tractor with a grapple bucket. After the biochar is ground, it is loaded into the bagging machine's hopper using a utility tractor with a regular bucket. The bagging machine is then used to bag the biochar. Once the biochar from the fast pyrolysis unit has cooled sufficiently it can be loaded directly into the biochar bagging machine using a utility tractor with a regular bucket. From there it too will be bagged using the bagging machine.

After biochar is bagged it will be loaded onto a trailer and hauled to a storage unit in Happy Valley-Goose Bay to be stored until sale or use. The transportation and storage stage of biochar is the same for both slow and fast pyrolysis processes.

Winter Work Considerations

Happy Valley-Goose Bay is subject to extreme cold and heavy snowfall during winter months. For example, daily averages are -4 degrees Celsius in November, -17.6 degrees Celsius in January, and then -1.1 degrees Celsius in April, making for a very long winter season. Snow begins to accumulate in the fall, with an average depth of 1 cm at month-end in October and 11 cm in November. Snow depth is still substantial in April, with an average of 45 cm, and the snow then melts to an average of 4 cm in May (Government of Canada, 2018). Due to these conditions, an outdoor operation to produce biochar would really only be feasible from approximately May 15th to November 15th. Operations could potentially exist during winter if a suitable indoor facility were constructed. To account for these factors, the enterprise budget includes 3 different options for the type of operation. The spreadsheet user can choose whether production will be an outdoor seasonal operation, an indoor operation during winter months with an outdoor operation during summer months, or a year-round outdoor operation. While the year-round outdoor operation might not be very realistic, it is still the default scenario used in the enterprise budget.

Fixed Costs

Categories in fixed costs include machinery, miscellaneous, and overhead. They also include repair and maintenance, insurance, depreciation, interest, and tax. These costs do not directly change when the amount of biochar produced during the operation changes.

Machinery

All equipment used in this enterprise budget is new. This will increase the productivity and reliability of equipment during the life of the project. Also, from a methodological standpoint, using new equipment helps produce the most accurate and consistent depreciation and maintenance cost estimates for the enterprise budget. Used machinery would substantially decrease purchase prices, but also increase maintenance costs and decrease salvage value. It is uncertain how this would affect the overall cost of the project. Purchase prices are not actually part of total fixed costs, but they are used to calculate a number of fixed costs in the enterprise budget. Since all equipment will be assigned a salvage value (this may equal zero), the capital costs are equal to deprecation instead of the purchase price.

For slow pyrolysis, Earth Systems' CharMaker MPP20 mobile pyrolysis plant was selected as a representative model (Earth Systems Bioenergy, 2018). While this particular mobile pyrolysis unit is manufactured by a company in Australia, it was selected due to its high degree of mobility, simplicity to operate, and affordability. This pyrolysis unit requires very little pre-processing work before pyrolysis. Additionally, there is already sufficient documentation available on the CharMaker MPP20 to accurately build an enterprise budget. Wrobel-Tobiszewska et al (2015) listed this unit as $250,000 AUD in 2014. This equals $256,501.33 after converting to 2017 Canadian dollars.

For fast pyrolysis, a mobile pyrolysis plant from Biochar Solutions Inc. was selected (Biochar Solutions Inc., 2018). This company is based in the United States. The unit was selected due to a favourable balance between mobility and productivity, as well as its fairly affordable cost. Additionally, there is already sufficient documentation available on the unit to accurately build an enterprise budget. Kim et al (2015) reported this unit to cost $350,000 USD in 2011. This equals $366,017.01 after converting to 2017 Canadian dollars.

The truck selected for use is a 2018 Chevrolet Silverado 3500HD with four wheel drive, a regular cab, long box, and dual rear wheels to help stabilize when pulling heavy loads. The truck has a gross vehicle weight rating of 8500 kilograms (Labrador Motors Ltd, 2018) and a towing capacity of 23,200 pounds (10,523 kg) (Tom Gill Chevrolet, 2018), so it will be able to carry heavy supplies in the box and pull heavy loads of bagged biochar and machinery on a trailer. The truck would be purchased from Labrador Motors in Happy Valley-Goose Bay and the price from the website for the regular gasoline engine is $48,070 CAD (Labrador Motors Ltd, 2018). The Duramax diesel engine is estimated to cost an additional $9,000 USD (Hearst Communications, Inc., 2018), which is necessary to reach the full towing capacity of the truck. This totals $59,230 after converting to 2017 Canadian dollars and combining the two amounts.

The trailer selected for use is a 25 foot (7.6 m) Classic Pintle with Duals from PJ Trailers Canada Inc. This is a flatbed gooseneck trailer with a gross vehicle weight rating of 25,000 lbs (11,340 kg) (PJ Trailers Canada, Inc., 2015). This type of trailer would be ideal for transporting heavy equipment to the worksite and stacked bags of biochar back to Happy Valley-Goose Bay. The price of $15,364 CAD is for a trailer from Leamington, Ontario's inventory (PJ Trailers Canada, Inc., 2015). The price for the most expensive trailer of this kind in the inventory was used to account for possible additions to the trailer or transportation to Happy Valley-Goose Bay.

The chainsaw selected for use in slow pyrolysis pre-processing is a Stihl MS 661 C-M chainsaw (STIHL, 2018). This is a professional chainsaw designed for the forestry industry. A chainsaw like this is necessary for the amount of logs that need to be cut while preparing feedstock for pyrolysis. Battlefield Equipment Rentals sells these chainsaws in Happy Valley-Goose Bay. For the enterprise budget the more expensive option from Battlefield Equipment Rentals was used to account for the possibility of having a longer guide bar or some other additional features. The price of $1,569.95 CAD (for a 20 inch bar) was taken from Battlefield Equipment Rentals' website (STIHL, 2018).

The grinder selected for use is a Morbark 2600 Horizontal Grinder. Grinders are better suited than wood chippers for large jobs and material that isn't as clean (Ehm; Rotochopper, Inc., 2017). Horizontal grinders are better suited than tub grinders for long material such as whole trees or logs (Berndtson, 2005). Morbark horizontal grinders also have the ability to transform feedstock into desired particle size after one pass (Parker, 2016). This makes the Morbark 2600 Horizontal grinder very suitable for grinding logs before fast pyrolysis or charcoal logs after slow pyrolysis. The price for the Morbark 2600 Horizontal grinder is $360,000 USD and comes from Alexander Equipment Company Inc. (2018) in Illinois. This equals $467,496 after converting to Canadian dollars.

The rotary screener selected for use is the Revolver RT508. A rotary screener was used by Kim et al (2015) to preprocess material for fast pyrolysis, making it a suitable choice since we are using the same pyrolysis unit. A rotary screener will efficiently ensure that only particles which do not exceed the maximum dimensions make it into the fast pyrolysis unit. The price of $92,500 CAD for the Revolver RT508 is from Machinery Trader (2018).

The utility tractor selected for use is the John Deere 5125R Utility Tractor (Deere and Company, 2018). This is a 125 horsepower enclosed tractor that can easily handle all parts of the operation with the right packages and attachments. The additional packages and attachments needed are front loader preparation and cold weather packages, John Deere 540R Loader, John Deere AP12F Pallet Forks, and a John Deere AD11E Debris Grapple Bucket. This will enable the utility tractor to pick up logs using the debris grapple bucket, and load the pyrolysis units using either the pallet forks or the regular bucket with the loader. Prices for the base model and packages are from the John Deere website and total $98,205 USD combined (Deere and Company, 2018). The price for the loader attachment is from Iron Search and is $10,622 USD (IRON Solutions, Inc., 2018). The prices for the pallet forks and debris grapple bucket are from Mutton Power Equipment and are $929 (Mutton Power Equipment, 2018) and $3,399 (Mutton Power Equipment, 2018) respectively. This totals $146,934.08 after converting to Canadian dollars.

Options that include fast pyrolysis or an indoor facility during the winter require diesel powered generators. The generator selected to power the fast pyrolysis unit is a mobile 30,000 watt generator with a John Deere diesel-powered engine. This generator has the ability to run continuously and power industrial operations like the fast pyrolysis unit. Diesel fuel enables the generator to operate where no other power sources are available. The price of this generator is from Central Maine Diesel, and after including a 250 gallon fuel tank with a double-axle trailer, it totals $17,294 USD (Central Maine Diesel, 2018). This equals $22,457.99 after converting to Canadian dollars. The generator selected to power the facility during winter months is a 9,875 watt Kubota Diesel generator. This generator is sufficient to power the lights and heating of the indoor building, which is all that will be needed. Since it uses diesel fuel, it will also be able to operate where no other power sources are available. The price of this generator is also from Central Maine Diesel, and after including a 100 gallon Subbase fuel tank, it totals $8,490 USD (Central Maine Diesel, 2018). This equals $11,025 after converting to Canadian dollars.

The bagging machine selected for use is the Rotochopper Go-Bagger 250. The Rotochopper Go-Bagger 250 is an easy to use, 20 horsepower, diesel powered bagging machine. It can fill and seal 250 bags an hour with a large range of material including landscape mulch, decorative rock, fuel pellets, and topsoil (Rotochopper, Inc., 2018). This makes it a very suitable bagging machine to use for biochar. The price for the Rotochopper Go-Bagger 250 was $47,145.13 USD in 2015 and comes from an “Authorized Federal Supply Service” document published by Rotochopper Inc. (Rotochopper Inc., 2015). This equals $62,018.81 after converting to 2017 Canadian dollars. The bags used are from Poly Pak America. They are two cubic feet, white, polypropylene bags that cost $83.10 USD for a case of 100 (PolyPack America Inc., 2018). This equals $110.90 after converting to Canadian dollars. The weight capacity of these bags is 40 to 50 pounds, however Rotochopper’s promotional video suggests not exceeding 40 pounds per bag with the Go-Bagger 250. This would mean using 55.1 bags for each tonne of biochar produced, which would cost $61.11 CAD per tonne of biochar.

The pyrolysis setup and transportation cost depends on the type of pyrolysis unit used. The CharMaker from Earth Systems only requires transportation to the worksite, but no real setup costs. Kim et al (2015) included an initial setup cost of $9,880 USD in 2011 as part of the total cost of their pyrolysis unit. This included $5,000 USD in 2011 for transportation. We use $5,000 USD as a minimum value for initial transportation of Earth Systems' CharMaker and $9,880 USD as a minimum value for initial transportation and setup of Biochar Solutions' fast pyrolysis unit in the enterprise budget. This equals $5,380.70 and $10,632.27 after converting to 2017 Canadian dollars for the slow and fast pyrolysis units respectively.

Biochar must be stored indoors at Happy Valley-Goose Bay between the time it is produced and sold. The Labrador Institute rents an unheated indoor storage area that is 900 square feet for $10,000 CAD per year. A similar storage unit would be used for this project, therefore this price is used in the enterprise budget.

Due to the need to leave equipment at the Muskrat Falls production site a fenced compound and machine shed are required. Home Advisor gives a range from $1,100 USD to $2,300 USD for a metal or chain fence (HomeAdvisor, Inc., 2018). Due to the remote location of Muskrat Falls, the upper range is used, equaling $2,986.78 after converting to Canadian dollars. Buildings Guide gives cost estimates for a 40 by 60 foot steel building, which would be suitable for the machine shed. Material costs are estimated as $7 USD to $10 USD per square foot; labour costs are estimated as $5 USD to $8 USD per square foot; delivery is estimated as 5 percent to 10 percent of material costs; construction is estimated as $4 USD to $8 USD per square foot; and the foundation is estimated as $4 USD to $8 USD per square foot (BuildingsGuide.com Online Inc., 2018). This will be a very basic steel shed used to secure equipment and protect it from the elements. Therefore the lower ranges of $7 USD, $4 USD, and $4 USD per square foot are used for material cost, construction cost, and foundation cost respectively. However, Muskrat Falls is a remote location, therefore the higher ranges of $8 USD per square foot and 10 percent of material costs are used for labour and delivery costs respectively. This totals of $56,880 USD, which equals $73,864.37 after converting to Canadian dollars.

The option for indoor operation during the winter months requires a steel frame building. Buildings Guide gives an estimate for the average commercial steel building. Material, delivery, foundation, and the cost of construction are estimated to cost $16 USD to $20 USD per square foot. Including additional finishing like insulation is estimated to cost a total of $30 USD to $40 USD per square foot (BuildingsGuide.com Online Inc., 2018). Prices would likely be high due to the remote location of Muskrat Falls and insulation would be essential for winter months, therefore the estimate used in the enterprise budget is $40 USD per square foot. In order to be practical the costs for plumbing, electrical and heating also need to be included. A commercial and industrial construction blog called The Ross Group provide estimates on these. It estimates $4 USD to $10 USD per square foot for plumbing, $6 USD to $13 USD per square foot for electrical, and $6 USD to $13 USD per square foot for heating and air conditioning (The Ross Group, Inc., 2014). This indoor facility will not have elaborate plumbing, electrical, or heating systems, and no air conditioning will be needed, therefore the lower estimates of $4 USD, $6 USD, and $6 USD per square foot are used in the enterprise budget for plumbing, electrical, and heating respectively. The size of the facility will be 100 by 80 feet, giving a total cost of $448,000 USD. This equals $581,772.80 after converting to Canadian dollars.

Water must be transported to the production site at Muskrat Falls in order to provide water for biochar quenching at the end of the pyrolysis process. A 425 gallon horizontal leg tank from Plastic-Mart was selected to transport the water (Plastic-Mart, 2017). This tank weighs 120 pounds when empty, and fits in the bed of a pickup truck, making it ideal for transporting water to the site. Two bolt down hoops are needed to secure the tank to the truck bed. The tank costs $479.99 USD, and the two hoops cost $59.99 USD combined, totaling $539.98 USD. This equals to $701.22 after converting to Canadian dollars.

During warmer months the operation would be outside and a form of plumbing would be needed for the workers. At a minimum a portable toilet and portable septic tank would be needed. The portable toilet selected is the PolyJohn PJN3 Portable Restroom from Global Industrial, which costs $902 CAD (Avenue Industrial Supply Co. Ltd., 2018). The portable septic tank selected is the PolyJohn 250 Gallon Holding Tank from Global Industrial, which costs $711 CAD (Avenue Industrial Supply Co. Ltd., 2018).

Following the guidelines of the Ontario Ministry of Agriculture, Food and Rural Affairs, legal and accounting fees and other administrative expenses are estimated at 5 percent of total expenses before rebates (Ontario Ministry of Agriculture, Food and Rural Affairs, 2017). For this estimate, 5 percent of total machinery costs, total miscellaneous costs, fees, permits, and other payments, and total variable costs were calculated for total administrative fees in the enterprise budget. This value changes according to the production option selected in the spreadsheet.

Information on business fees and permits comes from Canada Business Network (Government of Canada, 2018) and the Town of Happy Valley-Goose Bay (Town of Happy Valley-Goose Bay, 2016). Business fees and permits include a compliance certificate of $100 CAD, tax certificate of $100 CAD, annual timber purchase licenses of $100 CAD, an environmental assessment determination of $400 CAD, and crown land tenure of $150 CAD (plus HST). Additionally, health, safety and compensation coverage and registration is needed, which is 98 cents (assessment rate) for every 100 dollars spent on assessable payroll. Additional fees for water and sewage also come from the Town of Happy Valley-Goose Bay (Town of Happy Valley-Goose Bay, 2015). Water and sewage cost $17.50 CAD and $25 CAD per month respectively.

Depreciation

Equipment was assigned depreciation rates depending on the method used to estimate remaining values (salvage values). Salvage values for the truck, trailer, and utility tractor were estimated using the American Society of Agricultural and Biological Engineers' (ASABE) formula (American Society of Agricultural and Biological Engineers, 2011). The formula's parameters for the truck, trailer, and utility trailer come from the society's parameters for skid steer loader and all other vehicles, manure spreaders and all other miscellaneous equipment, and a medium tractor (80-150 HP), respectively. These salvage values are estimated to be 26 percent of the cost for the truck, 35 percent for the trailer, and 36 percent for the utility tractor. For many types of equipment remaining value formulas are less available. For this equipment we followed Brinker et al. (2002) and assigned each piece of equipment a salvage value of 20 percent of the purchase price. This included the horizontal grinder, the rotary screener, the generators, the bagger, the fenced compound, the machine shed, the warehouse, the water tank, the portable toilet, and the portable septic tank. For the pyrolysis units we followed Kim et al (2015) and assigned a salvage value of 10 percent. Lastly, for the chainsaw we followed Clearly et al (2015) and assigned a salvage value of zero. All equipment were assigned useful lives of 10 years except for the chainsaw, which was assumed to have a useful life of 5 years. Due to this, two chainsaws are needed over the course of the 10-year project.

Maintenance

Maintenance costs for the truck are estimated following a research report from the Minnesota Department of Transportation (Barnes & Langworthy, 2003). Parameters for these estimations are from values for extremely poor pavement quality, since the truck will be hauling heavy loads and often driving on winter roads, as well as short distances off paved roads to the site. These parameters convert to approximately $0.052 CAD per km for maintenance excluding tires and $0.013 CAD per km for tires. The distance from Muskrat Falls to Happy Valley-Goose Bay is 45.2 km measured from Google Maps, making total truck maintenance for a round trip cost $5.90 CAD. This extrapolates to $1,444.40 CAD per year. Maintenance costs for the trailer's tires are the same as the truck's tires, but maintenance costs for the rest of the trailer are much lower, as the trailer has fewer mechanical parts that need to be serviced. For this reason, maintenance costs excluding tires are assigned to be 50 percent of depreciation, totaling $792.76 per year with the cost of maintaining tires.

Chainsaw maintenance costs follow the same methods as Popovici (2013) for chain replacements and Miyata (1980) for chainsaw maintenance. Popovici (2013) finds 0.01 chains to be used for every cubic metre of wood cut. Using a density of 440 kilograms per cubic metre for air dried black spruce (Forintek Canada Corp., 2006) this converts to 0.02 chains per tonne of feedstock. This then converts to 44.5 chains per year, which at $41.14 CAD (converted from $31.68 USD) per chain (Bailey's Inc., 2018) is equal to $1,832.58 CAD per year. Other chainsaw maintenance is estimated as 100 percent of depreciation (Miyata, 1980), equal to $313.99 CAD per year. Combining these two segments equals $2,146.57 CAD per year for total chainsaw maintenance.

Pyrolysis maintenance costs follow the same method as Ahmed et al (2016), which is 1.5 percent of depreciation. This equals $5,490.26 CAD per year.

For other equipment we use methods similar to Brinker et al (2002) to estimate maintenance costs as a percentage of depreciation. This is 100 percent for the horizontal grinder, rotary screener and generators, and 90 percent for the utility tractor. The grinder, screener, and utility tractor match similar equipment used by Brinker et al (2002) to provide estimates, and the generators used a high maintenance cost due to the fact they are almost continuously running. While estimates for other equipment follow a similar method to Brinker et al (2002), only 30 percent of depreciation is used since the equipment is used more lightly. This includes the bagger, fenced compound, machine shed, and warehouse. There are no costs for the maintenance of the water tank, portable toilet, and portable septic tank. The annual costs for maintenance are $37,399.68 CAD, $7400 CAD, $1,939.49 CAD, $882.01 CAD, $8,452.36 CAD, $1,488.45 CAD, $71.68 CAD, $1,772.74 CAD, and $13,962.55 CAD for the horizontal grinder, rotary screener, pyrolysis generator, warehouse generator, utility tractor, bagger, fenced compound, machine shed, and warehouse respectively. The sewage fee includes service for the portable toilet and septic tank.

Insurance

Insurance rates in other literature range from 1 percent to 7 percent of purchase price. Brinker et al (2002) use 1.5 to 5 percent, Zhang et al (2016) use 7 percent, Dodson et al (2015) use 1.3 percent, Ahmed et al (2016) use 1 to 1.5 percent, Polagye et al (2007) use 2 percent, Brown et al (2011) use 3 percent, Clearly et al (2015) use 4 percent, and Islam and Ani (2000) use 2 percent. On the other hand, online tools to calculate insurance rates and machine costs from the Government of Alberta (2018) and the University of Washington (2018) use insurance rates of 1 percent and 0.5 to 1.5 percent of purchase price, respectively. Due to this large range in insurance rates, the enterprise budget provides the option to choose between 0.5 and 7 percent of purchase price, with the default set at 1 percent.

Interest

It is assumed that all equipment will need to be financed through a five to ten year loan. The enterprise budget provides the option to choose between five and ten years for the payment period, with the default set at ten years. Loan interest rates can vary too, and usually increase with payment period. The five year fixed closed interest rates for CIBC (2018), Scotiabank (2018), and TD (2018) were 4.99 percent, 5.14 percent, and 5.14 percent respectively. The ten year fixed closed interest rates for CIBC, Scotiabank, and TD were 6.29 percent, 6.39 percent, and 6.1 percent respectively. Due to the potential range the enterprise budget provides the option to choose between 3 and 10 percent for the interest rate, with the default set at 6 percent.

Tax

All fixed costs except for pyrolysis setup and transportation, the storage unit in Happy Valley-Goose Bay, administrative costs, and fees, permits and other payments are subject to a harmonized sales tax (HST) of 15 percent (Government of Newfoundland and Labrador, 2018). This is the current HST rate in Newfoundland and Labrador.

Fixed Costs Summary

The total fixed costs for each item in the enterprise budget except pyrolysis setup and transportation, the storage facility in Happy Valley-Goose Bay, administration costs, and fees, permits, and other payments is equal to repair and maintenance, insurance, depreciation, interest, and tax. The Annual fixed cost for each item is equal to the total fixed cost divided by 10, since this project is projected to last 10 years. The cost per tonne of biochar is then equal to the annual fixed cost divided by the number of days worked per year, multiplied by the technical availability, and then divided by the number of tonnes of biochar produced per day. Total fixed costs in the enterprise budget equal total machinery fixed costs, plus total miscellaneous fixed costs, plus total overhead charges.

Variable Costs

Variable costs consist of all costs for fuel, oil and lubricants, labour, and miscellaneous costs. These are costs that are directly affected when the amount of biochar produced changes.

Fuel

Equipment that uses diesel includes the truck, horizontal grinder, rotary screener, utility tractor, pyrolysis unit, both generators, and the biochar bagger. The chainsaw uses gasoline and a chainsaw oil mix of 50 parts gasoline for every part oil. The chainsaw, horizontal grinder, rotary screener, utility tractor, pyrolysis unit, both generators, and biochar bagging equipment all have additional lubricant costs. The diesel price used in the enterprise budget, $1.31 CAD per litre, is the average retail price of diesel for 2017 in Labrador City (Government of Canada, 2018). The gasoline price used in the enterprise budget, $1.38 CAD per litre, is the average retail price of premium gasoline for 2017 in Labrador City (Government of Canada, 2018). Premium gasoline is used since this is a small two-cycle engine. The two-cycle engine oil price used is from Kooy Brothers (2018). 100 mL of Stihl Premium two-cycle engine oil costs $2.04 USD. This equals $2.65 after converting to 2017 Canadian dollars, or $26.49 CAD per litre. The chainsaw bar and chain oil price used is from Lowes. One gallon of Husqvarna premium bar and chain oil costs $19.99 CAD (Lowe's, 2018). This converts to $5.28 per litre. Oil price for the generators is from Green Part Store, an authorized John Deere dealer in United States. One quart of oil costs $4.25 USD (AHW LLC, 2018). This is equal to $5.52 after converting to Canadian dollars, or $5.83 per litre. Lubrication costs for the horizontal grinder, rotary screener, utility tractor, pyrolysis unit, and bagging machine are simply a function of the cost of fuel, therefore no per-unit costs are needed.

Diesel

The fuel efficiency of the 2018 Chevy Silverado 3500HD depends on a lot of different variables. Unfortunately government organizations don’t provide estimates on the fuel efficiency of heavy duty pickup trucks. Therefore, alternative sources have been used. Agency Autotrader reported the truck to achieve 12 miles per gallon in the city and 17 miles per gallon on the highway without a load (Autotrader, Inc., 2018). On the other hand, TFLTruck reported the truck to achieve 6.6 miles per gallon when pulling a heavy load (Smirnov, 2018). For this project, the truck should have a fuel efficiency somewhere in between these values, since it will be pulling an empty to partially full trailer on highways most of the time. A discussion on Heartland Owners Forum found that a truck pulling an empty trailer achieves approximately 10 miles per gallon, while a truck pulling a partially empty trailer achieve s approximately 8 miles per gallon (Heartland Owners, 2009). For this project the truck will make almost all trips from Happy Valley-Goose Bay to Muskrat Falls with an empty trailer, but trips back to Happy Valley-Goose Bay will have a partially full trailer as biochar is transported to storage. To account for this, a fuel efficiency of 10 miles per gallon is used for the trip from Happy Valley-Goose Bay to Muskrat Falls and a fuel efficiency of 8 miles per gallon is used for the trip from Muskrat Falls to Happy Valley-Goose Bay. This converts to approximately 0.24 litres per kilometre for the trip to Muskrat Falls and 0.29 litres per kilometre for the trip to Happy Valley-Goose Bay. The distance from Happy Valley-Goose Bay to Muskrat Falls on Google Maps is 45.2 km. Therefore, approximately 10.6 litres of diesel are used for the trip to Muskrat Falls and 13.3 litres of diesel are used for the trip to Happy Valley-Goose Bay. Adding these values together gives a total of approximately 23.9 litres of diesel per day.

To estimate the diesel consumption for the horizontal grinder, rotary screener, utility tractor, and biochar bagger we followed a method used for calculating machine rates developed by Brinker et al (2002). Each of these machines uses approximately 0.02 gallons or 0.08 litres of fuel per horsepower hour. The horizontal grinder, rotary screener, utility tractor, and biochar bagger have 300, 48, 125, and 20 horsepower engines respectively. The horizontal grinder, rotary screener, and biochar bagger are all expected to operate approximately 2 hours per day, while the utility tractor is expected to operate approximately 4 hours per day. This means that the horizontal grinder, rotary screener, utility tractor, and biochar bagger will use approximately 600, 96, 500, and 40 horsepower hours per day respectively, which would convert to approximately 49.2, 7.8, 41, and 3.3 litres of diesel per day for the horizontal grinder, rotary screener, utility tractor, and biochar bagger respectively.

The diesel consumption for the Earth Systems CharMaker is provided by Wrobel-Tobiszewska et al (2015). One batch requires 10 litres of diesel, and each batch takes about 4 hours. It is assumed that the slow pyrolysis unit will produce two batches of biochar every day. Therefore the slow pyrolysis process will use 20 litres of diesel per day.

The Biochar Solutions Inc. fast pyrolysis unit is powered with electricity generated by the 30,000 watt diesel generator. This generator uses 1.3 gallons per hour of diesel on half load capacity, 1.8 gallons per hour of diesel on three quarter capacity, and 2.4 gallons per hour of diesel on full load capacity (Central Maine Diesel, 2018). It is assumed that the generator will run on three quarter load capacity. This value converts to approximately 6.8 litres of diesel per hour. It is assumed that the fast pyrolysis unit operates the same number of hours the employees are at the worksite. The amount of diesel used per day is equal to the amount of diesel used per hour multiplied by the number of hours the pyrolysis unit is in operation.

The 9,875 watt diesel generator that powers the electricity for the winter facility is reported to use 0.41 gallons per hour at half load, 0.63 gallons per hour at three quarter load, and 0.84 gallons per hour at full load (Central Maine Diesel, 2018). It is assumed that the generator will operate at three quarter load during hours of production, but only half load during other times between May 15 and November 15. This will ensure there is still adequate power to heat the building, while providing additional power for lighting during the day. The fuel consumption for half load and three quarter load convert to approximately 1.6 and 2.4 litres of diesel per hour respectively. To calculate the amount of diesel used during a day, the hourly fuel consumption for three quarter load is multiplied by the number of hours per day that production is taking place at the site, multiplying the number of hours left in a day (24 minus the number of hours per day that production is taking place at the site) by the hourly fuel consumption for half load, and then adding the two derived values together. To calculate the total amount of diesel used in a year, the daily amount derived from combining both three quarter and half load is multiplied by the total number of days worked between May 15 and November 15, the hourly fuel consumption for half load is multiplied by 24 (a full day) for each day not worked (weekends and public holidays), and then these two newly derived values are added together.

Gasoline and Mixed Engine Oil

To estimate gasoline consumption for the chainsaw, we use values from Popovici et al (2013). A chainsaw is reported to use approximately 0.4 litres of gasoline per cubic metre of wood cut. Using 440 kilograms per cubic metre as the density for air dried black spruce (Forintek Canada Corp., 2006) this converts to approximately 1 litre per tonne of feedstock. It is assumed that approximately 8 tonnes of feedstock will be used each day to produce approximately 2 tonnes of biochar, or the equivalent of 2 batches with the Earth Systems CharMaker slow pyrolysis unit. To calculate the amount of gasoline used per day, 1 is multiplied by the amount (in tonnes) of feedstock used per day (8). This amount is then multiplied by the number of days worked per year to calculate the amount of fuel used per year. The cost is found by multiplying the litres of gasoline used by the price for a litre of gasoline.

STIHL gasoline-powered equipment requires a 50:1 mixture of gasoline and 2-cycle engine oil (STIHL, 2018). This means that for every litre of 2-cycle engine oil 50 litres of gasoline are used in the fuel mixture. To estimate the volume of 2-cycle engine oil used per tonne of feedstock, the volume of gasoline used per tonne of feedstock (approximately 1 litre) is divided by 50, which equals approximately 0.02 litres. To calculate the amount of 2-cycle engine oil used per year, the gasoline used per year is also divided by 50.

Lubricants

To estimate chainsaw lubrication costs, we also used values from Popovici et al (2013). A chainsaw is reported to use approximately 0.18 litres of lubricating oil per cubic metre of wood cut. Using 440 kilograms per cubic metre as the density for air dried black spruce, this converts to approximately 0.4 litres per tonne of feedstock. To calculate the amount of lubricating oils used per day, 0.4 is multiplied by the amount (in tonnes) of feedstock used per day (8). This amount is then multiplied by the number of days worked per year to calculate the amount of fuel used per year. The cost is found by multiplying the litres of lubricant used by the price for a litre of lubricant.

To calculate the lubricant cost for the horizontal grinder, screener, utility tractor, pyrolysis unit, and biochar bagger, a method developed by Brinker et al (2002) is used, wherein lubrication costs are equal to 37 percent of fuel costs. This eliminates the need to know per-unit costs of these lubricants and simplifies calculations.

To estimate fuel consumption for the generators, service support tips from John Deere on oil consumption guidelines for tractor engines are used (Deere & Company, 2013). It made sense to use this approach instead of the method developed by Brinker et al (2002) since generators are mostly just engines and therefore have fewer moving parts that require lubrication than the other equipment.

Guidelines for the oil consumption of a John Deere tractor's engine were used because the 30,000 watt generator powering the fast pyrolysis unit has a John Deere tractor engine (Central Maine Diesel, 2018). The guideline is that a normal amount of oil needed for 100 gallons of fuel is 1 quart or less. Using 1 quart of oil for every 100 gallons of fuel, this converts to 0.0025 litres of oil for every litre of fuel. To calculate the volume of oil used (in litres), the volume of diesel used (in litres) was simply multiplied by 0.0025. To calculate the cost of the fuel, this amount was multiplied by the price of a litre of engine oil.

Labour

Wage rates are calculated using information from the Canadian Government Job Bank and Employment Standards published by the Government of Newfoundland and Labrador. The median hourly wage for logging machinery operators in Newfoundland and Labrador is $25 CAD (Government of Canada, 2018). This seemed an appropriate wage since the work done in this operation is similar to some of that done by logging machinery operators. Happy Valley-Goose Bay is also fairly far north, meaning wages would probably be higher than areas in southern Canada, making wages for normal labourers too low. According to regulations set by the Government of Newfoundland and Labrador, any time worked in excess of 40 hours in a week is overtime and must be paid at the minimum overtime rate of 1.5 times the normal wage (Government of Newfoundland and Labrador, 2017). It is assumed that employees will be paid for both the transportation to and from the Muskrat Falls worksite and the time working at the site. It is also assumed that employees will work five days a week with weekends off, meaning any time in excess of 8 hours per day will be paid an hourly overtime wage of $37.50 CAD. With these assumptions, calculating wages from regular pay consists of multiplying 25 by the number of hours worked equal or less than 8, and then multiplying this by the number of employees working. Calculating wages from overtime pay consists of multiplying 37.5 by the number of hours worked in excess of 8, and then multiplying this by the number of employees working. Calculating total wages paid consists of simply adding together the wages from regular pay and overtime pay.

In addition to wages, employers in Newfoundland and Labrador are required to give employees vacation time or pay, paid time off for public holidays, or twice the regular wage if asked to work on a public holiday (Government of Newfoundland and Labrador, 2017). Vacation pay is 4 percent of gross wages for employees who have worked less than 15 continuous years and less than 12 continuous months with the same employee. Paid vacation time is 2 weeks per year for employees who have worked less than 15 continuous years and at least 12 continuous months with the same employer. For simplicity, annual vacation time is paid for the same amount of work as a normal day in the model used for the enterprise budget. The option in the enterprise budget where employees work year-round incorporates paid vacation time for the workers. The option in the enterprise budget where employees work only from May 15 to November 15 incorporates a vacation pay for the workers. The rationale here is that seasonal workers cannot receive annual vacation time since they do not work for 12 continuous months for the employer. Public holidays in Newfoundland and Labrador that employees must be paid for are New Year's Day, Good Friday, Memorial Day (Canada Day), Labour Day, Remembrance Day, and Christmas Day. All six public holidays are included in the year-round production option, while three public holidays are included in the seasonal production option from May 15 to November 15. For simplicity, employees are paid for the same amount of work as a normal day on public holidays in the model used for the enterprise budget.

A number of steps are taken to calculate the actual days paid and actual days worked per year. Gross days paid per year is calculated by subtracting the number of weekend days per year from the total number of days per year. The year-round production covers all 365 days per year with 104 weekend days and the seasonal production option from May 15 to November 15 covers 185 days per year with 52 weekend days. In the year-round production option, net days paid per year is the same as the gross days paid per year since public holidays and vacation days are already included in the total days per year. In the seasonal production option net days paid per year is equal to the gross days paid per year plus 4 percent of the gross days paid per year for vacation pay. This is because public holidays are already included in the total days per year, but vacation pay is not. Net days paid per year equals 261 for the year-round production option and 138.32 for the seasonal production option. Days worked per year is calculated by subtracting the number of public holidays and vacation days or pay from the net days paid per year. Days worked per year equals 245 for the year-round production option and 130 for the seasonal production option. The numbers of actual days paid per year and actual days worked per year simply depend on whether a year-round or seasonal production option is selected in the enterprise budget.

To calculate technical availability, we follow Polagye et al (2007). Technical availability factors in the amount of downtime due to technical problems with equipment such as maintenance and repairs. It is unrealistic to assume equipment will operate 100 percent of the time to enable production on every working day. To account for this, we use 85 percent as the default value for technical availability, and provide an option to change this to values between 75 and 100 percent. This is incorporated into the enterprise budget in two steps. The first step is multiplying the number of hours the machinery is expected to operate by the technical availability when calculating fuel and lubricant consumption for both slow and fast pyrolysis options. During downtime and repairs, biochar production will most likely not occur, meaning that most equipment will also not be operating. All machinery except for the truck and warehouse generator are included in this variation. This doesn't change the cost of production per tonne of biochar by very much. The second step is multiplying the number of days worked by the technical availability when calculating the cost per tonne of biochar for the slow pyrolysis option. This second step is not applied to the fast pyrolysis option, because the values used for biochar production by Kim et al (2015) already account for equipment downtime. While the study only looks at a small period of time, Kim et al (2015) find the unit from Biochar Solutions Inc. to have a utilization rate between 75.1 and 84.2 percent.

Miscellaneous

An important part of biochar production is disposing of the unwanted waste from the process. In an analysis done by Brown et al. (2011), the cost of waste disposal was estimated as $5,000 USD per year. This equals $5,380.70 when converted to 2017 Canadian dollars and is used as a minimum value for waste disposal in the enterprise budget.

Spreadsheet Design

The Enterprise Budget Excel file is broken into four Excel sheets. The first sheet contains the fixed costs for biochar production. This includes machinery costs, miscellaneous costs, overhead charges, and total fixed costs. From left to right this sheet includes the item purchased, the type or name of the item, the number of items per unit, the quantity of units purchased, the price per unit, the total purchase cost, the salvage value, the useful life of the item, the cost for repair and maintenance, the annual insurance rate, the total insurance paid, the total depreciation, the annual interest rate, the payment period, the monthly payments, the total interest paid, the tax on purchases, the total fixed costs, the annual fixed costs, and the cost per tonne of biochar produced. Total fixed costs are equal to repair and maintenance, insurance, depreciation, interest, and tax. Annual fixed costs are equal to total fixed costs divided by 10. The cost per tonne of biochar is what really determines the feasibility of the project, which will depend heavily on the selling price for biochar. Cost per tonne of biochar produced is equal to the annual fixed cost divided by the actual days worked per year multiplied by technical availability, all divided by the tonnes of biochar produced in a day. The top right corner of the Excel sheet also contains options to be able to choose slow or fast pyrolysis operations, and outdoors year-round, outdoors seasonal, or indoors during winter. All cells highlighted in yellow can be changed, and all cells highlighted in light red show total derived amounts.

The second sheet contains the enterprise budget, which is made up of all variable costs for biochar production, fixed costs from the first sheet, and then total fixed and variable costs at the bottom. The variable costs include fuel, oil and lubricants, labour, miscellaneous, and total variable costs. From left to right, this sheet includes the type of cost, the cost per unit, the unit used, the number of units used per year, the annual cost, the total cost, and the cost per tonne of biochar produced. The annual cost is equal to the cost per unit multiplied by the units used per year, and the total cost is equal to the annual cost multiplied by 10. The variable cost per tonne of biochar produced is calculated the same as for the fixed costs – annual variable cost divided by the actual days worked per year multiplied by technical availability, all divided by the tonnes of biochar produced in a day. No cells can be changed in this sheet.

The third sheet contains all the parameters for the model that can be changed depending on the operation's expected efficiency. The first box of parameters contains the expected number of hours per day for machinery use. The default values are two hours for the horizontal grinder, two hours for the rotary screener, four hours for the utility tractor, eight hours for the slow pyrolysis unit, ten hours for the fast pyrolysis unit, ten hours for the pyrolysis generator, two hours for the biochar bagger, and ten hours for total preprocessing and operations. While the default values represent the assumed times, the values for all of these machines or activities can be changed to account for higher efficiency except for the pyrolysis units and generator. The slow pyrolysis unit will always be set at eight because it takes eight hours to complete two batches of biochar regardless of the operation's efficiency. Efficiency in the slow pyrolysis operation is only reflected by the additional time spent in pre-processing and bagging stages. The fast pyrolysis unit will begin operating as soon as production begins. Therefore it will always be the same as the total number of hours in preprocessing and operations, which can be changed. The generator is used to power the fast pyrolysis unit, and therefore it will always be the same as the fast pyrolysis unit. The second box of parameters contains the tonnes of biochar produced per hour, per day, and the technical availability of the operation. The technical availability is the only value that can be directly changed in this box. The selected type in the bottom row changes according to whether slow or fast pyrolysis was selected. The third box of parameters just contains the number of employees working in the production process. The default value here is set to two, but can be changed between two and four.

The fourth sheet contains tables with all the data and many of the calculations used in the enterprise budget. These tables include business permits and fees, administrative costs, labour rates, days worked and paid, equipment depreciation, maintenance costs, fuel consumption, lubricant consumption, miscellaneous, and data for drop-down menus.

Inflation and Exchange Rates

Currency exchange rates and consumer price indexes were used to convert all prices to 2017 Canadian dollars. For all calculations converting a 2017 foreign currency to 2017 Canadian dollars, the Bank of Canada's annual exchange rates were used (Bank of Canada, 2018). These were mainly conversions from US dollars to Canadian dollars, which is approximately one US dollar to 1.3 Canadian dollars. To convert foreign currency from years before 2017 to Canadian dollars, historical exchange rates were used from CanadianForex (2018). Specifically, the exchange rate given for the last month of the year was used in conversions for that year. To account for inflation and convert all currency from nominal to real 2017 values, the consumer price index (CPI) from Statistics Canada was used (Government of Canada, 2018). To make this conversion, a deflator was calculated by dividing the 2017 CPI by the nominal year's CPI. The nominal value was then multiplied by the deflator. Nominal values of foreign currencies for past years were always converted to Canadian dollars first, and then converted to 2017 real Canadian dollars using a deflator.

Conclusions

The largest constraint to using a mobile pyrolysis unit is the limited amount of biochar that can be produced. A large amount of equipment is still needed for preprocessing and pyrolysis, even though the scale of the operation is very small. Many of these machines will not be used to their full capacity (e.g. Horizontal Grinder, Rotary Screener, Biochar Bagger). Total costs would most likely not rise at the same level as the operation's scale, meaning that units capable of producing more biochar could lower the per-tonne cost of production. Therefore, one of the most effective ways to increase the feasibility of this project could be to identify a mobile unit that can produce significantly more biochar.

Transportation to and from the worksite at Muskrat Falls did not add a significantly high cost through fixed costs or fuel. However, the labour cost during transportation, a period of time when production cannot occur, was more significant. The per-tonne cost of production could be significantly reduced if the transportation time was actually spent producing biochar. This would mainly affect the fast pyrolysis operation, since the slow pyrolysis unit operates under four-hour intervals to produce a batch. Extending the number of days worked per year would also decrease the per-tonne cost of production.

Another potential problem could be the difficulty in getting the finished product to the biochar market after it is produced. Happy Valley-Goose Bay is a fairly remote community in northern Canada. High costs will likely be added to ship biochar for sale. This is a challenge that can be addressed in a future segment of the project.

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