Economics of mobile and stationary biochar production systems using juniper feedstocks in Oregon

Report prepared for USDA ARS JuBop project

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Executive summary

The USDA Agricultural Research Service and Oregon State University are leading a study of biochar made from Juniper (*Juniperus occidentalis*) feedstocks in eastern Oregon. The overarching goal of the Juniper Biomass Optimization Project (JuBop) is to develop an integrated strategy to overcome current economic barriers to profitably restore sagebrush steppe habitat. One key component of the work is to see if biochar made from juniper feedstocks can generate economic value to private ranchland owners, local juniper sawmill businesses, and juniper harvest operators, while achieving environmental benefits (decreased pile burning, enhance grass and forbes production, and creation of improved sagebrush habitat).

The purpose of this report is to provide an update on one component of JuBop project activities. Namely, an economic analysis of mobile and stationary biochar production technologies at various scales. The purpose of the analysis is to articulate how juniper harvest and restoration costs can be partially offset through biochar production and utilization.

The Natural Resource Conservation Service (NRCS) and the Wheeler Soil and Water Conservation District (SWCD) are treating about 2,000 acres of juniper lands per year (Herb Winters pers. comm.). Over the course of the project's five-year time frame, they expect to treat 10,000 acres of Phase II juniper rangelands. At 17 to 35 green tons per acre, the project will generate between 34,000 to 70,000 tons of juniper material per year. However, we estimate there are only about 9,800 acres in the 346,000 acre project area that contain valuable juniper sawtimber (~5.0% of the project area).

Larger sawmills pay by weight of juniper logs. Smaller sawmills use a variety of approaches, sometimes weight, sometimes by the thousand board feet of juniper logs. Sawmills in the project region say prices for Juniper "track closely to western redcedar" (*Thuja plicata*). We were told the prices paid for logs were $950 per thousand board feet ($/MBF). Others said "about $1,500 per load of juniper logs".

We ran our economic analysis on four biochar production technologies: a kon-tiki mobile kiln, a biochar bin, a Biochar Solutions machine, and an Air Curtain Burner (ACB). We also provided data to the US Forest Service Forest Products Lab (Nate Anderson and Robert Campbell) who ran the values through their own economic model. They used the ACB technology for their analysis (suitable for mobile or stationary applications). At 38,000 dry tons of juniper in per year and 3,000 tons of biochar produced (8% feedstocks in to biochar) they calculated the Net Present Value (NPV) over a 10 year time frame at different biochar price points. When biochar price = $800 per ton NPV = $3,154,057, If Biochar Price = $1,000 per ton NPV = $5,174,889, If Biochar Price = $1,200 per ton NPV = $7,195,721. NPV is not cash positive when we use just a 3% conversion rate of raw feedstocks to biochar.

Biochar can cover NRCS costs of juniper treatments (~$255/acre), if juniper biomass stocks are about 25 green tons per acre, and biochar can be sold for at least $800 or more per ton in off-site markets. If biochar is instead used on site without NRCS cost-share support, it would cost in the range of $470/acre (to cut & pile juniper, make biochar and then spread it on the landscape). Our goal with this analysis was to take a broad look at the relative costs and returns across a variety of biochar production technologies (both mobile and stationary) and should not be considered an endorsement of any particular machine. We hope that this analysis provides valuable information for agencies, landowners, and biochar practitioners about the costs and values of juniper based biochar.

1.0 Introduction and Overview

The US Department of Agriculture, National Institute of Food and Agriculture (NIFA) Sun Grant program provided funds to Oregon State University and USDA Agricultural Research Services (USDA ARS) to determine if an integrated strategy for juniper utilization can increase the pace and scale of sagebrush steppe habitat restoration in eastern Oregon. This $299,000 project started in 2016, and is titled the Juniper Biomass Optimization Project (JuBop). The overarching goal of the JuBop project is to develop a integrated strategy to overcome current economic barriers to profitably restore sagebrush steppe habitat in eastern Oregon. Key components of the work include assessment of how biochar made from juniper feedstocks can generate economic value to both private ranchland owners, local juniper sawmill businesses, juniper harvest operators, as well as environmental benefits (decreased pile burning, enhanced grass and forbes production, and create improved sagebrush habitat). The project team consists of a combination of Federal researchers at USDA ARS, academic researchers at Oregon State University, state agencies (Oregon Department of Forestry) and private collaborators (Karr Group, Delaney Forestry and T.R. Miles Consultants).

The 345,298 acre project area covers three key watersheds in and around Wheeler County, Oregon (Figure 1) that is part of a separate Natural Resource Conservation Service (NRCS) sponsored program called the North Slope Ochoco Holistic Restoration Project[1]. With NRCS funding, this five year program (2015 to 2019) seeks to treat private juniper lands and restore rangeland and sage brush habitat. Much of the juniper being treated in the project area is currently piled and burned on site, so the JuBop project team is attempting to evaluate economically viable alternatives to support local agencies achieve restoration outcomes, increase business investment in juniper wood product markets, and create valuable coproducts (biochar).

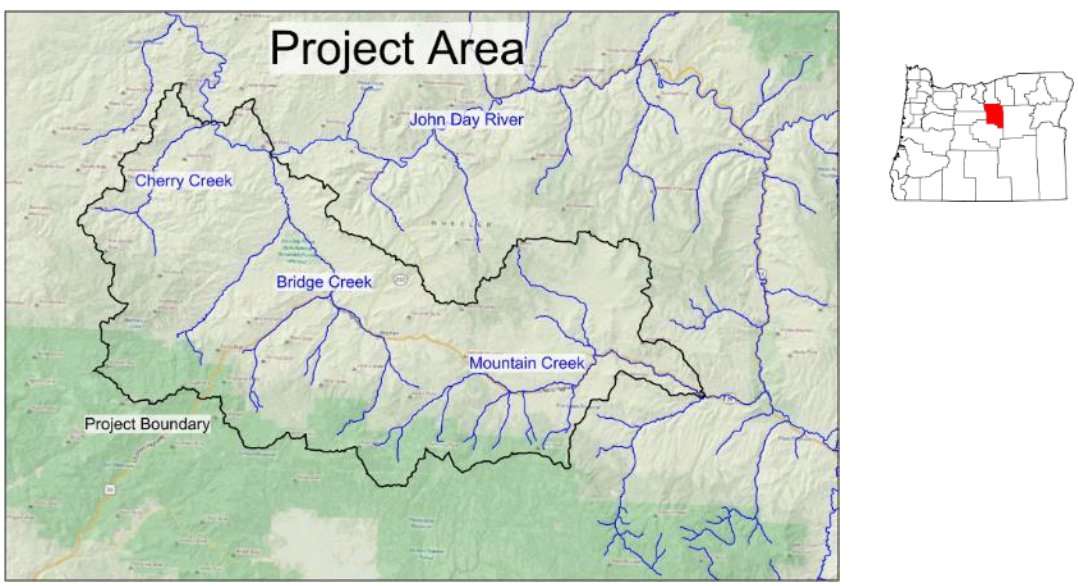

Figure 1. North Slope Ochoco Holistic Restoration Project area in Oregon (map courtesy of NRCS).

JuBop activities seeks to compliment the North Slope Ochoco Holistic Restoration Project goals by assessing the value proposition of juniper biochar production at various scales. Specifically, to

[1] North Slope Ochoco Holistic Restoration Project.
https://www.nrcs.usda.gov/wps/portal/nrcs/detail/or/home/?cid=nrcseprd346417

determine when (or if) juniper biochar enterprises can be cash positive over some reasonable time frame (five to ten years). Our team has therefore conducted an economic sensitivity analysis of the costs and revenues associated with mobile and stationary biochar production technologies that use juniper as feedstock inputs. In addition to the economic analysis, we provide an initial estimate of juniper biomass and sawtimber volume in the project area (details below in Section 2.4).

2.0 Methods and approach

Our approach to the economic analysis of hypothetical juniper based biochar production enterprises involved conducting interviews with juniper sawmills in the project area and discussing juniper harvest and transportation costs with loggers and restoration contractors. We also estimated existing juniper feedstocks using spatial GIS resources in coordination with our local partners at the Wheeler County Soil and Water Conservation District (SWCD).

Our economic analysis considered biochar production technology (capital costs, throughputs, operational & labor costs) as well as financial factors such as borrowing costs, marketing resources, various prices per ton of biochar products, and estimates of future biochar sales. We combined all of these variables into an economic analysis financial spreadsheet (originally constructed by Jack Hess[2]), who granted us permission to use his economic spreadsheet as a framework for the juniper analysis so long as the model was not sold for commercial purposes. We also ran a second economic analysis with assistance from the US Forest Service using a model they originally developed as part of the Waste-to-Wisdom project. The agency ran their model after we provided local JuBop variables to them.

2.1 Biochar technology—mobile and stationary

As part of our assessment of biochar technologies we reviewed publicly available reports and in some cases direct discussions with manufacturers. We summarized information on capital costs, throughputs, percent biochar produced per ton of biomass in, and other relevant metrics (Table 1). It is important to note that the stationary Biochar Solutions information is based on publicly available data provided by the Redwood Forest Foundation Incorporated (RFFI) as part of their participation in the Waste-to-Wisdom project[3]. The RFFI report was published online in 2015 and referred to input rates of about ¼ of a ton per hour and a capital cost of $205,000. However, we understand since 2015, Biochar Solutions is offering a new version of their stationary system which has a ½ ton per hour in feedstock capacity which sells for $400,000 (T. Miles pers. comm). For purposes of our analysis, we will use the costs and throughputs reported by RFFI in their 2015 publication.

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[2] Jack Hess. Executive Director of CivicLab. https://www.linkedin.com/in/jackhess

[3] Redwood Forest Foundation Incorporated. 2015. Biochar Demonstration Project Economic Analysis. http://rffi.org/biochar/Biochar_Demonstration_Project_Economic_Analysis-Harwood.pdf

Table 1. Capital cost and production rates of various biochar technologies (ranked by feedstock input capacity per hour).

Type	Scale	Suppliers	Wood fuel input form	Capacity tons per hour in	Biomass tons in per year	Percent biochar per feedstock in	Biochar per 8 hour day (tons)	Biochar per 240 day year (tons)	Capital Cost
Mobile	Small	Kon Tiki	Chunks, slash	0.18	346	20.0%	0.29	69	$2,500
Stationary	Small	Biochar Solutions	Chips	0.27	518	10.0%	0.22	52	$205,000
Stationary	Small	Biogreen	Chips 1/2 inch	0.66	1,267	25.0%	1.32	317	$1 million
Mobile	Medium	Pyreg, Pyrocal	Chips	2.00	3,840	25.0%	4.00	960	$1.5 to $2.0 million
Mobile	Medium	Air current burners (ROI Equipment)	Bulky fuel	3.00	5,760	7.5%	1.80	432	$485,000
Mobile	Medium	Biochar Bin	Chunks, slash	3.13	6,000	20.0%	5.00	1,200	$15,000
Stationary	Large	Rotary kiln biochar machine (FEECO)	Chips	2.00	3,840	25.0%	4.00	960	$2.0 million
Stationary	Large	Phoenix Energy	Chips	7.00	13,440	15.0%	8.40	2,016	$10 to $20 million
Stationary	Large	ICM	Chips	13.50	25,920	10.0%	10.80	2,592	$1 to $4 million
Stationary	Large	Karr Group	Chips	17.00	32,640	36.0%	48.96	11,750	$17,500,000

We then selected a subset of these biochar technologies for our economic analysis. Namely,

1. Kon Tiki/Oregon Kilns (mobile)
2. Biochar bin (mobile or stationary)
3. Air curtain burner (ACB) / ROI Envirosaver (mobile)
4. Biochar Solutions (modular stationary)

We organized the selected biochar technologies in three size categories.
- Small mobile biochar systems that process 0.1 to 1.0 tons of material feedstock in per hour.
- Medium systems (both portable and stationary) that process 1.0 to 3.0 tons of feedstock in per hour.
- Large stationary systems that process 4.0 to over 17 tons of feedstocks in per hour

Additional variables were used in the production aspects of the evaluation include:
- Scenarios assume 240 working days a year, one eight hour shift
- Moisture content of the juniper feedstocks assumed to be 50% "on the stump". In the case of juniper feedstocks (once they are cut and on the ground) we used between 20% and 50% moisture content to account for assumed variations in juniper biomass used in biochar production. In some cases the juniper may sit out on the landscape for one to two seasons before being used for biochar production and in other cases it could be used right after it was cut down.
- Biochar is estimated to be 250 pounds per cubic yard, approximately 8 cubic yards per ton

These and other variables were used to assess the economics of juniper biochar production. Results are listed in Section 3.0 below.

2.2 Juniper harvest & transportation costs

In addition to capital costs and machine capacity, the cost of juniper harvest, transportation and harvest costs are also important for any assessment of biomass based enterprises. We collected local relevant information on juniper harvest and transport costs by talking with local sawmills, landowners, and logging operators and values in the literature. Data collected include:

- **Mechanical harvest costs**: NRCS cost share programs contributions to the landowner for hot-saw mechanical juniper treatment work on <30% slopes: are $240/acre. Hot saw can treat between 5 and 10 acres of juniper per day. The machine and operator costs about $144/hour.

- **Chainsaw teams**: NRCS cost share programs contributions to the landowner for chainsaw juniper treatment work on >30% slopes: are $189/acre. An individual chainsaw operator can treat about 1.5 acres per day. Chainsaw teams do not typically pile material. They charge about $80/hour.

- **Lop and scatter**: Private ranch landowners not part of the NRCS cost share program pay about $100/acre to cut down juniper (and leave it on site) using chainsaw crews.

- **Haul costs**: Drivers hauling juniper sawtimber charge around $110/hour. Loggers told us they are willing to haul up to 3 to 4 hours one way (if needed to get a better price for their juniper logs from distant mills).

- **Pile burning costs**: we were unable to find data on juniper slash pile burning costs for the project area. NRCS pays for mechanical treatments, which includes piling the material. Data from western Oregon (collected as part of our work on a different project) indicates that timberland owners pay about $175/acre to pile logging slash (Cascade Timber Inc., pers. comm). Western Oregon burning costs were reported to be about $1.00 to $1.50 per thousand board feet (MBF) of gross timber volume in a harvest unit. If we assume an acre of timberland in the Willamette Valley has 10 MBF/acre and an average harvest unit size of 100 acres, and take a mid-point value of $1.25 per MBF, that means it costs a landowner about $1,000 to burn piles in a hundred acre harvest unit (or $12.50 per acre). Because juniper stocks are less than Westside conifer forests, and likely more spread out across the landscape, we used $15 per acre cost for burning in our calculations.

Treating juniper generates landowner benefits via rangeland improvements and in some cases enhanced water flows. However the rangeland improvements which lead to higher carrying capacities of the land for cattle are fairly modest compared to the costs of the juniper treatments. NRCS economists report that landowners gain about $2.11 per acre per year from enhanced grassland Animal Unit Month (AUM) improvements from treating Phase II juniper lands (L Ruffin, USDA NRCS pers. comm). Hence, to generate the amount of revenue needed to cover the cost of juniper treatments (that can be at least $255 per acre) higher value bi-products from the treatments (i.e. biochar) are needed. As part of a different aspect of this project, USDA ARS is measuring any improvements to range habitats (via improved germination, better water infiltration) following biochar additions. The results should be available after the 2019 growing season.

2.3 Land distribution

Oregon State University, College of Forestry will provide more refined information as it pertains to juniper biomass, merchantable stocks, and supply estimates given existing road networks. However, for the economic sensitivity modeling we made some initial estimates of land distribution by ownership to help estimate the amount of sawtimber volume in the project area. To complete this rapid assessment, we used spatial GIS layers (provided by Chris Heider, Watershed Professionals Network) and US Forest

Service FIA data of lands within the North Slope Ochoco Holistic Restoration Project area (also known as the "RCPP").

Our analysis indicates the following:

- About 66% of lands in the project area are in private ownership
- Across public and private lands about 15% of the vegetation is pure juniper, only about 3% of the land contains "ideal" sawtimber juniper in a juniper/ponderosa pine mix.
- If we just look at the private land portion of the RCPP, about 4% is in the "ideal" juniper/ponderosa pine mix and about 9,800 acres of that is above 3,000 feet in elevation

This rapid GIS analysis did not identify specific pixels of vegetation associations within the RCPP (Figure 2), and further refinement of these layers will be needed to assist Wheeler SWCD with planning and targeting merchantable juniper in the region.

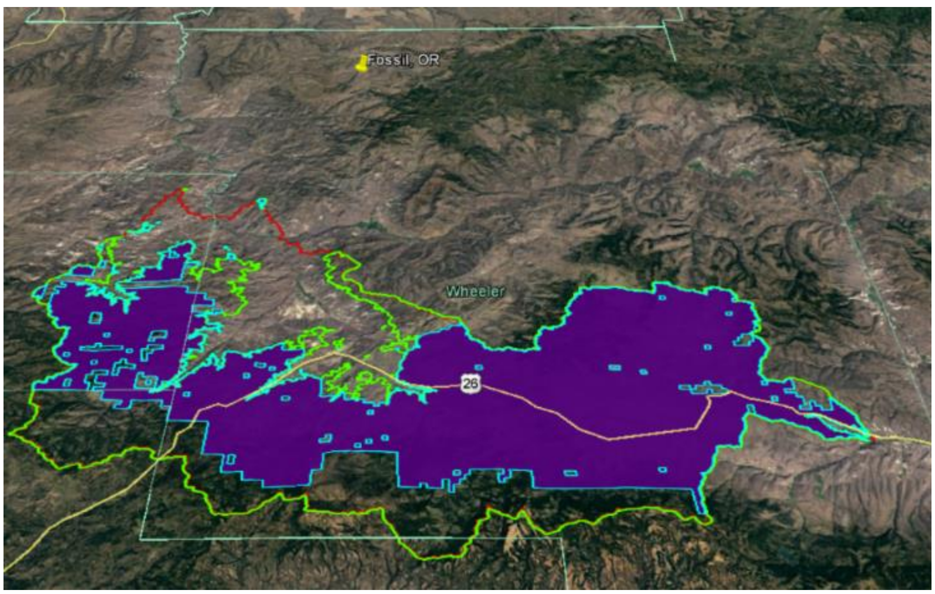

Figure 2. Project area boundary. Red border is the RCPP, Green boundary are private lands within the RCPP, and the purple filled in area are private lands >3,000 feet.

2.4 Juniper biomass and sawtimber supply

The final numbers of juniper biomass and sawtimber supply will be completed by Oregon State University, however based on some simplifying assumptions from our basic GIS analysis in addition to discussions with logging operators and juniper mills we have made an initial per acre estimate of biomass and juniper sawtimber in the RCPP project area.

Our first step in estimating juniper supply in the region, was to query US Forest Service Forest Inventory and Analysis (FIA) plots in a 25 mile radius of the town of Fossil, Oregon (Figure 3) using an online resource tool called GCOLE[4].

[4] USFS FIA data from GCOLE. http://www.ncasi2.org/GCOLE/gcole.shtml

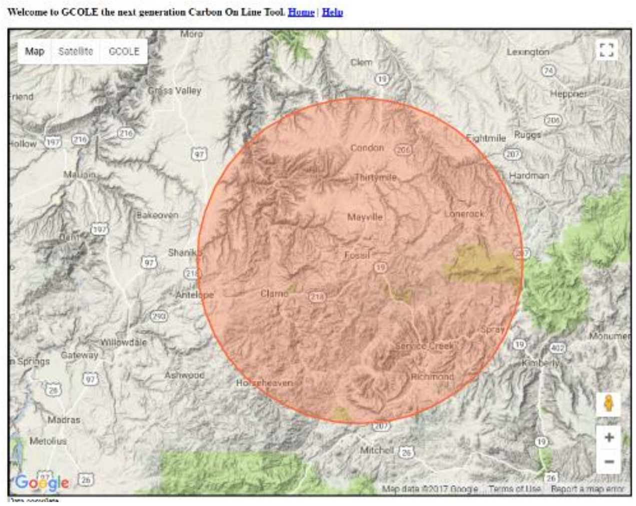

Figure 3. USFS FIA data from GCOLE in a 25 mile radius of Fossil, Oregon

Based on this initial query, the estimated total biomass per acre was 17.5 dry tons per acre or about 35 tons green tons per acre (assuming 50% moisture content for juniper "on the stump"). A review of the FIA plot based estimate, showed that areas within the 25 mile radius circle labeled "western juniper only" had a biomass of 12 green tons per acre (6 dry tons per acre).

The NRCS-SWCD project is treating about 2,000 acres per year (Herb Winters pers. comm.). So over the course of the project's five year time frame, we estimate about 10,000 acres of Phase II juniper rangelands will be treated, generating between 34,000 to 70,000 tons of juniper material per year.

Based on our GIS analysis, we estimate only about 5% of the juniper stocks on the landscape contain juniper sawtimber.

In our discussion with loggers who haul juniper in the region, we estimate there are about 170 board feet of juniper sawtimber per green ton brought to a juniper mill. The method of bringing juniper saw logs to a local mill, is variable ranging from short log trailers to pickup truck & trailer set ups (Figure 4). We estimate that each pickup truck load of juniper logs contains about 7.5 green tons (about 25 logs per load, average dbh of 12 inches in diameter, 1,200 pounds per log).

Figure 4. Truck and trailer set up, bringing juniper sawlog to "In the Sticks" mill in Fossil, Oregon

Researchers at Oregon State University are studying lumber recovery from raw log inputs for small and large sawmills in the project region. For larger mills (Ochoco Lumber in John Day) juniper lumber recovery is about 40%. In theory, the company could use a carbonizer (like the Biochar Solutions machine) to make biochar and heat from some of the waste juniper biomass not recovered as merchantable lumber.

Small sawmills, like "In the Sticks" in Fossil process about 8,000 board feet per day or about 50 tons of solid wood (Kendall pers. comm 2018). Lumber recovery is about 50% due to a more diverse product line (slabs for fencing, firewood, and other products). An ROI carbonizer could be run at this mill as was demonstrated in January 2019 (Figure 5 and video[5]). The machine can process 20 tons per hour or 160 tons per eight hour day.

Figure 5. ROI Carbonizer demo at the "In the sticks" juniper mill outside of Fossil, Oregon.

3.0 Financial calculation results

For the economic analysis of both mobile and stationary biochar production systems, we conducted two separate analyses. The first approach was to calculate costs, revenues and other relevant financial operational data of different biochar production systems using an excel based model. The second approach involved working with the US Forest Service Forest Products Laboratory to provide them base financial data for two selected biochar platforms (the Air Curtain Burner and the Biochar Bin), which the agency used to run Net Present Value calculations over 10 and 20 year time frames. The results from each analysis are listed in detail below.

3.1 Model one—Excel based tool

Most of the values used in our economic analysis are based on publicly available studies from other projects and regions and not on operational experience in the JuBop project area. Existing studies we used include the Redwood Forest Foundation Incorporated (RFFI) published experience with a Biochar Solutions machine, and the OSU IWFL project in Southern Oregon. Each study characterized costs, production, and other key variables slightly differently. For example, the RFFI project reported production costs on a "*Total cost per unit of biochar output*" rather than on a tons of biomass in per hour basis. The RFFI project also included grinding and feedstock drying costs in their biochar

[5] ROI Carbonizer demo video from Fossil, Oregon. Jan 2019. https://www.youtube.com/watch?v=kEdOXhJQWYo

production cost info. By contrast, for Kelpie Wilson's study for the Forest Service in North Dakota[6] having to do with the Kon-Tiki kilns and the Flame Cap system (biochar bin) grinding and drying costs are not needed (or considered) however, water quenching and skid steer equipment hourly costs for loading feedstocks are included.

Other variables at play for biochar economic calculations, include labor costs. For the RFFI project, their biochar production economic estimates included labor rates of $45 to $50 per hour in California, whereas reported labor rates in eastern Oregon are more in the $18 to $30 per hour range (Herb Winters pers. comm.). We used local labor rates in our economic model.

Feedstocks are an additional challenging metric to capture in a juniper biochar economic analysis. In the context of a juniper feedstock, slash piles are located across the landscape and can be picked up and fed into an Air Burner, Biochar Bin, or Kon-Tiki set up at no charge from the landowner. Hence, the feedstock cost is simply the cost of getting the equipment out there and running it through the biochar machine. By contrast, if the juniper biomass needs to be chipped and dried (like in the case of a Biochar Solutions machine or a FEECO stationary biochar machine) then there will be a feedstock cost associated with transportation, chipping, and drying the material. However, if a Kon-Tiki platform was set up next to a juniper sawmill and used non-sawlog material, they are not likely to be charged for the feedstock since they are disposing of a waste material that the mill owner would otherwise need to get rid of. Given these differences, and a lack of data on grinding or chipping and drying costs in the project area we did not include feedstock costs in our initial analysis. We did however calculate "operational" costs based on literature values. For example, Kelpie Wilson's experience with the Air Burner reports that the company said it costs about $2,000 a day to run their machine in the woods. Air burner operational costs include diesel to run the blower, labor, and use of a front end loader.

We summarized the key production and cost variables of selected biochar machine platforms which were used in our economic analysis (Table 2).

Table 2. Production costs of selected biochar technology (on a green tons in basis).

Tech	Biomass in per day (tons)	Biomass in per year (tons)	Feedstocks to biochar (%)	Biochar tons/day	Biochar yds/day	Biochar pounds/day	Grinding costs	Operations cost $/ton in
Kon-tiki	1.45	348	20%	0.29	2.32	385	None	$25
Biochar solutions	2.2	528	10%	0.22	1.76	292	Included	$129
Biochar Bin	25	6,000	20%	5	40	6,640	None	$25
Air curtain burner	160	38,400	8%	12	96	15,936	None	$13

In addition to capital and operational costs, we used 10% of the capital costs as an average amount of money spent on marketing and advertising on an annual basis. However, we did not include the costs of transporting the biochar products to market because it isn't clear if the products would be used locally or in more distant markets (e.g. home gardens in Portland, farms in the Willamette Valley). Given the uncertainty in market location(s) we chose not to include biochar product transportation costs in our analysis. Costs are assumed to be FOB mill.

[6] Wilson, Kelpie. (2017). Converting Shelterbelt Biomass to Biochar: A feasibility analysis by Wilson Biochar Associates for North Dakota Forest Service. North Dakota State University – North Dakota Forest Service, Bismarck, North Dakota, February 10, 2017. http://greenyourhead.typepad.com/files/wba-converting-shelterbelt-to-biochar.pdf

The initial results show that for each of the systems, all can be profitable in less than five years. The most lucrative system appears to be the "Biochar bin" also called the Flame Cap kiln (Table 3). The reason has to do with the low capital cost ($15,000 for the bin + labor and operational costs) and its high volume output (19,200 yards per year). The lowest margin (but still profitable) system appears to be the Biochar Solutions machine due to its higher capital costs ($205,000) and comparatively low output (840 yards biochar product per year). The economics of the stationary Biochar Solutions machine would improve if generated heat was used for a higher-value use (for example drying lumber or firewood).

Table 3. Costs, annual revenues, and simple payback (in years) for selected biochar technologies.

Variable	Units	Kon Tiki	Biochar bin	Biochar Solutions	Air Burner
Cost of production (feedstock, operations)	$/yd. biochar	$15.60	$15.60	$80.00	$20.00
Capital costs--machine, forklift, other	$	$28,750	$67,250	$257,250	$537,250
Number of people	FTE	2	2	2	2
Amount of biochar made & sold	yards	552	19,200	840	46,080
Amount of biochar made & sold	tons	69	2,400	105	5,760
Sale price of biochar	per yard	$125	$125	$125	$125
Margins on biochar product A*	$/yard	$84	$84	$20	$80
Margins on biochar product B*	$/yard	$119	$119	$70	$110
Profit on the year	$	-$179,376	$2,031,109	-$639,537	$5,019,809
Sales target to break even	$	$248,376	$368,891	$744,537	$740,191
Years to payback	yrs.	1	<1	4	<1

* Margins on products are a function of the costs of production minus the sales price. For the analysis we considered product A to be a raw biochar product that could be used for something like composting, which requires little or no product processing. Product B was a higher-margin specialty biochar product market.

3.2 Model 2—US Forest Service

The second model used in the analysis was constructed by the US Forest Service, specifically Nate Anderson and Robert Campbell. The USFS model was originally developed as part of the Waste to Wisdom project. We provided information about the JuBop project to the USFS team for the ROI Equipment Air Curtain Burner as well as the Biochar bin platforms. The main assumptions and variables used in their analysis are listed below (Table 4). Of note, the USFS calculations use a $25 per dry ton cost to obtain the feedstock, although that does not mean the landowner is paid money for the material. The USFS suggest that the $25 per dry ton cost is for collecting and getting the material to the machine. The financial analysis does not include any biochar post-processing costs (agglomeration, inoculation etc.). The USFS also clarified that they did not know if an air curtain burner could operate for 20 years, which would impact the NPV calculations. According to Air Burner Inc., with proper care & maintenance their machines can run for more than 20 years. We have accounted for some maintenance costs in our calculations (set at 6% of capital costs) however if something major did occur with the machine within the 20 year timeline then the NPV numbers could change significantly.

Table 4. Financial model inputs for the Air Curtain Burner.

Parameter	Campbell Air Curtain Inputs	Notes
Nominal discount rate	7.5%	
Inflation rate	2.5%	
Real discount rate	10%	
Loan financing	99%	
Loan interest rate	7.5%	
Loan term	7 years	
Federal income tax rate	21%	
Plant life	20 years	Standard in the literature
Depreciation	Variable declining balance (MACRS). 7 year period	current tax depreciation system in the United States
Construction spending	1 year construction period. 1% of capital costs accounted for here (other 99% is accounted for as loan payment)	
Biochar price	$800, $1,000,and $1,200 per ton	
Feedstock Price	$25 dry ton cost of obtaining feedstock.	Assuming 20% moisture content, 1 green ton = 0.8 dry ton. Machine cost per dry ton is $25. This assumes zero stumpage cost.
Biochar conversion rate	8%	Assumed this is conversion from dry feedstock.
Fixed Capital Investment	$485,000	Capital cost value
Working Capital	$78,000	
Land	$5,000	
Total Capital Investment	$568,000	Sum of Fixed Capital, Working Capital, and Land
Maintenance	$34,080	6% of total capital cost
Insurance and Taxes	$3,000	
Annual Labor Expense	$193,600	($121k + $44.8k overhead) Overhead is based on 37% of salaries.
Annual Variable Expenses	$6,000	
Annual Feedstock Consumption	38,400 dry tons per year	20 tons in per hour of operation
Annual Biochar Production	3,072 ton per year	(1.6 ton hr * 8 hr per day * 240 day per year)
Loss in Production	15%	

The USFS analysis shows that both for a 10 year and 20 year time frame, the Net Present Value (NPV) of both the Air Curtain Burner and the Biochar Bin are cash positive.

Financial Performance Results for Air Curtain Burner: $485k capital cost, and 8% biochar conversion rate

For a 10 year project period:

Biochar Price = $800 per ton: NPV = $3,154,057

Biochar Price = $1,000 per ton: NPV = $5,174,889

Biochar Price = $1,200 per ton: NPV = $7,195,721

For a 20 year project period:

Biochar Price = $800 per ton: NPV = $4,992,325

Biochar Price = $1,000 per ton: NPV = $8,063,762

Biochar Price = $1,200 per ton: NPV = $11,135,200

The USFS also ran financials using a higher-priced air burner technology platform called the "ROI Carbonator[7]". In this case, we asked USFS to assume an 8% and 3% feedstock to biochar conversion rate. The 20 year NPV numbers for these scenarios (Table 5) shows that a lower feedstock to biochar conversion rate loses money regardless of the biochar price. At 8%, NPV is always positive.

Table 5. NPV outputs for different feedstock-to-biochar conversion rates and different price points.

Fixed Capital Investment	Conversion Rate	Biochar Price ($ ton^{-1})	20-year NPV
$650,000	3%	$800	-$3,574,356
$650,000	3%	$1,000	-$2,116,395
$650,000	3%	$1,200	-$662,979
$650,000	8%	$800	$4,035,339
$650,000	8%	$1,000	$6,601,350
$650,000	8%	$1,200	$9,167,361

For the low-cost biochar bin technology, assuming everything being the same as above (in Table 4), except for a capital cost investment of only $105,000 the NPV outcomes over 20 years are:

Financial Performance Results for the Biochar Bin

For a 20 year project period:

Biochar price = $800 per ton: NPV = $5,338,251

Biochar price = $1,000 per ton: NPV = $8,409,688

Biochar price = $1,200 per ton: NPV = $11,481,125

3.3 Economic sensitivity analysis

In addition to the two methods of assessing juniper biochar production economics, we also examined how different cost and revenue assumptions impacted a "break-even" calculation on a per acre basis using the Air burner technology platform. The purpose of the calculation was to determine how different juniper density and biochar sales price assumptions influence the amount of revenue that can be generated from biochar production. We then determined the point where biochar sales revenue could cover the NRCS cost share contributions (of $255/acre).

The fixed costs used as part of this calculation are:

Operational costs: $20 per ton of material in

[7] ROI Carbonator 500. https://roi-equipment.com/carbonator-500/

NRCS cost share dollars devoted to treating juniper: $240/acre
Costs of burning piles on a per acre basis: $15/acre
Total treatment and burn costs in a "business as usual" scenario: $255/acre

Variable costs and assumptions were:
Juniper biomass density either 10 or 25 green tons per acre
Biochar sales price: $50, $75, $100, or $125 per cubic yard ($400, $600, $800, or $1,000 per ton, respectively)

According to recent operational data available from ROI equipment their tracked "Enviro 350" has been processing 100 yards of forest residues per hour (producing 10 yards of biochar per hour) in the southeast US (Figure 6).

Figure 6. Carbonizer models available from ROI equipment (image courtesy of ROI equipment)

Since we do not know how much juniper slash pile volume or biomass exists in the JuBop project area we used the US Forest Service "Playground" model developed by the Seattle Fire Lab[8] for our estimates.

According to the USFS Playground model, there are between 2 and 8 tons per slash pile in areas around Fossil, Oregon, with an average density of 37 pounds per cubic foot (about 1,000 pounds per cubic yard). If we use 5 tons of slash in a juniper pile as an average (10 yards), it seems reasonable that the ROI Enviro 350 ACB could handle our estimated 10 to 15 tons of juniper material per acre in an hour of operation in the JuBop project area.

Our analysis indicates that when juniper density is only 10 tons per acre, biochar revenue (from off-site sales) does not generate sufficient revenue above the NRCS cost share payment ($255/acre) until the price for biochar reaches $1,000 per ton (Figure 7).

[8] USFS Fire Lab Playground program—Seattle, WA: http://www.playground.airfire.org/home.php

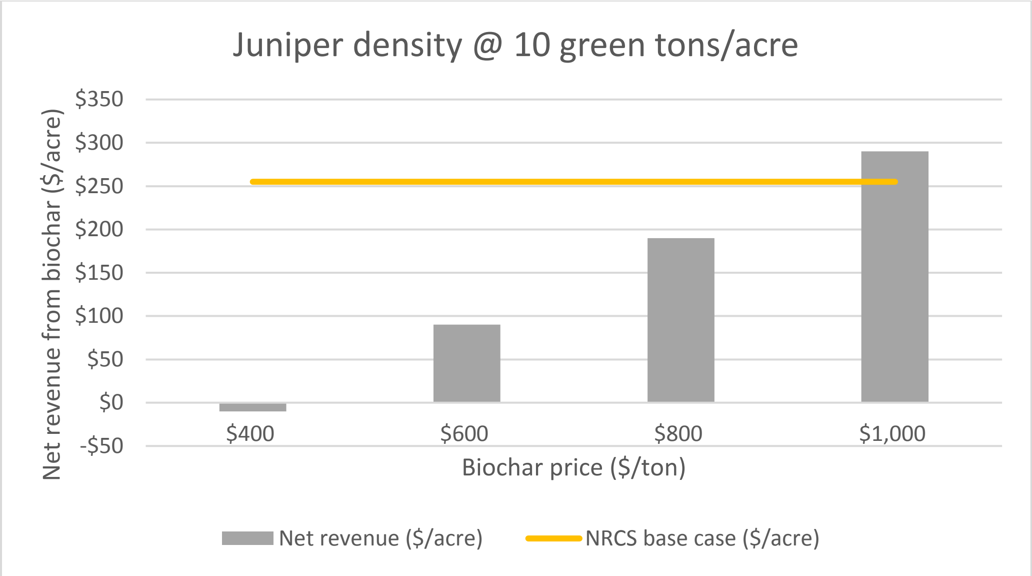

Figure 7. Net revenue generated from biochar production per acre at different product price points ($/ton) and an assumed juniper density of 10 green tons per acre

The situation on a per acre basis does improve when we assume a higher juniper density of 25 green tons per acre (Figure 8). At these densities, biochar revenue exceeds the NRCS cost share base case ($255/acre) at price points of $800 and $1,000 per ton of biochar. Again, a biochar enterprise loses money (on a per acre basis) at the lowest price point ($400 per ton, column on the left below) but is cash positive for all other scenarios.

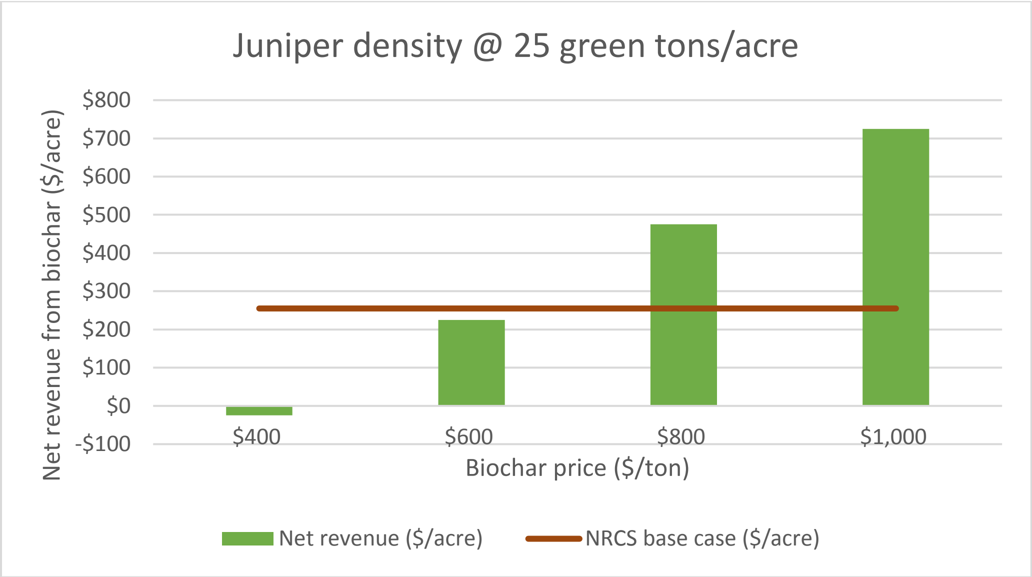

Figure 8. Net revenue generated from biochar production per acre at different product price points ($/ton) and an assumed juniper density of 25 green tons per acre

4.0 Conclusions

Based on our analysis, we conclude that both mobile and stationary biochar production can be profitable using juniper feedstocks, particularly if there are at least 25 tons of juniper per acre across the landscape and biochar price points are $800 per ton or more in off-site markets.

At production levels of 38,000 tons of juniper feedstocks in annually (producing around 3,000 tons of biochar), NPV calculations over 10 year time frames are $3.1 million at $800 per ton of biochar and $7.1 million at $1,200 per ton of biochar.

Although not part of our economic analysis as part of the JuBop project--the USDA Agriculture Research Service is conducting a study of rangeland restoration benefits associated with adding juniper biochar (made with a Kon-Tiki kiln). Any benefits from increased seed germination, or improved range conditions will be quantified later this year. This study can be thought of as a proxy for using biochar on-site, instead of shipping the product to off-site markets. Based on the data collected for this report, we learned that it takes about $20 per ton to make biochar with the ROI Carbonizer. To machine cut and pile juniper, it costs about $240 per acre (according to NRCS cost-share programs). If we assume 10 tons of juniper per acre, then it appears that a landowner (without NRCS assistance) would have to pay $440 per acre to cut & process juniper and run it through an ROI Carbonizer. The landowner would then have to apply the biochar to their rangeland. Pasture seeding costs are about $30 per acre in parts of the Pacific Northwest (T. Miles pers. comm). If we use that as a proxy cost for applying biochar to rangelands, the total cost of treating juniper, making ROI carbonizer biochar, and applying it to rangeland habitat are approximately $470 per acre.

Our analysis demonstrates that biomass per acre, biochar conversion rates (from raw feedstocks to finished product), machine capital costs, off-site markets, and biochar prices are important considerations when evaluating the economic viability of new biochar production enterprises.

It is also important to note that this report is not meant to endorse one type of biochar technology over another or to say that one particular system is better for a particular application compared to another. In addition, our analysis had to make some simplifying assumptions, particularly pertaining to feedstock type & moisture content. Some biochar machine providers need ground or chipped feedstock material with 15% moisture content or less. Other biochar technologies featured required year old dried slash, while others could use a combination of freshly cut green slash in combination with dried mill slabs. All of these various feedstocks have different moisture contents and hence impact biochar production per hour or per day. In addition, we also based our calculations on one 8 hour work day, and clearly some of the machines featured in this report could run 24 hours a day. All of these variables could impact NPV calculations over time. Our goal with this analysis was to take a broad look at the relative costs and returns across a variety of biochar production technologies (both mobile and stationary). We hope that this analysis provides valuable information for agencies, landowners, and biochar practitioners about the costs and values of juniper based biochar.