

Biochar Production in Biomass Power Plants: Techno-Economic and Supply Chain Analyses

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List of Abbreviations

CO ₂	carbon dioxide
kWh	kilowatt hour
M	million
MSP	minimum selling price
MT	metric ton
MVP	marginal value product
MW	megawatt
MWh	megawatt hour
TEA	techno-economic analysis
WSDA	Washington State Department of Agriculture

Abstract

This study examined the potential market for biochar in the Pacific Northwest by estimating production cost and agricultural use values. Through techno-economic analysis, it was determined that there is a scenario where the minimum viable selling price for biochar is in the vicinity of \$150 per metric ton. The potential value of biochar based on carbon sequestration and yield improvement was analyzed. This analysis led to the conclusion that without a climate policy compensating farmers for carbon sequestration, there is only one type of crop (mixed vegetables) which under a fairly optimistic yield improvement assumption (30%), could justify the use of biochar. Biochar use in agriculture becomes much more feasible if there is a carbon market with prices nearing \$40 per metric ton of carbon dioxide equivalent. Depending on feedstock cost and electricity price there are situations in which biochar can be produced at a price low enough to be used in agriculture to enhance soil fertility and fight global warming. However, the conclusions of this report, based on new estimates of production costs and agricultural use values, are that the widespread utilization of biochar in the Pacific Northwest will likely require appropriate public policies that provide direct financial incentives to farmers for sequestering carbon.

Introduction

An improved understanding of biochar techno-economics and potential use values in our region will help target future research work to identify ways that the nascent regional biochar sector can be supported. (A view of the current sector, and the various entities that operate within that sector, can be seen in map form at <https://www.pnwbiochar.org/producers/>). In order to develop policies to increase adoption, it is critical to know the minimum selling price at which biochar can be produced and the maximum purchase price to a potential buyer. The ultimate goal of this work is to facilitate adoption of biochar soil amendments, both to reduce and recycle woody biomass waste streams in Washington State and to draw down atmospheric carbon dioxide.

Biochar production, and its use as a soil amendment, is considered one of the most promising alternatives to mitigate climate change. In most of the world, biochar is currently produced with kilns that make poor use of the energy contained in the volatiles. The poor utilization of biomass volatiles and the highly labor-intensive operation of these kilns results in biochar selling prices between \$500 and \$1,000 per ton. Fast pyrolysis technologies make a better use of the volatiles resulting in the recovery of more than 60% of bio-oil. However, the lack of refinery technologies capable of processing these crude oils into a usable fuel is a major hurdle for the deployment of fast pyrolysis. Production of electricity from the combustion of biomass is perhaps the only commercially available technology in use today. Using this technology, it is possible to obtain 0.8 MWh (megawatt hour) of electricity per ton of biomass processed. In 2017, there were 188 biomass power plants operational in the U.S. with the capacity to produce 23,035 MWh. The same year, there was a plant under construction for 50 MW (megawatt) and other 16 plants were proposed with a capacity of 602 MW (Biomass Magazine, 2018). However, in recent years, biomass boilers in Washington State have been shuttered, with the low selling price of electricity in Washington as one primary contributing factor. While electricity prices in the U.S. range from \$0.06 to \$0.35 per kilowatt hour (kWh), Washington's average electricity price is \$0.07 per kWh, which is 23% less than the national average (Electricity Local, n.d.). The low selling price of electricity in the Pacific Northwest limits the use of this technology for the processing of the woody fraction of demolition debris and municipal and industrial waste fractions.

Some regional producers of biochar have been producing high carbon, low ash biochar from large boilers. Oregon Biochar Solutions, a 30 MWh woody biomass plant in White City, Oregon, has begun producing biochar with boilers. Each year, this plant burns close to 335,000 tons of wood debris (Oregon Biochar Solutions, n.d.). At current electricity prices the unit would receive \$10.4 million from selling electricity. Working in the biochar production mode (15% by weight of biomass converted to biochar) could result in a 30% reduction in electricity output and revenue losses of \$3.12 million. These revenue losses could be compensated for by selling the 50,250 tons of biochar produced annually for at least \$62 per ton. The quality of the biochar produced is very high (surface area more than 500 m² per gram and fixed carbon over 85% by weight, ash content below 10% by weight).

The goal of this report is to assess the potential market for biochar in the Pacific Northwest by comparing production costs relative the value of biochar for agricultural uses. Production costs are estimated by a techno-economic analysis along with an evaluation of the potential regional supply of feedstocks at different price levels (supply analysis). The value of biochar, which can

be thought of as the maximum purchase price, is based on yield improvements and carbon sequestration. We incorporate data for the region that includes acres and profitability by crop type. While a number of strong assumptions are required to arrive at estimates, this report provides a valuable perspective on the conditions required for a viable biochar market.

Related Studies

This study builds most directly from Galinato et al. (2011), which estimated the value of biochar for agriculture in the wheat growing Palouse region of Washington State. They consider yield improvements and a carbon offset component, which includes sequestration and avoided use of greenhouse gas emitting inputs such as agricultural lime. Our study is larger in scope than Galinato et al. in that we estimate a value for biochar for the entire Columbia River Basin portion of Washington State rather than just for winter wheat production in Whitman County. Galinato et al. consider six different sources for biochar that vary in carbon content from 60 to 80%. In terms of value of biochar from carbon sequestration, they arrive at a very wide range of \$2.93 to \$90.83 per metric ton.

More recent studies have contributed to our understanding of the potential benefits of biochar in crop production. Hussain et al. (2017) focus on the increase in crop yields and water holding capacity that results from applying biochar. They show that there is considerable variability in these outcomes across published studies, and potential downsides in terms of weed control. Yield improvements result from increasing soil nutrient supply and microbial activity. Application rates by Hussain et al.'s summary of other studies range from 10 to 137 tons per hectare. The authors caution that yield improvements of 20% to 100% are only typical in nutrient poor soils. In a meta-analysis, Jeffrey et al. (2011) estimated an average yield effect of +10%, which was subsequently replicated by Liu et al. (2013) and Biederman and Harpole (2013). Application rates associated with this yield effect were from 10 to 100 tons per hectare. Filiberto and Gaunt (2013) point out that there is considerable uncertainty in the costs of applying biochar to fields in many areas because the practice is not widespread. They report biochar cost estimates as ranging from \$50-\$500 per ton depending on feedstock, collection and transportation, processing, and by-products. However, application rates above 50 tons per hectare often result in more variable yield effects extending into yield reductions relative to no biochar (Lehmann et al., 2011; Biederman and Harpole, 2013; Kammann et al., 2015; Asai et al., 2009).

There has been an emphasis more recently on developing economically richer evaluations of biochar returns that account for market volatility. Campbell et al. (2018) show that market swings can induce price changes that swamp variation in technical values (such as biochar conversion rates) in terms of financial return. Campbell et al. also make the important point that biochar properties can vary to such a degree that it should be considered a differentiated product rather than a commodity. In this way, it is similar to compost.

A couple of recent studies have argued that the greatest potential for biochar is in the production of higher value crops. After showing modest returns for biochar in cereal grain production, Dickinson et al. (2015) note that high value crops, such as various types of horticultural crops, are more promising. Liu et al. (2013) show that biochar values are likely to be much higher on higher value crops due to both yield and price. They found vegetables and legumes to have crop

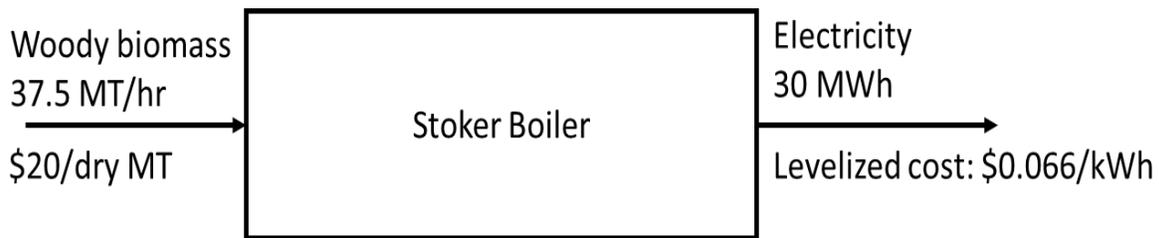
productivity increases in the 14% to 30% range compared to 10% or less for lower value cereal grains. This is a major motivation for this study given the substantial acreage of high value horticultural crops in Central Washington that are in close proximity to abundant biochar feedstocks.

Techno-Economic Analysis

The first step is a baseline techno-economic analysis (TEA) for a 30 MW power plant producing electricity. We calculate biochar minimum selling price as a function of feedstock cost, electricity price, and production capacity. In our second study we conduct TEAs for a modified power plant producing biochar. In this case, we calculate the biochar minimum selling price as a function of electricity wholesale price, feedstock cost, biochar yield and production capacity. This task is conducted with information from the literature (California Biomass Collaborative, n.d.; Tiangco et al., 2005) and interviews with industry representatives.

Figure 1 summarizes the mass and energy balances of the two cases studied. In the baseline case (Case 1) we are processing 37.5 tons/hour to produce 30 MWh of electricity. The biomass is purchased at \$20 per ton and the levelized cost of electricity is estimated to be \$0.066 per kWh. In the second case study the same unit is used to produce biochar (5.62 tons per hectare), but with a subsequent reduction in electricity production (25.5 MWh). The minimum selling price (MSP) of biochar is estimated to be \$151.5 per ton. The only difference between the cases is that in the second case the grade velocity is accelerated to limit the combustion of fixed carbon. Table 1 summarizes the financial assumptions used in the analysis. Table 2 lists values for capital costs, while Table 3 summarizes operational costs.

Case 1



Case 2

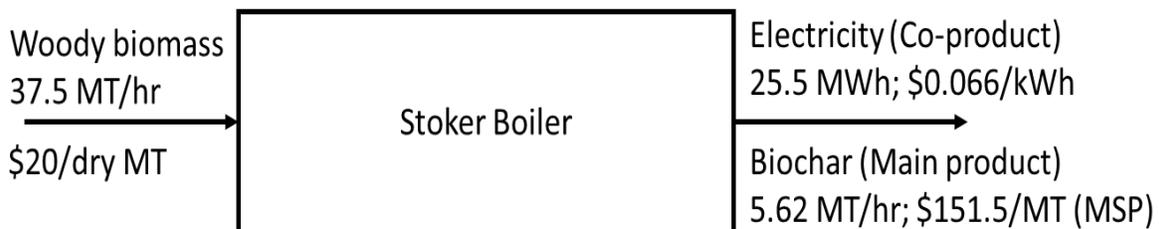


Figure 1. Overall mass balance of the two cases studied for biochar production. (MT=metric ton)

Table 1. Technical and financial assumptions of techno-economic analysis.

Parameter	Value/unit
Capacity	37.5 dry MT/h, 900 dry MT/day or 279,200 dry MT/year
Ash	5 %
Feedstock Price	\$ 20.0 / dry MT
Operating hours	7,446 h/year
Net station efficiency	20 %
Power yield	0.8 MWh/dry MT
Biochar yield	15 %
Analysis year	2015
Electricity price (levelized)	\$ 0.066 / kWh
Plant lifetime	20 year
Assumed annual inflation	2 %
Equity % of total investment	30 %
Loan interest	8 %
Loan term	10 years
Depreciation	7 years (Double declining balance): 200 %
Depreciation (for power plant) ^a	20 years (straight line)
Income tax rate	17 %
Targeted nominal financial discount rate	12.2 %
Actual nominal financial discount rate	12.2 %
Real Discount Rate	10 %

^a For power plant components such as boiler operation, IRS recommends using the entire plant life to depreciate (IRS, 2018)

Table 2. Capital cost (Source: Tiangco et al., 2005)

Parameter	Value/unit
Feedstock handling	\$ 5.3 M
Stoker boiler	\$ 12.9 M
Steam turbine and auxiliaries	\$ 6.1 M
Baghouse and cooling tower	\$ 2.9 M
Balance of plant (emission control, etc.)	\$ 8.8 M
Total Indirect Costs (General facilities and engineering fee, project and process contingency)	\$ 21.5 M
Owner cost (working capital)	\$ 2.7 M
Land cost	\$ 0.9 M
Total Installed cost:	\$ 60.2 M

Table 3. Operational and Maintenance costs (Source: Tiangco et al., 2005)

Parameter	Value/unit
Fuel (demolition debris)	\$ 6.0 M/year
Labor	\$ 2.0 M/year
Maintenance	\$ 1.5 M/year
Insurance/property taxes	\$ 1.4 M/year
Utilities	\$ 0.8 M/year
Ash disposal (in the case of complete combustion)	\$ 0.1 M/year
Management/administration	\$ 0.2 M/year
Total Operational and Maintenance cost	\$ 11.7 M/year

Figure 2 shows the effect of feedstock cost and electricity price in the estimation of MSP of the char produced in the boilers. It is important to understand that the biomass cost can be positive or negative depending on the type of biomass used. Figure 2 shows that there may be economic situations in which biochar production costs could be low enough to justify its use in large scale agriculture. For example, if the biochar unit is able to receive a feedstock at \$ 20 dry ton and is able to sell the electricity for \$0.1 per kWh (gray line), then the unit is able to give the biochar for free (i.e., MSP is zero).

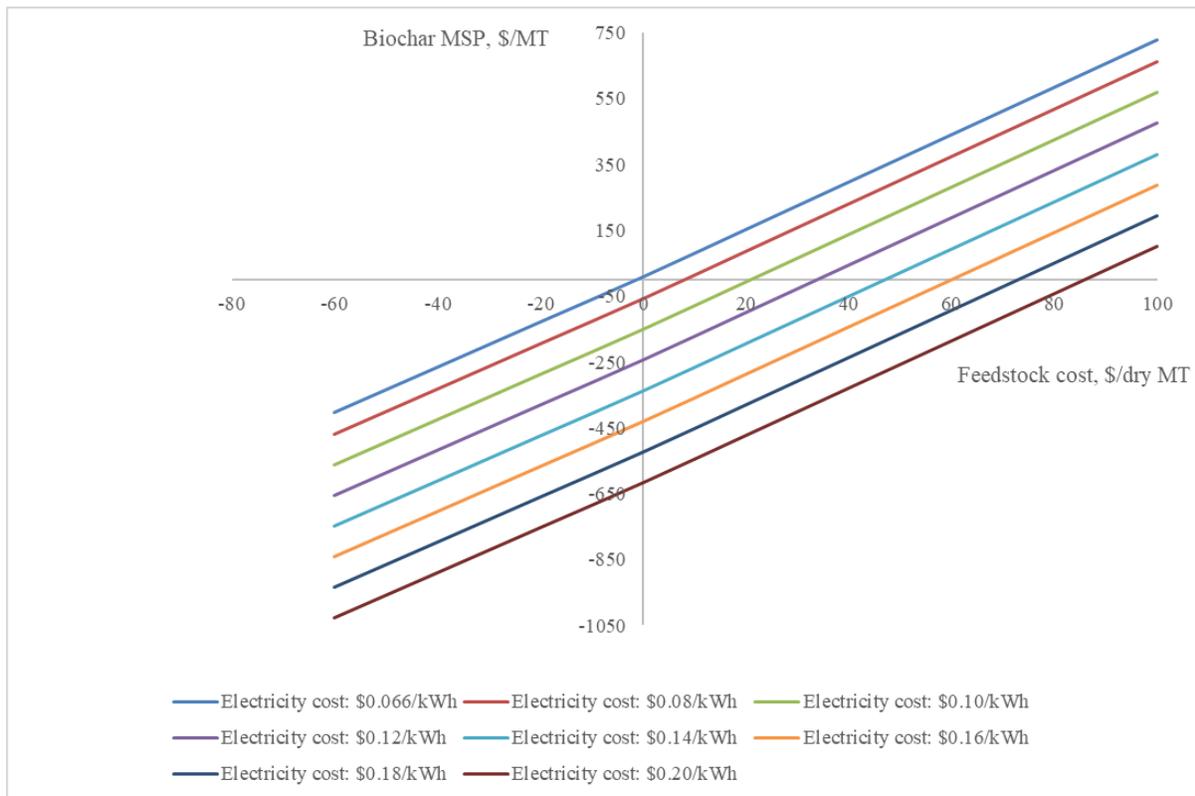


Figure 2. Biochar minimum selling price (MSP) as a function of feedstock cost and electricity price.

Our team also calculated the biochar price needed to compensate for the lost energy revenue. The results are shown in Table 4. The reader should note that the main concepts and premises used to calculate Table 4 are very different to those used to calculate Figure 2. In the case of Figure 2, electricity production and commercialization is subsidizing the production of biochar. In the case shown in Table 4, the biochar price accounts for the foregone revenue from selling electricity.

Table 4. Biochar production cost to compensate losses on electricity revenue.

Levelized cost of electricity (\$/kWh)	Present worth of total revenue (millions of dollars)	Corresponding biochar price \$/Metric ton
2.5	\$35.0	506
3.5	\$48.9	524
4.5	\$62.9	543
5.5	\$76.9	562
6.6	\$92.1	583
7.5	\$104.9	600
8.5	\$118.8	619

Regional Feedstock Availability

To gain a regional perspective on biochar production, we consider the amount of biochar feedstock available at different price levels. At a regional scale, there will be some finite amount of lower cost feedstock. The cost of producing biochar is assumed to be constant until all of the low cost feedstock is used. Costs then jump up to a higher unit cost level once the medium cost feedstock is being used, and so on. Previous studies provide quantities of feedstocks at varying price points. According to the U.S. Department of Energy (2011), Washington is estimated to have just under 1 million dry MT of feedstocks at \$20 or less per MT annually. Just under 1.1 million dry MT of feedstocks are thought to be \$40 per MT or less. Then, there is about 1.5 million dry MT at \$200 per MT or less.

Given the fact that biochar is still a nascent market, it makes sense to simplify the analysis by assuming that only the 1 million dry MT of low cost feedstock may be used. However, this may be an oversimplification given that the cost varies within this low cost group. The step nature of the quantities at various price points can be used to create a smooth gradually upward sloping curve. Transportation costs are major reason to make this adjustment. The cost of each unit of feedstock will vary along with transportation costs even if it is the exact same “roadside” cost. Bringing all this information together, we construct a regional supply curve for biochar as shown in Figure 3. The results from the previous section simply shift this curve upward to produce a (marginal) cost curve, which is simply the cost of producing each MT of biochar.

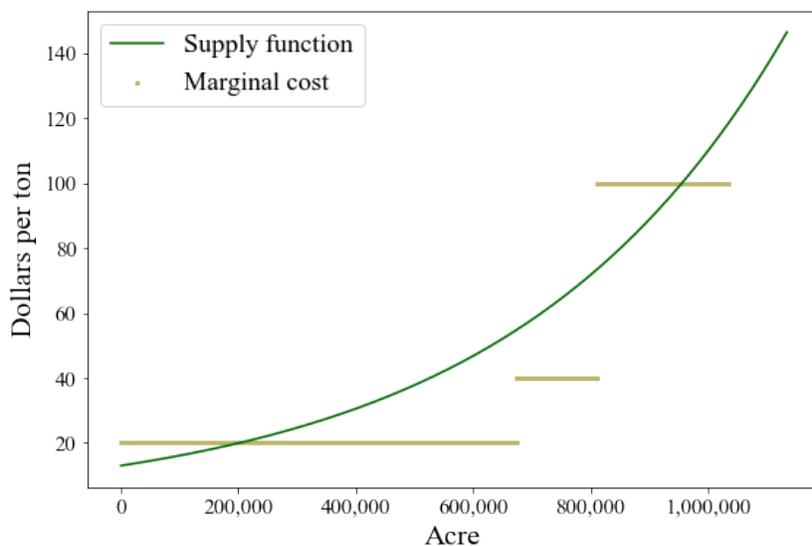


Figure 3. Regional supply curve for biochar for Washington State.

Biochar Value for Agricultural Uses in Washington State

The value of any input to production to a producer is the additional profit generated by using that input. Sometimes the “with and without” scenario is binary in that it is either used or not. For example, a farmer either using precision agriculture technology or does not. However, for many inputs the question is more a case of “how much.” To estimate the value of a “how much” input, it is helpful to understand the concept of “marginal value product”. The term “marginal” captures the idea that the producer is considering the additional benefits versus the additional costs of using a bit more or less of the input. Examples include water for irrigation and fertilizer. For these inputs that can be used in variable amounts, they eventually have a diminishing effect on production as more is used. Biochar is another example of this type of input to production. Our ultimate goal is to estimate a value for biochar if it were to be applied to every agricultural field in the Washington State portion of the Columbia River Basin.

Previous studies have considered three potential sources of value for biochar: carbon sequestration, avoided emissions, and yield improvement. The former two are only possible if there is a climate policy that compensates farmers for providing these services, which is not currently present in the U.S. However, we calculate values for carbon sequestration assuming such a policy exists. A biochar application rate of 10 MT per acre is assumed throughout this report. Previous studies, including Galinato et al. (2011), included an avoided emissions value because using biochar affects soil acidity in a way that offsets the need to apply lime, which would emit greenhouse gases. The soil acidity issue on agricultural fields is more pressing in the Palouse region than in Washington State, as a whole. We do not see a strong motivation to consider avoided emissions through this channel in this study given our wider geographic focus. Also, the value derived from avoided emissions is likely to be a much smaller component than value derived from carbon sequestration and yield improvements.

Carbon Sequestration

Biochar reduces carbon in the atmosphere by sequestering carbon that otherwise would have been released (Laird, 2008). Currently, there is no direct financial incentive for a farmer in the U.S. to use biochar for this purpose. They do not receive a financial payment in accordance with the amount of carbon that they are responsible for removing from the atmosphere. However, it is important to be prepared to understand the role that biochar could play if a climate policy like a carbon tax or cap and trade policy were adopted. A carbon tax was put to the voters of Washington in 2018 (Initiative 1631). It did not pass, but the fact that it gathered enough political momentum to reach the ballot box means it is a reality worth considering.

Galinato et al. (2011) estimated biochar values with carbon prices ranging from \$1 to \$31 per MT of carbon dioxide equivalent, which was based on trading on the Chicago Climate Exchange in 2008. This corresponds to a biochar value of \$2.93-\$90.83 per ton. To calculate this value, apply a number for the carbon content of biochar, which Collins (2008) estimates to range from 60% to 80%. The factor for converting from carbon dioxide to carbon is 3.67. The price of \$2.93 per MT carbon dioxide in Galinato et al. (2011), assuming a carbon content of 80%, is calculated as follows: $1 \text{ MT} \times 0.8 \times \$1 \text{ per MT} \times 3.67 = \2.93 per MT . More recently, carbon has been trading for anywhere from \$1 to \$125 per MT of carbon dioxide equivalent (World Bank Group, 2019). Most of the observed prices are at the lower end of this range in the vicinity of \$10 per MT, which motivates assuming a price in the lower end of the \$1 to \$31 range. However, the pricing of carbon is meant to provide incentives to reduce emissions so that the worst case scenario does not happen. Stiglitz and Stern (2017) have argued that the price required to alter behavior enough to avoid the worst climate change impacts is \$40-\$80 per MT of carbon dioxide equivalent.

Given that the motivation of this report is to provide perspective on potential outcomes, we calculate biochar values assuming carbon prices of \$10, \$40, and \$80 per MT carbon dioxide equivalent. This corresponds to biochar values of \$29.36, \$117.44, and \$234.88 per MT. These values are added to the yield value described below.

Yield Improvement

Biochar has the potential to improve crop yields by increasing the uptake of soil nutrients and increasing water holding capacity of soil (Hussain et al., 2016). In order to construct a regional-level valuation for biochar, four pieces of information are needed:

1. Net revenue per acre by crop group (\$/acre)
2. Rate of yield improvement (%)
3. Biochar application rate (tons/acre)
4. Acres by crop group (acres)

The first three values are used to calculate a value per ton of biochar. Biochar creates value by increasing production. That additional production has a value that is equal to the change in yield due to biochar multiplied by the price per unit of output (i.e., crop price). To convert from a value per acre to value per unit (ton) of biochar, the additional value (yield change x crop price) is divided by the biochar application rate. In economics, this value is referred to as the marginal value product (MVP).

$$\text{Marginal Value Product} = \frac{\text{Net revenue per acre} \times \text{The rate of yield improvement}}{\text{Biochar application per acre}}$$

Several studies have reported yield increases from biochar application with rates between 2 and 20 tons per acre if appropriate nutrient management is followed (Galinato et al., 2011; Filiberto and Gaunt, 2013; Hussain et al., 2017). As discussed earlier in this report, there is a great deal of uncertainty over yield improvements from biochar. However, the two recent meta-studies both arrive at 10% as a reasonable starting point (Jeffrey et al., 2011; Liu et al., 2013). Information on profit per acre is taken from recent crop enterprise budgets. We use the same set of values assumed in recent benefit-cost analyses on water storage projects (Yoder et al., 2014).

Table 5. Assumed values for profit per acre (in dollars) and total acres in the Columbia River Basin of Washington State by crop group.

Crop Group	Profit per acre ^a	Total acres in region ^b
Alfalfa	678	410,155
Apples	2,248	180,868
Asparagus	238	4,870
Concord	1,509	21,466
Hops	3,481	35,988
Mint	804	27,697
Miscellaneous	785	16,091
Other Grain	3	1,696,983
Other Hay	240	344,253
Other Tree	833	73,332
Other Veg	5,422	480,315
Pasture	479	311,193
Potatoes	1,155	180,254
Sweet Corn	436	65,643
Timothy	701	101,990
Wheat	40	2,309,819
Wine	2,630	56,969

^a from Yoder et al., 2014

^b from WSDA, 2016

Table 6 reports the estimated value for biochar for each crop group under three different yield improvement assumptions. Values vary widely from nearly \$0 per MT of biochar to \$163 per MT. Since a 10% increase in yields is the value most supported by the existing literature, as discussed previously, Table 7 reports biochar values by crop assuming a 10% increase in yield under all three carbon prices (\$10, \$40, and \$80 per MT carbon dioxide equivalent). The take-home message comparing Table 6 and Table 7 is that the value of biochar depends significantly on whether there is a climate market for carbon sequestration. Increasing yield from 10% to 30% increases the value of biochar somewhat, but an equivalent proportional change in carbon price has a much more significant effect. This is important to consider given the number of studies that question really high yield increases for non-tropical soils, as discussed earlier in this report.

Table 6. Estimated value of biochar (in dollars) from three different levels (10%, 20%, and 30%) of yield improvement.

Crop Group	Yield improvement		
	10%	20%	30%
Alfalfa	6.78	13.56	20.34
Apples	22.48	44.96	67.44
Asparagus	2.38	4.76	7.14
Concord	15.09	30.18	45.27
Hops	34.81	69.62	104.43
Mint	8.04	16.08	24.12
Miscellaneous	7.85	15.7	23.55
Other Grain	0.03	0.06	0.09
Other Hay	2.4	4.8	7.2
Other Tree	8.33	16.66	24.99
Other Veg	54.22	108.44	162.66
Pasture	4.79	9.58	14.37
Potatoes	11.55	23.1	34.65
Sweet Corn	4.36	8.72	13.08
Timothy	7.01	14.02	21.03
Wheat	0.4	0.8	1.2
Wine	26.3	52.6	78.9

Table 7. Estimated value of biochar (in dollars) assuming a 10% yield increase and three different prices for MT CO₂ equivalent.

Crop Group	Carbon price		
	\$10/MT	\$40/MT	\$80/MT
Alfalfa	36.14	124.22	241.66
Apples	51.84	139.92	257.36
Asparagus	31.74	119.82	237.26
Concord	44.45	132.53	249.97
Hops	64.17	152.25	269.69
Mint	37.4	125.48	242.92
Miscellaneous	37.21	125.29	242.73
Other Grain	29.39	117.47	234.91
Other Hay	31.76	119.84	237.28
Other Tree	37.69	125.77	243.21
Other Veg	83.58	171.66	289.1
Pasture	34.15	122.23	239.67
Potatoes	40.91	128.99	246.43
Sweet Corn	33.72	121.8	239.24
Timothy	36.37	124.45	241.89
Wheat	29.76	117.84	235.28
Wine	55.66	143.74	261.18

The final step to gaining a regional perspective on the demand for biochar is to consider total acres of each crop group. This involves imagining biochar being applied to every field in the study region, which is the Columbia River Basin portion of Washington State. Acres by group are reported in Table 5, which are based on the 2016 Washington State Department of Agriculture Cropland Data Layer (WSDA, 2016). One way to conceptualize the potential regional demand for biochar is with a demand curve. In economics, a demand curve is a plotted relationship that shows the value of each unit of a good used. In this case, the good is biochar and its value is the additional profit generated by increasing crop production. A demand curve is constructed by assuming that the first unit of biochar is used on the field where it would create the greatest value. Referring to values in Table 5, the first application of biochar would go to the crop group “Other Veg.” Additional biochar would continue to go to this crop group until all of its acres have received biochar. Then, biochar would move onto the next highest valued crop group, which is hops. If one plots out the value of every unit of biochar potentially used in the region in this way, the result is the series of horizontal red lines as shown in Figure 4. An approximation to these series of “steps” is a smooth curve drawn through them (blue line).

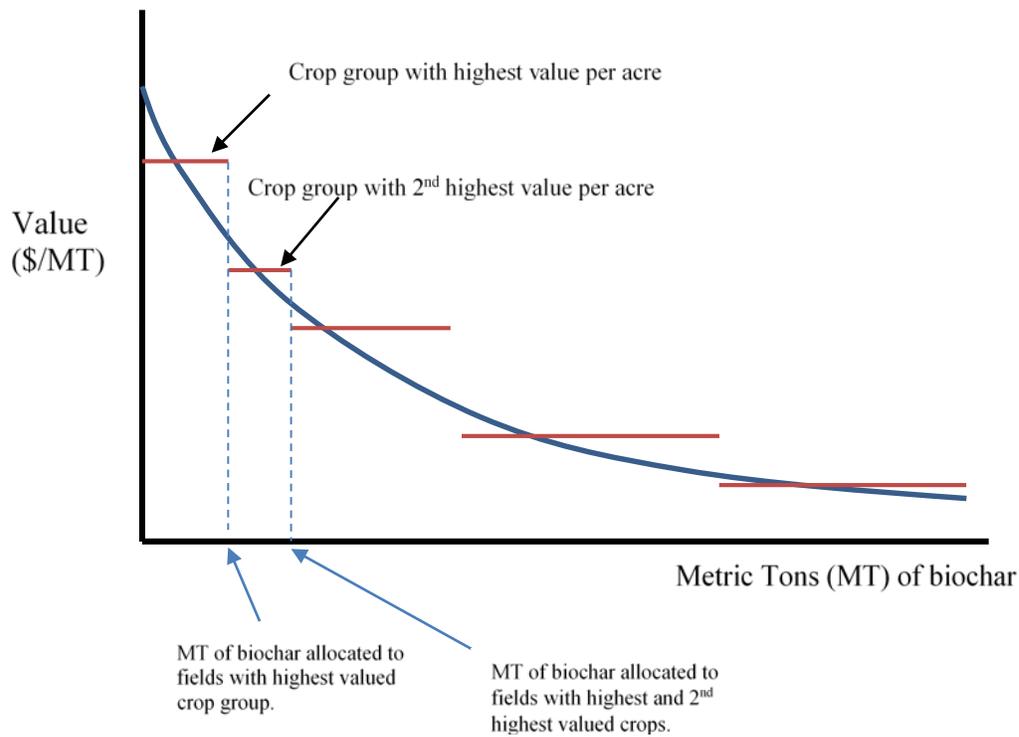


Figure 4. Example of a demand curve for biochar with five crop groups.

A large number of potential scenarios were considered in this study, and a demand curve could be drawn for each one of them. However, the curve only has much of a downslope if yield increase is the primary source of value. If carbon prices are over \$10 per ton, then the demand curve becomes fairly flat with a low value of \$117 per ton and a high value of \$170 per ton. Figure 5 puts these values in perspective by showing approximations to biochar demand curves with a 10% increase only and a 10% yield increase with a carbon price of \$40 per ton. There is about 6.5 million acres where biochar could be applied in Washington, which is used to specify the x-axis.

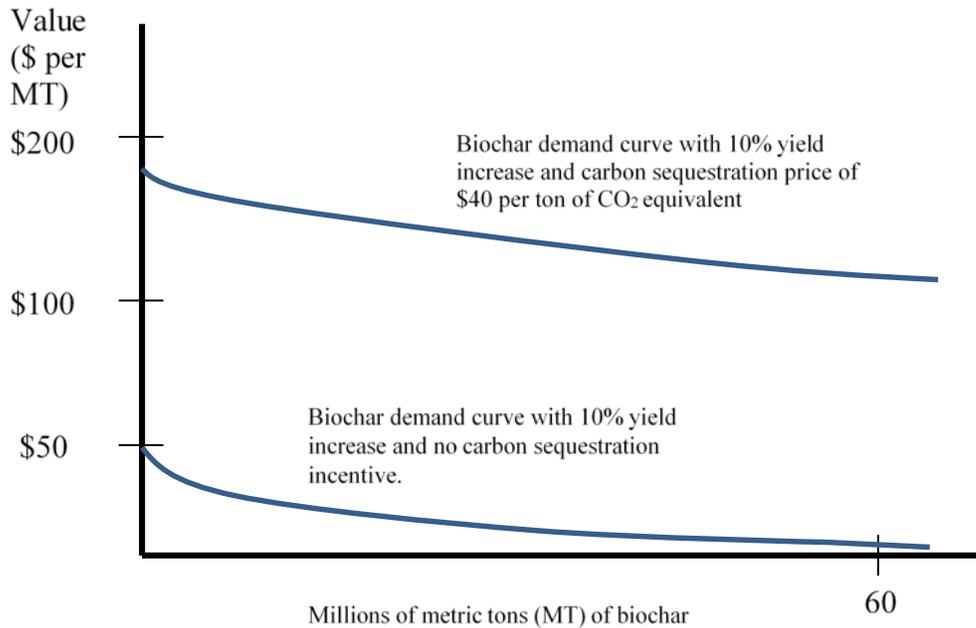


Figure 5. Approximations to biochar demand curves assuming a 10% yield increase, with and without a carbon market.

The fact that supply and demand curves for biochar were constructed separately highlights a key idea from economics, which is that one does not depend on the other. However, the market price and quantity transacted can only be revealed by bringing together the supply and demand curves. The supply curve reports the cost of producing each unit of biochar, which can be interpreted as the minimum selling price. Of course, the producer would hope to get a price higher than this unit cost. Similarly, each point on the demand curve is the value for the next unit of biochar where the buyer would hope to pay less than the value. They would certainly not pay more. Constructing the supply and demand curves is the hard part. The market analysis is simply bringing the two curves together on the same space as long as there is an assumption of many potential buyers and sellers (i.e., competitive market assumption). The point where the two curves intersect is used to predict a market outcome in terms of price and quantity.

Summary of Market Potential

There is clearly a potential market for biochar in the Pacific Northwest considering production cost and agricultural use values estimated in this report. However, a number of conditions need to be met for the value of biochar to exceed production costs. As discussed in the techno-economic analysis, there is a scenario where the minimum viable selling price for biochar is in the vicinity of \$150 per MT. In the agricultural use value section, there are a number of fields and scenarios where the value of biochar to agriculture exceeds this value. However, there is only one type of crop (mixed vegetables) that could justify the use of biochar without a climate policy that compensates farmers for sequestering carbon, which required a fairly optimistic yield

improvement assumption. Biochar use in agriculture becomes much more feasible if there is a carbon market with prices nearing \$40 per MT of carbon dioxide equivalent. It should be noted that there are a number of assumptions in this study that are uncertain. Our hope is that this report provides a better perspective on the conditions required for an active biochar market to develop. Most importantly, it provides a reference point for others to identify the potential market impacts if costs are lowered or values are increased.

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