Techno-economic Assessment of Biomass Conversion to Charcoal for Carbon Sequestration

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by

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Executive Summary

Climate change is one of the important environmental issues facing the world today. It is caused by the greenhouse gas (GHG) effect. This rise in global temperature could have adverse affect on the climate. This could have adverse affect on biodiversity and weather pattern resulting in floods, droughts, high precipitation etc. Hence global warming is a major challenge for our society today.

The energy consumption in the world is growing and most of this energy is fossil fuel based. In Alberta, most of the energy is fossil fuel based. Biomass usage, specifically capturing energy from biomass that would otherwise decay, is one of many options available to mitigate the impact of the buildup of GHG emissions from fossil fuel utilization. Biomass is considered carbon neutral because the amount of CO_2 released during its combustion is essentially the same as absorbed by the plants during their growth. Current biomass usage is minimal but the interest is growing and there is federal and provincial support for developing bioeconomy. Most of the biomass utilization today is for energy and fuels and these are based on mill residues. Utilization of lignocellulosic biomass is minimal. Alberta has large biomass resource potential for energy purposes. It is important to evaluate various pathways of biomass utilization for Alberta. There is limited amount of work on the conversion of biomass to an intermediate product and its storage for carbon sequestration. This work will explore the utilization of biomass in this area. This study draws on actual data to determine the cost of charcoal production and estimates the cost of carbon sequestration to compare this pathway with other carbon sequestration pathways.

Charcoal is a solid fuel which can be produced from biomass. When charcoal is produced from biomass it is called as bio-char. Charcoal is an organic solid and is produced by heating of biomass in absence of air. Charcoal can be produced from a range of biomass feedstock which can include forest biomass (e.g. whole forest biomass (trees), forest harvest residues) as well as agricultural biomass (e.g. straw). Various research groups around the world have studied charcoal and are developing technologies for its production and utilization. Currently, charcoal is mostly used for fuel, chemicals and as fertilizers.

This work involved a conceptual techno-economic study to estimate the cost of production of biomass based charcoal in a centralized plant and its storage in a landfill to sequester carbon in the Province of Alberta. The work focused on forest biomass (whole tree biomass and logging residues). The overall objective was to the estimate the cost of carbon sequestration through landfilling of biomass charcoal. The key objectives of the work included: estimation of the overall delivered cost of forest biomass to the charcoal production plant; estimation of the cost of transportation of charcoal to the landfill site; estimation of the cost of landfilling; and estimation of the overall cost of carbon sequestration through charcoal landfilling. Additional cases were developed for use of municipal solid wastes (garbage) for conversion to charcoal and production of charcoal in a mobile unit. Two different types of conversion technologies were evaluated. First technology was a continuous process kiln called Lambiotte kiln which uses the volatile vapor produced during the process for the carbonization and has high capital cost per unit. Second technology was a batch process kiln called Adam retort which uses additional biomass for carbonization process and has a low capital cost per unit.

In this study, it is assumed that trees are cut, skidded to the roadside and whole trees are chipped. The chips are transported to the plant by a chip van truck where it is used to produce charcoal. The forest harvest residues are forwarded and piled on the roadside and then chipped. Forwarding and piling cost of the forest harvest residues is the harvesting cost in this

case. These chips are transported to the charcoal production plant through chip van truck. In case of municipal solid waste, waste is collected and converted to charcoal near the landfill site.

Key results of the study:

Charcoal Production from Forest Biomass

- Charcoal cost is estimated for a plant at a capacity of 200 dry tonnes of charcoal per day. The charcoal plant at this size will produce about 73,000 dry tonnes of charcoal per year. This plant will require about 4 million tonnes of wood over 20 years. The plant consists of 10 Lambiotte kilns, each having a capacity of processing 20 dry tonnes of wood per day.

- Table S1 shows cost components of charcoal production from a 200 dry tonnes per day plant using whole forest biomass and forest harvest residues. Capital recovery cost includes an 10% pre tax return on total capital. Cost of charcoal production from forest harvest residues is lower than whole forest biomass. Two main reasons: first is the high capital cost for the whole forest biomass based plant due to its remote location. The forest harvest residue based plant would be located near the existing infrastructure which would be developed by the logging companies. This results in extra cost of road construction and transmission lines for the whole forest case. Second is the higher harvesting cost for whole forest biomass. In case of whole forest biomass there is cost of felling, skidding and chipping of biomass while cost for harvesting residue include costs of piling, forwarding and chipping only. Other cost components for both the biomass sources are the same. Cost of producing charcoal in mobile kilns is significantly higher than the centralized plant for both the forest biomass sources.

Table S1: Cost composition of Lambiotte kiln based charcoal delivery to landfill

Cost Elements	Whole Forest Biomass	Forest Harvest Residues
Delivered Biomass Cost Components	**$/dry tonne of charcoal**	**$/dry tonne of charcoal**
Harvesting cost	54.08	32.84*
Transportation cost	25.80	41.88
Silviculture cost	20.15	0
Road Construction cost	22.45	0
Chipping cost	12.62	0*
Premium/Royalty cost	19.39	19.39
Total delivered biomass cost	***154.49***	***94.11***
Capital cost recovery	***27.43***	***25.54***
Operation and Maintenance Cost Components		
Storage cost	6.98	6.98
Maintenance cost	4.65	4.34
Operating and administration cost	16.76	15.96
Plant electricity consumption cost	6.72	6.72

Cost Elements	Whole Forest Biomass	Forest Harvest Residues
Transmission line cost	0.96	0
Total operation and maintenance cost	*36.07*	*34.01*
Charcoal production cost	*217.99*	*153.66*
Charcoal transportation cost to landfill	*10.69*	*10.69*
Charcoal landfilling cost	*8.34*	*8.34*
Total cost of landfilling biomass based charcoal	**237.02**	**172.68**

[*] - Harvesting cost includes cost of piling and forwarding residues. Chipping cost is also included in this.

Charcoal Production from Whole Forest Biomass using Adam Retort

- Charcoal can be produced in different types of kilns using various operating conditions. In this case a batch process kiln called as Adam retort is evaluated as a possible technology for production of charcoal in the Province of Alberta using forest biomass. This retort has low capital cost but the production of charcoal is in batches and it uses additional biomass as energy source.

- Charcoal cost is estimated for a plant at a capacity of 100 dry tonnes of charcoal per week. The charcoal plant at this size will produce about 4,680 dry tonnes of charcoal per year. The plant consists of 100 Adam retorts, each having a capacity of processing 1 dry tonnes of wood per week. Table S2 shows cost components for charcoal production from a plant using Adam retort for conversion.

Table S2: Cost of production of charcoal in an Adam retort using whole forest biomass

Cost Components	$/dry tonne of charcoal
Delivered Biomass Cost Components	
Harvesting cost	64.42
Transportation cost	31.98
Silviculture cost	24.00
Road Construction cost	26.74
Chipping cost	15.04
Premium/Royalty cost	23.09
Total delivered biomass cost	**185.27**
Capital cost recovery	**5.71**
Operation and Maintenance Cost Components	
Storage cost	8.49
Maintenace cost	0.40
Operation and administration cost	116.07
Electricity cost	7.27
Transmission line cost	1.04

Cost Components	$/dry tonne of charcoal
Total operation and maintenance cost	**133.27**
Cost of charcoal production	**324.25**
Charcoal transportation cost	10.69
Charcoal landfilling cost	8.34
Total cost of landfilling charcoal from waste	**343.28**
Amount of carbon sequestered (kg of C/tonne of charcoal)	**800**
Carbon sequestration cost ($/tonne of CO_2 sequestered)	**117.03**

The cost of charcoal production from the Adam retort is $324.25 per tonne of charcoal produced. The feedstock delivered cost constitutes about 57% of the total cost of production of charcoal. Operation and maintenance cost constitutes about 41% of the total cost of production. Capital cost contribution is very small in the total cost. The carbon sequestration cost is about $117 per tonne of CO_2 sequestered which is higher than the Lambiotte kiln case.

Charcoal Production from Municipal Solid Waste using Lambiotte Kiln

- Charcoal can be produced from municipal solid waste (MSW). In the City of Edmonton, significant amount of solid waste is generated which can be used for charcoal production. The waste consists of paper products generated from household and offices, food waste generated by the restaurants, shipping materials such as cardboards and wood, used wood boards, construction wood materials. All these waste streams constitute the municipal solid waste. This municipal solid waste can be used to produce charcoal which can be further landfilled nearby. The landfill tipping fee is $55 per tonne of waste. A charcoal production plant can be located near the disposal site. A case was developed for conversion of municipal solid waste to charcoal by using the Lambiotte kiln technology. Once charcoal is produced, it can be landfilled nearby so that there is negligible additional cost of transporting it. There would be cost of loading and unloading costs of charcoal. The capacity of the plant was assumed to be the same as was for forest biomass cases. Operating parameters and general assumptions were also assumed to be the same as for forest biomass cases. As compared to whole forest case, there is no feedstock delivery cost. As the MSW is already delivered to the landfill site, if this MSW is used for production of charcoal, the cost of collection and delivery wouldn't be incurred. There would be cost of only landfilling charcoal. Also, there is no cost of constructing the transmission lines and penalty for remote location.

- Table S3 shows the various cost components of using municipal solid waste for charcoal production and landfilling. The biggest component of the total charcoal delivery cost to the landfill is capital cost. It is about 38% of the total cost.

Table S3: Cost composition of charcoal production from municipal solid waste

Cost components	$/dry tonne of charcoal
Feedstock collection cost	0
Capital recovery	25.50
Storage cost	6.98

Cost components	$/dry tonne of charcoal
Maintenance cost	4.34
Operation and administration cost	16.76
Electricity cost	6.72
Total charcoal production cost	**60.30**
Charcoal transportation cost (only loading and unloading component)	5.05
Charcoal landfilling cost	10.00
Total cost of landfilling charcoal from waste	**75.35**

Carbon Sequestration Cost for Landfilling Charcoal Produced from Three Biomass Feedstocks

- In this study, a "cradle-to-grave" approach has been adopted for estimating emissions from production of charcoal from whole forest biomass, forest harvest residues and municipal solid waste. Emission factors over the life cycle of the charcoal production plant have been estimated. The carbon mitigation potential of landfilling charcoal was estimated based on the net carbon stored in the landfill. An emission factor for transportation has been calculated separately for forest harvest residues and whole forest biomass as the distance of biomass transportation in the two cases are different. For municipal solid waste, there is no incremental emission during its transportation to the landfill where charcoal plant is located and also in the landfilling of charcoal, hence no emission has been calculated for this part.

- Table S4 gives the carbon emission during charcoal production and landfilling from the three feedstocks using Lambiotte kiln. The amount of carbon released during production and transportation of charcoal from forest biomass is only 7% of the total carbon sequestered by landfilling charcoal. The net abatement cost of sequestering charcoal by landfilling for whole forest, forest residue and municipal solid waste are $88 and $64 and $26 per tonne of CO_2 sequestered, respectively. Based on the cost of carbon sequestered, use of municipal solid waste for charcoal production using Lambiotte kiln is the best alternative.

Table S4: Abatement cost of landfilling charcoal produced from forest biomass

Items	Whole Forest Biomass	Forest Harvest Residue	Municipal Solid Waste
Total carbon emitted in production and landfilling charcoal (kg of C/ dry tonne of charcoal)	62.1	64.7	0
Carbon sequestered by landfilling charcoal (kg of C/ dry tonne of charcoal)	800*	800*	800*
Net carbon sequestered by landfilling charcoal (kg of C/ dry tonne of charcoal)	737.9	735.3	800
Total cost of landfilling charcoal	237	173	75

Items	Whole Forest Biomass	Forest Harvest Residue	Municipal Solid Waste
($/dry tonne of charcoal)			
Abatement cost of sequestering carbon by landfilling charcoal ($/ tonne of CO_2 sequestered)	**88**	**64**	**26**

* Charcoal has 80% fixed carbon.

Summary:

The cost of producing charcoal from whole forest biomass depends on the type of technology for production of charcoal. The cost of production of charcoal from whole forest biomass in the Province of Alberta ranges from $218 to $324 per tonne of charcoal from a continuous process kiln (i.e. Lambiotte kiln used in this study which has high capital cost per unit but low operating cost) and a batch process kiln (i.e. Adam retort used in this study which has low capital cost per unit but high operating cost), respectively. The corresponding costs of carbon sequestration by landifilling charcoal for two types of kilns using whole forest biomass are $88 and $117 per tonne of CO_2 sequestered, respectively. The cost of production of charcoal from forest harvest residues (limbs and tops generated by logging operation) in a 200 dry tonnes charcoal production per day plant using Lambiotte kiln is about $154 per dry tonne of charcoal, respectively. The carbon sequestration cost by landfilling charcoal produced from forest harvest residues is $64 per tonne of tonne of CO_2 sequestered. This sequestration cost is 27% lower than the whole forest case based on Lambiotte kiln. Mobile units were also evaluated for production of charcoal but the cost of production of charcoal is higher than the centralized plants.

The cost of production of charcoal using municipal solid waste is $75 per tonne of charcoal from a 200 dry tonnes charcoal production per day plant using Lambiotte kiln. This is based on the assumption that there is no cost of collection of MSW as this is already being done. The carbon sequestration cost for this case is $26 per tonne of tonne of CO_2 sequestered.

Among the three feedstocks, cost of production of charcoal is cheapest from MSW. One of the key parameters for comparing the charcoal production and its storage in a landfill from the three feedstocks is the cost of carbon sequestration. The cost of carbon sequestration depends on total cost of landfilling charcoal and the net amount of carbon sequestered. The costs of carbon sequestration from whole forest biomass, forest harvest residues and municipal solid waste are $88, $64 and $26 per tonne of CO_2 sequestered using Lambiotte kiln technology. Based on the cost of carbon sequestered, MSW case is the best alternative.