11-1-2018

Evaluation of Three Forest-Based Bioenergy Development Strategies in the Inland Northwest, United States

Jill Moroney
Boise State University

RESEARCH ARTICLE

J. For. 116(6):497–504
doi: 10.1093/jofore/fvy042

biomass, carbon & bioenergy

Evaluation of Three Forest-Based Bioenergy Development Strategies in the Inland Northwest, United States

Darin Saul, Soren Newman, Steven Peterson, Eli Kosse, Ryan Jacobson, Robert Keefe, Stephen Devadoss, Tammy Laninga, and Jill Moroney

In this article, we compare three bioenergy scenarios that use woody biomass from US Inland Northwest forests. The scenarios are based on current bioenergy research, development efforts, and stakeholder input. They include a small-scale system that produces drop-in transportation biofuel and biochar, a large, regional system that produces bio-aviation fuel, and a midsized pellet production system. We modeled woody biomass harvest, processing, and transportation, and then evaluated profitability and potential socioeconomic impacts to determine the overall viability of each strategy. Through interviews, we found widespread stakeholder support for all three scenarios. Wood-pellet production was profitable and feasible with current prices and conditions, whereas liquid biofuel production was profitable only at levels that greatly exceed current prices.

Keywords: biomass, woody, stakeholders, development, production

Interest in forest-based bioenergy has grown in recent years, driven largely by concern over climate change, desire for energy independence, policy changes [e.g., the Renewable Fuel Standard (RFS)], and government incentives such as carbon taxes (McKay 2006, Raison 2006, Wiser et al. 2007, Nicholls et al. 2009, US Energy Information Administration 2012).[1] In the US Northwest, the abundance of forest biomass and corresponding challenges, such as high wildfire risk, have prompted land managers and others to seek cost-effective uses for forest residues, including for small-diameter trees and postharvest slash piles (Keefe et al. 2014). In addition to enabling thinning projects to decrease wildfire risk, the use of forest biomass for bioenergy could lessen fossil fuel consumption to decrease greenhouse gas (GHG) emissions, reduce slash pile burning to improve air quality, provide economic opportunities, and provide supplementary markets to keep sawmills profitable (Adams and Latta 2005, McKay 2006, Cambero and Sowlati 2014).

Economic development that increases income and job opportunities is an important goal in many rural, forested areas. For example, whereas Idaho had the fastest-growing population in the country as of 2017, some of its most rural counties are losing population owing in part to declining employment in natural resource industries. The steepest population declines and highest unemployment rates have occurred in counties with historically vibrant timber industries (US Census Bureau 2014). Since its peak in 1978, wood and paper product employment in the Northwest has declined

Received December 1, 2017; accepted July 20, 2018; published online September 17, 2018.

Affiliations: *Darin Saul (dsaul@uidaho.edu), Office of Grant and Project Development, College of Agricultural and Life Sciences, University of Idaho, 875 Perimeter Drive MS2331, Moscow, ID 83844. Soren Newman (newman@uidaho.edu), Office of Grant and Project Development, College of Agricultural and Life Sciences, University of Idaho, 875 Perimeter Drive MS2331, Moscow, ID 83844. Steven Peterson (stevenp@uidaho.edu), Department of Business, University of Idaho, 875 Perimeter Drive MS3161, Moscow, ID. Eli Kosse (elijah.kosse@sdstate.edu), Department of Economics, South Dakota State University, South Dakota State University Economics, ABS SSB 140, Box 0504. Brookings, SD 57007. Ryan Jacobson (rjacobso@alumni.ubc.ca), Chemical and Biological Engineering, University of British Columbia, 2360 E Mall, Vancouver, BC, V6T 1Z3, Canada. Robert Keefe (robk@uidaho.edu), Department of Forest, Range, and Fire Sciences, University of Idaho, 875 Perimeter Drive MS 1133, Moscow, ID. Stephen Devadoss (stephen.devadoss@ttu.edu), Department of Agricultural and Applied Economics, Texas Tech University, 2500 Broadway Lubbock, TX 79409. Tammy Laninga (tammi.laninga@wwu.edu), Environmental Studies Department, Western Washington University, 516 High Street MS9085, Bellingham, WA 98225. Jill Moroney (jillianmoroney@boisestate.edu), Human–Environment Systems, School of Public Service, Boise State University, 1865 W. Cesar Chavez Ln, Boise, ID 83725.*

Acknowledgments: *This work was supported by the USDA National Institute of Food and Agriculture under award no. 2012-00948 from the Agriculture and Food Research Initiative. We thank Christy Dearien, Debbie Gray, Scott Metlen, and Priscilla Salant for their contributions.*

by nearly 120,000 jobs, or 63 percent (US Bureau of Labor Statistics 2001–2016, EMSI 2016). The causes include automation and competition from other nations and US regions, and reduced harvesting on federal lands (Charnley et al. 2008, Keegan et al. 2010). The impact on rural communities has been highly negative, contributing to substantial losses in jobs and income (Helvoigt et al. 2003). Forest-based bioenergy offers an opportunity to revitalize this historically declining industry.

Public investments in the region have supported forest-based bioenergy development through three large grants from the US Department of Agriculture's Agriculture and Food Research Initiative (USDA AFRI). The Northwest Advanced Renewables Alliance (NARA) researched and piloted a supply chain that uses post-harvest forest residues to produce bio-aviation fuel (Martinkus et al. 2017). The Advanced Hardwood Biofuels Northwest consortium is researching methods to convert sustainably grown hardwood into bio-based chemicals and liquid biofuels. And, the Bioenergy Alliance Network of the Rockies (BANR) is researching a conversion process that produces drop-in transportation fuels and biochar for a soil supplement using beetle-killed trees as a primary feedstock (BANR 2015). These projects explore different conversion processes, feedstocks, supply chains, markets, and scales and locations of operations.

Additionally, numerous bioenergy and heating project feasibility studies have been conducted, usually at the county or community scale (e.g., Adams County (Idaho) 2010). These generally identified common constraints such as the lack of reliable feedstock supply, cost-prohibitive haul radiuses, and harvest costs that exceed biomass's value as an energy feedstock. Policy drivers intended to support large-scale bioenergy development include the RFS at the federal level and Low Carbon Fuel Standards in California and other states. These and other policies incentivize bioenergy use and will help shape future markets (Whistance et al. 2017).

Overcoming obstacles and implementing bioenergy projects will require careful consideration of multiple ecological, social, and economic factors (Buchholz et al. 2007). This requires a focus not only on project profitability but also on other factors that influence long-term sustainability, such as regional and community economic development impacts. Community and stakeholder engagement is critical to building social acceptance and overcoming controversy (Wüstenhagen et al. 2007, Stidham and Simon-Brown 2011) as stakeholders can facilitate or stymie bioenergy project implementation and sustainability (Devine-Wright 2010, Jenssen 2010). Stakeholder engagement and understanding of diverse perspectives are also important to ensure forest management and industry development projects are socially equitable and well aligned with the values and interests of affected localities (Becker and Viers 2007, Marciano et al. 2014).

In this article, we explore how several forest-based bioenergy development options would impact communities in the Inland Northwest. To better understand the social and economic opportunities and challenges forest-based bioenergy development poses, we carried out four research efforts we: (1) conducted in-depth interviews and facilitated meetings to understand stakeholder perspectives on opportunities, tradeoffs, and obstacles to forest-based bioenergy development in the region and to define meaningful scenarios for feedstock and economic analyses; (2) modeled woody biomass availability to better understand the costs and size of facilities that available feedstock can consistently and sustainably supply; (3) modeled supply chains to better understand profitability and likelihood of success; and (4) analyzed economic impacts to evaluate tradeoffs at community and regional scales. Synthesizing the analyses from each project component helped investigators and stakeholders better understand potential forest-based bioenergy development in the region.

Methods

Scenario Development and Stakeholder Research Methods

Our study region included the forested areas of eastern Washington and Oregon, northern Idaho, and western Montana (Figure 1). A focus group with land managers and forest industry representatives helped us develop realistic forest-based bioenergy scenarios for the project (Newman et al. 2017). This group identified three production scenarios that address different markets at different scales of forest biomass use. The three scenarios are described in Table 1.

The scenarios include technologies that have been successfully piloted and are currently being optimized through further research (scenarios 1 and 2) or are established technologies (scenario 3). Wood pellets are produced in numerous facilities throughout the United States in varying scales, ranging in production from 500,000 to 1,000,000 tons of pellets annually in the US Southeast. China was chosen as the end-use destination for the international-use scenario based on forest industry representative interest in China as a new market, even though considerably higher volumes of pellets currently are sold in Japan and Korea (Madison's Pellet Report 2017). At the far low end of the production spectrum, even small landowners can successfully produce pellets with equipment sized as farm tractor attachments (Qin et al. 2018). Woody feedstock from a variety of sources on small landowner properties (e.g., fire salvage,

Management and Policy Implications

Our work is relevant to bioenergy developers, foresters, policymakers, the forest industry, fire managers, researchers, forest communities, and economic development. Viable forest-based bioenergy supply chains could be profitable and consistent, and provide needed jobs and benefits to people, communities, and forests supplying the feedstock. Densifying forest biomass for transportation is important for liquid biofuel production, enabling Inland Northwest forests to contribute to regional biofuels production. Increasing pellet production could have immediate positive benefits for local economies and forest health. Existing markets can support increased pellet production to gain these benefits without being directly tied to conversion technologies still under development or the development of production facilities. Our models will be useful for siting facilities or operations: Our Forest Residue Economic Assessment Model (FREAM) determined the viability and cost of developing a consistent supply; our regional optimization model identified locations with the highest profits for facilities development; our economic impacts research identified locations where development would have the most economic benefits; and our social research identified key factors that would build or align with stakeholder support.

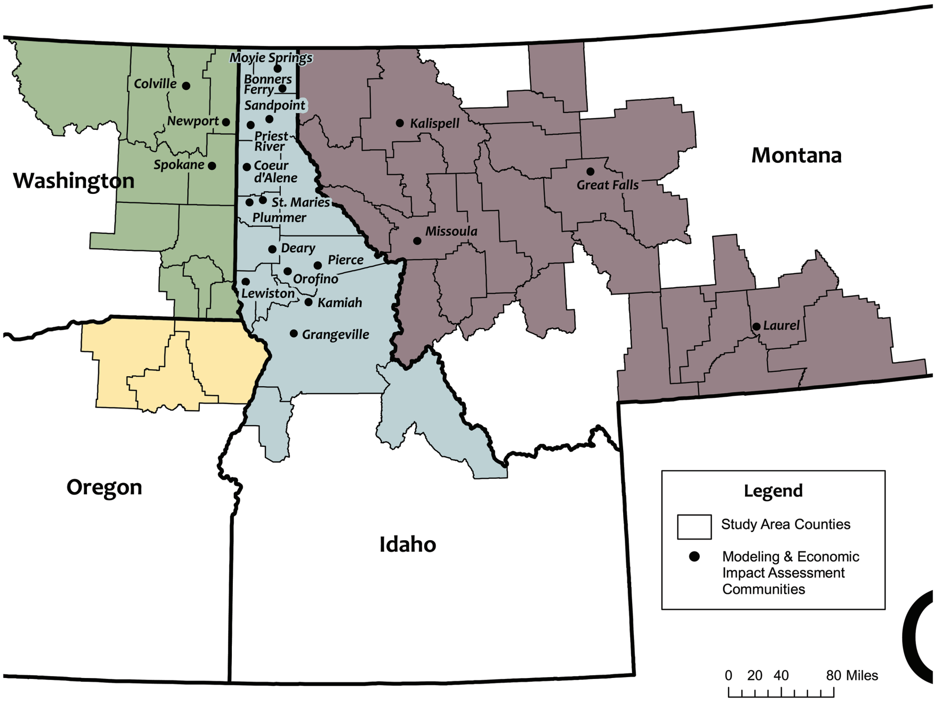

Figure 1. Study area.

beetle-kill, and green timber) can be used to produce pellets (Qin et al. 2018), and larger-scale pellet supply chains from fire salvage are profitable (Mansuy et al. 2015). Medium- and large-scale production of biofuels, by contrast, are emerging systems likely to undergo continued process improvement as they evolve over the next decade.

Once our scenarios were defined, we conducted 45 semistructured interviews involving 48 participants, including representatives of the forest industry, environmental organizations, city and county governments, state and federal land management agencies, tribes, economic development organizations, nonindustrial private forestland owners, and other key informants (Newman et al. 2017).[2] We identified participants through purposive and snowball sampling to include a range of perspectives. Interviewers first asked participants to share their perspectives on the benefits, costs, and barriers to forest-based bioenergy in general. The second set of questions explored participants' perspectives on the potential tradeoffs, desirability, and feasibility of our project scenarios. Interviews ranged from 45 to 90 minutes and were audio-recorded, transcribed, and then analyzed with ATLAS.ti. The analysis involved coding segments of data and organizing them into inductive categories (Charmaz 2006). Stakeholders also helped investigators understand the context for proposed bioenergy industries and interpret results and their implications. Data and iterative feedback from the stakeholder process helped refine the scenarios and inform modeling and analysis. A more detailed description of stakeholder research methods and results is available in Newman et al. (2017).

Simulation and Modeling

We developed the FREAM to facilitate landscape-scale comparison of woody biomass development options for this study (Jacobson et al. 2016). FREAM uses GIS layers with county-level unused forest residue volumes, networked roads, and city locations to determine the supply and routing of forest residues and rough production costs for a proposed biorefinery or pellet mill (Jacobson et al. 2016). We used FREAM to evaluate the three scenarios for 20 communities in northern Idaho, eastern Washington, and western Montana (Figure 1). We estimated 20 communities to be the minimum needed to supply a processing facility sized to the regional-use scenario. Results from the FREAM analysis provided production costs, transportation costs, and employment inputs for

Table 1. Scenario descriptions.

Scenario	Description
S1: local use	Liquid drop-in fuels and a biochar coproduct would be produced from logging residues and small-diameter trees in our study area. This scenario would use approximately 200,000 bone-dry ton (BDT)/year of forest residues. Chips and hog fuel would be produced at log landing sites and then transported to conversion units. Finally, 9,985,704 gallons of drop-in fuel and 20,000 tons of biochar would be transported to nearby end-use locations, using an allocation of 4 pounds of biochar produced per gallon of fuel. Fixed and operating costs associated with the local-use scenario correspond generally to the Cool Planet Energy System's catalytic pyrolysis process being researched as part of the BANR project (BANR 2015; Cool Planet 2014).
S2: regional use	The regional-use scenario would collect and upgrade feedstock, consisting of chips or hog fuel from commercial logging residues and small-diameter trees, for transportation to a large, centralized biofuels facility located, for example, in Colville, WA. Aviation fuel would be sold to Spokane International and other regional airports. Of the three scenarios, the regional-use scenario presents the largest production process: it would draw approximately 700,000 BDT/year of forest residues and would be based on Gevo's integrated fermentation aviation fuel technology to produce bio-jet fuel (Cavalieri et al. 2014). As with the local-use scenario, biochar was used to represent potential coproducts in this scenario. This scenario was based on a portion of the NARA project focused on biofuels development in our study area.
S3: international use	This scenario would produce industrial wood pellets for sale to transpacific energy markets. Chips or hog fuel from commercial logging residues and small-diameter trees would be transported by truck directly to a midsized wood pellet manufacturing facility in the study area. Pellets would be transported to the Port of Seattle for delivery by ship to China to represent Asian markets. The international scenario would draw 300,000 BDT/year of forest residues, making it 50 percent larger than the local-use scenario and 38 percent of the volume of the regional-use scenario (Goh et al. 2013). This scenario was informed by similar pellet supply chains in the US Southeast and British Columbia, which is beginning to partner with Asian pellet markets. Cost assumptions were based on a pellet mill of similar size in Burns Lake, British Columbia (Sorensen 2011).

the regional optimization modeling and economic impacts analyses reported in this article.

Regional Optimization Modeling Methods

We then evaluated the three scenarios for the same 20 potential production locations identified in the FREAM analysis through optimization modeling. First, the profit-maximizing level of output and final-use locations were found for each of the three scenarios at each of the 20 potential production sites. To accomplish this task, we developed a profit equation for each scenario. Profits are total revenues (price times quantity sold) minus total costs (fixed, variable, and transportation) and are expressed on an annualized basis. Then, profits were determined for each scenario at each of the 20 locations. For the local-use and regional-use scenarios, revenues were from biofuel and biochar; for the international-use scenario, revenues were from pellets only.

Fixed costs, which do not vary based on output, include the annual amount paid for capital, operating, and maintenance costs. Variable costs depend on the level of production, including harvest, transportation, and production costs. Variable costs are expressed as cost per gallon produced for the local-use and regional-use scenarios and cost per ton produced for the international-use scenario. Transportation costs from the plant to the end-use location for fuel were included for all scenarios modeled in FREAM and were expressed in dollars per gallon per mile, reflecting the variability in transportation distances calculated based on available road network data. Transportation cost estimated in the international-use scenario differed because the scenario assumed the same end-use location in China for all pellets, and the transportation cost to the actual final site of use within China was not included, because it would not change the price US producers received.

In conjunction with the profit equation, we included constraints on production and demand. The production constraint limited the production of fuel to the amount of biomass available, whereas the demand constraint limited the amount of fuel shipped to a particular location to the amount of fuel demanded at that location.

Economic Impacts Methods

The next step was to complete 60 economic impact assessments: one for each of the three bioenergy scenarios for each of the 20 locations used in the FREAM analysis and regional optimization modeling. Custom multicounty IMPLAN models were developed for each of the 20 subregions corresponding to the 20 locations using 2011 data, and these economic models were then configured to each subregion to capture supply chain effects. Each economic impact assessment included results for four categories of bioenergy operations: (1) forest landing (accumulation of biomass at roadside), (2) depot (consolidation of biomass at an intermediate location), (3) processing (converting biomass into fuel at a bioenergy facility), and (4) transportation, including from the landing to end-use site based on road network analysis. The outputs for each scenario and location combination included sales transactions, gross regional product (GRP), total compensation, employment, and state and local taxes.

IMPLAN is the most widely employed US input–output modeling software and economic data package.[3] The analysis from IMPLAN measures the economic impacts arising from changes or shocks to a specific industry (or firm), which create multiplier effects as the impacts ripple through the economy. The multipliers used in this analysis, known as SAM or Type II multipliers, have three components: (1) direct impacts of bioenergy expenditures on each respective economy; (2) impacts of purchases from other regional businesses that provide goods or services to the bioenergy operations—the indirect impacts; and (3) the impacts of employee and consumer spending on the economy—the induced impacts. An output (sales) multiplier of 1.80, for example, creates $1.80 of total new output for every $1.00 of new direct spending, and $0.80 represents the indirect and induced impacts.

The geographic subregions for the three project scenarios were configured for each supply chain and included biomass collection, processing, and distribution. Individual county and city IMPLAN models were constructed in targeted subregions to measure the impact disbursements within the subregions.

Results

Stakeholder Perspectives

Most stakeholders supported converting forest biomass to bioenergy. For most, support was conditional on specific concerns: foremost was that any proposed project should benefit forest health, which participants generally conceptualized as improving with "active management" (Newman et al. 2017). Many stakeholders viewed woody biomass removal as potentially positive for forest ecosystems with benefits including reduction in wildfire risk and damage and insect and pest damage. Others mentioned the potential economic benefits of bioenergy development such as new employment opportunities, particularly at the local level. In terms of project scale, most preferred small over large projects. Many thought that small-scale projects could be locally owned, more responsive to community and forest health needs, and more easily scaled to available feedstocks (Newman et al. 2017).

These findings reinforce the importance of engaging stakeholders in bioenergy project planning from the earliest stages (Buchholz et al. 2007, Stidham and Simon-Brown 2011). Bioenergy projects will succeed not only where they are scaled to available biomass, but also where they align with the primary values, goals, capacities, and existing economies of the localities involved (Becker and Viers 2007, Marciano et al. 2014). Forest-based communities have a vital role to play in bioenergy development based on their knowledge and intimacy with local forests. Though most participants supported creation of forest-based jobs and forest industry infrastructure improvements, a few participants preferred tourism or telecommuting and other technology-based development, which may be an increasing trend, especially in areas with high natural amenities. Yet, given an appropriately scaled project, even amenity-focused localities may support some bioenergy development if it helps mitigate wildfire risk and severity in the wildland–urban interface.

Regional Optimization Modeling

Regional optimization modeling showed that the local-use scenario, which produces a substitute for gasoline, was profitable only at high prices when the producer price was approximately $4.50/gal. Since current producer prices for gasoline are less than $2.00/gal, this scenario is not viable at current prices. Even at the highest biofuel prices, many locations also required high biochar prices of $150/ton to be profitable. The estimated prices for biochar ranged from $91 to 329/ton (Shackley et al. 2010). The best locations based on profits for the local-use scenario were St. Maries, ID ($6.36

million), Plummer, ID ($5.60 million), and Colville, WA ($5.15 million) (Table 2).

The regional-use scenario was not profitable unless fuel prices were to rise to approximately $12.00/gal, considerably higher than the 2014 price of $3.71 per gallon (Air 2014), which are similar to current prices (Air 2018). This scenario entailed developing a large plant with high fixed costs of $95.44 million per year, a substantially greater cost than the local-use ($8.23 million) and international-use ($7.79 million) scenarios. Whereas no locations were profitable at any reasonable aviation fuel price, Coeur d'Alene, ID, Spokane, WA, and Newport, WA, accrued the lowest losses. These locations are close to the largest consumer of aviation fuel in the region, Spokane International Airport.

The international-use scenario, which produces wood pellets for sale in China, was profitable for a range of prices at nearly all locations. For prices per ton of $200, the optimal locations based on profit were Coeur d'Alene, ID ($13.76 million), Spokane, WA ($13.63 million), and Deary, ID ($13.45 million). These three locations are profitable for pellet prices at or greater than $170 per ton, similar to recent prices of $171/ton (Madison's Pellet Report 2017). Similar short supply radiuses and low capital costs resulted in low variation in final costs for these three sites.

Current fuel prices are not high enough to offset the production costs of liquid biofuels from woody biomass. Pellet production offers positive profits at current prices, whereas the other scenarios (drop-in biofuel and bio-aviation fuel) required prices that greatly exceed current prices to be profitable, largely because of production and transportation costs.

Economic Impacts

The subregions in the study area were vast and largely rural in nature: the average local-use scenario subregion had 15 counties, a land area of 31,000 square miles, and a total employment of 390,000. The average regional-use scenario subregion had 34 counties, a land area of 73,000 square miles, and a total employment of 763,855. The average international-use scenario subregion had 18 counties, a land area of 37,000 square miles, and a total employment of 539,740. Direct economic employment was unevenly distributed throughout each subregion. A substantial portion of the jobs were concentrated in small towns where the processing occurred. The remaining jobs were in the biomass gathering and transportation sectors dispersed across vast rural regions.

Overall, the total economic impacts on employment from the proposed scenarios were small compared with the region total, but very important to individual rural communities. The average total compensation (wage package) was about $43,000 per job, a solid living wage in the regional economy. The proposed scenarios would complement the wood products industries in the region and provide important economic cluster effects that may help revitalize these industries. Specifically, the bioenergy industry could help preserve the job skill sets and institutional know-how for wood products and paper manufacturing. The overall economic impacts for the three scenarios are summarized as follows:

- Local-use scenario: The average net additional contribution to GRP was about $20 million per year. Of this, $12.6 million was in total compensation (i.e., wages and benefits for 290 new jobs) and $1.5 million in state and local taxes, including multiplier effects.
- Regional-use scenario: The average net additional contribution to GRP was about $152 million per year, with $102 million in total compensation (2,382 jobs), and $10.6 million in state and local taxes, including multiplier effects.
- International-use scenario: The average net additional contribution to GRP was about $25 million per year, with $17 million in total compensation (406 jobs), and $1.7 million in state and local taxes, including multiplier effects.

The number of jobs varies considerably between locations within each scenario (Table 3). The regional benefits reflect the scale of production of each scenario.

The economic impact contributions came from four bioenergy production

Table 2. Annual profits for three bioenergy scenarios at 20 locations.

	Local use	Regional use	International use
Location	Biofuel: ≈$4.60/gal; biochar: $150/ton	Aviation fuel: $12.71/gal; biochar: $300/ton	Pellets: $200/ton
Coeur d'Alene, ID	$3,683,368	$19,072,618	$13,755,544
Spokane, WA	$2,051,256	$17,757,438	$13,632,994
Deary, ID	$952,168	–$2,637,138	$13,436,344
St. Maries, ID	$6,361,704	$6,784,368	$12,903,394
Lewiston, ID	$2,501,256	–$7,767,915	$12,840,694
Orofino, ID	–$3,682,296	–$15,271,929	$12,738,094
Plummer, ID	$5,597,224	$11,215,994	$12,022,744
Sandpoint, ID	$3,831,256	$10,240,069	$11,965,744
Kamiah, ID	$48,568	–$21,844,369	$11,250,394
Pierce, ID	–$7,616,056	–$23,700,259	$10,714,594
Priest River, ID	$2,713,816	$11,729,126	$10,338,394
Newport, WA	$1,856,360	$12,722,556	$10,287,094
Missoula, MT	$3,091,256	–$28,884,033	$9,925,144
Grangeville, ID	$2,101,256	–$25,611,256	$9,922,294
Colville, WA	$5,151,256	–$3,488,913	$7,984,294
Bonners Ferry, ID	$964,056	–$83,798	$5,778,394
Moyie Springs, ID	$2,654,360	–$2,773,592	$5,501,944
Kalispell, MT	$401,256	–$41,960,909	$4,131,094
Great Falls, MT	$301,256	–$92,787,206	$2,954,044
Laurel, MT	$1,271,256	–$93,257,082	–$6,539,307

Table 3. Total number of jobs created, by subregion and scenario.*

Subregion	S1: local use	S2: regional use	S3: international use
Bonners Ferry	305	1,764	351
Coeur d'Alene	261	1,732	342
Colville	270	2,165	375
Deary	269	2,001	368
Grangeville	322	2,557	457
Great Falls	304	4,094	544
Kalispell	281	2,581	477
Kamiah	304	2,392	432
Laurel	341	5,764	466
Lewiston	304	2,183	415
Missoula	304	4,094	430
Moyie Springs	312	1,828	359
Newport	261	1,535	412
Orofino	297	2,216	407
Pierce	317	2,399	436
Plummer	267	1,748	312
Priest River	264	1,530	411
Sandpoint	291	1,488	445
Spokane	262	1,743	333
St. Maries	271	1,836	347

* Job numbers include the multiplier effects (i.e., direct, indirect, and induced impacts)

operations: forest landing, depot, processing, and transportation. The forest landing and transportation operations occur in the most rural portions of each subregion, and the jobs impacts are the most dispersed. The depot and processing operations are in the larger communities. Given the importance of rural development and the historic decline of many rural communities, rural jobs are some of the most important employment forest-based bioenergy production creates. On average across all subregions, approximately 54 percent of the jobs (including the multiplier effects) were rural in the local scenarios, 80 percent were rural in the regional scenario, and 60 percent were rural in the international scenario. These findings suggest that forest-based bioenergy production has the capacity to create jobs and generate income in rural regions with the most need.

Synthesis Findings: Comparing Bioenergy Development Scenarios

We compared production system scenarios across a variety of attributes using findings from all project components to evaluate tradeoffs from multiple perspectives (Table 4). All three scenarios had economic benefits for rural communities, although the regional-use scenario, with its much larger scale of production, had more economic benefits in more communities. Although not significant nationally or regionally, job creation was large enough to benefit small communities and complement the local and regional wood products industries. Whereas the regional-use scenario had the greatest regional economic development potential, high production and fixed costs in the current bio-aviation fuel market indicate that it is not profitable enough to draw the necessary feedstock from the multistate region.

The regional-use scenario was also least likely to secure stakeholder support, for example, because many saw it as most likely to result in pressure to overharvest woody biomass. Interestingly, the local-use scenario, which had the most stakeholder support, had the smallest economic impacts; and the regional-use scenario, which had the greatest potential economic impacts, was the least popular (Newman et al. 2017).

Although the local-use scenario received the most interest and support from stakeholders, many supported all three production strategies. Stakeholders' preference for the local-use scenario was primarily linked to beliefs that this scenario (and other similarly scaled wood bioenergy projects) would be most likely to maximize benefits in the local area where the feedstock is sourced and to secure support from a diversity of stakeholder groups. The local-use scenario presents the lowest production costs but, like the regional-use scenario, is not profitable at current conventional fuel prices.

Our analyses suggest the international-use scenario presents the lowest risk and greatest likelihood of success because it uses a proven technology, the end product is profitable in the current market without subsidies, and it embodies many of the favorable attributes that stakeholder participants said would affect their level of support. For example, many stakeholders expected wood-pellet production to use more residues than the local-use scenario because of its larger scale but remain small enough to sustainably use existing feedstock with some flexibility and resilience (Newman et al. 2017). If wood pellet production was consumed in local and regional markets, this scenario would have received even greater support, since exporting biomass energy to benefit others and transportation impacts of shipping to China were main concerns of some stakeholders. Energy prices tend to be highly volatile, especially in international markets, and production for domestic markets could improve long-term project viability. Pellet prices in the US Northwest of $171/ton in October 2017 (Madison's Pellet Report 2017) would support profitable operations at multiple sites in our study.

To further illustrate our results, we now discuss "optimum" scenarios based on two criteria: profitability and economic impact. Profitability measures long-run economic viability. It measures stockholder or stakeholder return but does not indicate the

Table 4. Scenario ranking by attributes evaluated (1 = best, 3 = worst).

Attribute	Local use (liquid fuel/biochar)	Regional use (aviation fuel/biochar)	International use (pellets)
Stakeholder support/preference	1	3	2
Viability (cost and profitability)			
Production costs	1	3	2
Predictability of production costs	1	3	2
Fixed costs	2	3	1
Profitability (at 2015 prices)	2	3	1
Economic impact			
GRP	3	1	2
Net additional GRP contribution	3	1	2
Job creation	3	1	2
State and local taxes	3	1	2

degree of community impact. Economic impact analyses measure the magnitude of community economic contributions measured in terms of jobs, income, taxes, or overall economic development. Economic impact analyses do not measure profitability or financial sustainability but capture indirect economic contributions, including multiplier effects. Enterprises with a high community economic impact can be unprofitable and unsustainable. Conversely, highly profitable enterprises can make a modest contribution to local communities. Considered independently, our profitability and economic impact analyses could lead to contradictory conclusions in some locations. For example, the regional-use scenario in Laurel, MT, generates the greatest economic impacts (i.e., 5,764 jobs) and is also the least profitable with the largest estimated loss (–$93.26 million/year). Whereas the international-use (pellet) scenario was profitable in all locations modeled except for Laurel, MT, both the local-use and regional-use scenarios required large subsidies to be profitable, regardless of where they were sited. A pellet mill sited in Coeur d'Alene, ID, produced the greatest profit at $13.76 million/year (Table 2).

When choosing an optimal site, we also considered profitability and economic impacts in the context of other attributes, such as poverty, existing infrastructure, potential workforce, and benefit to diverse stakeholders. Using these criteria, we chose Plummer, ID, as the optimal location for several reasons: Plummer is centrally located; Benewah County has a higher-than-average poverty rate for the state and country; a cluster of wood products manufacturing facilities exist in the area (Benewah County, ID); and diverse stakeholders may benefit from development of a facility, including the Coeur d'Alene Tribe. Whereas Plummer was not the most profitable location for any of the scenarios, it was profitable and had strong economic impacts.

Conclusions

Our analysis, based on the assumptions and modeling described in Jacobson et al. (2016) and feedback from stakeholders in Newman et al. (2017), found that neither large bio-aviation fuel facilities nor mid-sized, pyrolysis-derived transportation biofuel production are currently economically viable in the Inland Northwest, assuming drivers of future forest harvesting will be similar to those of the recent past. However, we found general support for bioenergy development among diverse stakeholders, with the strongest interest in benefits to forest health, economic development in rural communities, and reduced wildfire risk and damage. Our research supports converting forest biomass into pellets for existing pellet markets while biofuels production continues to advance toward profitability and scale. Meanwhile, pellets provide a relatively simple mechanism for increasing biomass use and provide a uniform feedstock that can be refined later. Thus, pellet production provides an interim, transitional solution that may foster the cost-effective adoption of other advanced bioenergy developments as biofuel technology matures.

The FREAM model includes several simplifying assumptions, particularly for forest stand treatments. More comprehensive analysis from the USDA AFRI projects (NARA and BANR) will likely yield different results based on higher-resolution modeling of stand treatment and processing costs, such as those described in Zamora-Cristales (2016), Becker et al. (2017), and Kim et al. (2017). Substantial emerging results associated with both projects have co-occurred while we conducted this analysis. Thus, current production costs associated with biofuel facility siting and operations have likely decreased.

Policy support for use of bioenergy production to improve forest health and reduce fuel loads has the potential to help drive bioenergy development. For example, reduction in biomass volumes in overstocked forests prone to fire would be an important outcome of forest-based bioenergy development, and fire-prevention activities and future policy could include more support for the use of biomass for bioenergy to account for that value than currently exists. Such synergies between policy and management arenas could improve the viability of all three technology options. Profitability will also improve if gasoline and jet fuel prices increase in the future. Meanwhile, pellet production for existing markets will help build the volume of woody feedstock supply needed for domestic biofuel production. A first wave of pellet mills may eventually feed a future wave of liquid biofuel production. Therefore, policies that favor proven feedstock technologies such as wood pellets with a variety of markets at local to international scales may best benefit multiple management and policy goals. US Environmental Protection Agency's official recognition of the carbon neutrality of biomass use as of April 2018 may also help foster increased investment in biofuel production.

Increasing use of forest biomass for energy production needs to be carefully managed. Inland Northwest forests already have multiple land uses and wood-product markets. Research in the southeast United States has identified both positive and negative potential impacts of increased pellet production. Whereas it could help retain natural forest land from other uses such as urbanization and pine forest development and benefit biodiversity and carbon sequestration (Duden et al. 2017), potential negative impacts on land use, sawtimber markets, and carbon sequestration are also possible, as is the potential displacement of traditional wood-using industries (Abt et al. 2012).

Factors affecting the production costs and siting of biofuel facilities are complex and vary widely with facility scale. Biomass feedstock hotspots available for pellet production following wildland fires vary in quality more than other feedstock sources but can nonetheless generate profitable supply chains (Mansuy et al. 2015), and pellets can be produced from the thinned (green) materials and beetle-killed timber (Qin et al. 2018) in large supply in the Inland Northwest. As a result, biomass feedstock sourcing can become more stable at the landscape level by developing pellet facilities that integrate multiple feedstock sources to gain some resiliency to local policy and management shifts.

Taken together, our analyses show that successful facility development depends not only on supply availability and the nuances of transportation costs, but on broader economic impacts and profitability. Social acceptance and economic impacts can be as important as profitability in determining facility location and in developing policies and management goals for forest-based bioenergy.

Endnotes

1. Bioenergy is any renewable energy produced from biomass, including heat, electricity, and biofuel. Biofuel is liquid fuel made from biomass, such as wood residues.
2. Institutional Review Board number 15-1028.
3. http://www.implan.com/

Literature Cited

Abt, K.L., R.C. Abt, C. Galik. 2012. Effect of bioenergy demands and supply response on markets, carbon, and land use. *For. Sci.* 58(5):523–539.

Adams County (Idaho). 2010. *Project development and business plan for Adams County [Idaho] woody biomass power generation*. Council, Adams County.

Adams, D.M., and Latta, G.S. 2005. Costs and regional impacts of restoration thinning programs on the national forests in eastern Oregon. *Can. J. For. Res.* 35:1319–1330. doi: 10.1139/x05-065.

Air Navigation. 2014. Airports. Available online at www.airnav.com/airport/KSFF/WESTERN; last accessed November 11, 2014.

Air Navigation. 2018. Airports. Available online at https://www.airnav.com/fuel/local.html; last accessed July 2, 2018.

BANR. 2015. Bioenergy Alliance Network of the Rockies (BANR). banr.nrel.colostate.edu/; last accessed December 14, 2015.

Becker, R.M., Keefe, R.F., and N.M. Anderson. 2017. Use of real-time GNSS-RF data to characterize the swing movements of forestry equipment. *Forests.* 8(2):44. doi:10.3390/f8020044.

Becker, D.R., and J. Viers. 2007. Matching the utilization of the by-products of forest fuel reduction with community development opportunities. P. 157–170 in *People, fire and forest: a synthesis of wildfire social science*, Viers, J., T. Daniel, M. Carroll, C. Moseley, and C. Raish (eds.). Oregon State Press, Tucson, AZ.

Buchholz, T.S., T.A. Volk, and V.A. Luzadis. 2007. A participatory systems approach to modeling social, economic, and ecological components of bioenergy. *Energy Policy.* 35(12): 6084–6094. doi:10.1016/j.enpol.2007.08.020.

Cambero, C., and T. Sowlati. 2014. Assessment and optimization of forest biomass supply chains from economic, social and environmental perspectives: a review of the literature. *Renew. Sustain. Energy Rev.* 36:62–73. doi:10.1016/j.rser.2014.04.041.

Cavalieri, R.P., M. Wolcott, and L. Beltz. 2014. *Northwest Advanced Renewables Alliance (NARA) cumulative report*. Washington State University, Pullman.

Charmaz, K. 2006. *Constructing grounded theory: a practical guide through qualitative analysis.* 1st ed. SAGE, Thousand Oaks, CA.

Charnley, S., Donoghue, E.M., and Moseley, C. 2008. Forest management policy and community well-being in the Pacific Northwest. *J. For. December*:440–447. Available online at https://www.fs.usda.gov/treesearch/pubs/33294.

Cool Planet. 2014. *Cool planet starts construction on first commercial facility*. Business Wire, San Francisco.

Devine-Wright, P. (ed.). 2010. *Renewable energy and the public: from NIMBY to participation*. Routledge, New York.

Duden, A., P. Verweij, H. Junginger, et al. 2017. Modeling the impacts of wood pellet demand on forest dynamics in southeastern United States. *Biofuel Bioprod. Bioref.* 11:1007–1029.

EMSI. 2016. QCEW data 2001–2016. Available online at www.economicmodeling.com/; last accessed September 5, 2016.

Goh, C.S., M. Junginger, M. Cocchi, et al. 2013. Wood pellet market and trade: a global perspective. *Biofuel Bioprod. Bioref.* 7(1):24–42. doi:10.1002/bbb.1366.

Helvoigt, T.L., D.M. Adams, and A.L. Ayre. 2003. Employment transitions in Oregon's wood products sector during the 1990s. *J. For.* 101(4):42–46. doi:10.1093/jof/101.4.42.

Jacobson, R.A., R.F. Keefe, A.M. Smith, et al. 2016. Multi-spatial analysis of forest residue utilization for bioenergy. *Biofuel Bioprod. Bioref.* 10(5):560–575. doi:10.1002/bbb.1659.

Jenssen, T. 2010. The good, the bad, and the ugly: acceptance and opposition as keys to bioenergy technologies. *J. Urban Technol.*17(2):99–115. doi:10.1080/10630732.2010.515086.

Keefe, R.F., N. Anderson, J. Hogland, and K. Muhlenfeld. 2014. *Woody biomass logistics. In Cellulosic energy cropping systems, 251–279.* John Wiley and Sons, New York. Available online at www.treesearch.fs.fed.us/pubs/46720.

Keegan, C.E., T.A. Morgan, K.A. Blatner, and J.M. Daniels. 2010. Trends in lumber processing in the Western United States. Part II: overrun and lumber recovery factors. *For. Prod. J.* 60(2):140–143.

Kim, Y., W. Chung, H. Han, and N.M. Anderson. 2017. Effect of downed trees on harvesting productivity and costs in beetle-killed stands. *For. Sci.* 63(6):596–605.

Madison's Pellet Report. Average price US densified biomass fuel. Available online at www.madisonsreport.com. December 2017.

Mansuy, N., Thiffault, E., Lemieux, S., Manka, F., Pare, D., and L. Lebel. 2015. Sustainable biomass supply chains from salvage logging of fire-killed stands: A case study for wood pellet production in eastern Canada. *Appl. Energy.* 154:62–73.

Marciano, J., R. Lilieholm, M. Teisl, J. Leahy, and B. Neupane. 2014. Factors affecting public support for forest-based biorefineries: A comparison of mill towns and the general public in Maine, USA. *Energy Policy* 75:301–311. doi:10.1016/j.enpol.2014.08.016.

Martinkus, N., G. Latta, T. Morgan, and M. Wolcott. 2017. A comparison of methodologies for estimating delivered forest residue volume and cost to a wood-based biorefinery. *Biomass Bioenergy.* 106:83–94. doi:10.1016/j.biombioe.2017.08.023.

McKay, H. 2006. Environmental, economic, social and political drivers for increasing use of woodfuel as a renewable resource in Britian. *Biomass Bioenergy.* 30(4):308–315. doi:10.1016/j.biombioe.2005.07.008.

Newman, S., D. Saul, R. Keefe, R. Jacobson, T. Laninga, and J. Moroney. 2017. "The devil is in the details:" Inland Northwest stakeholders' views on three forest-based bioenergy scenarios. *For. Sci.* 63(6):614–20. doi:10.5849/FS-2016-083R1.

Nicholls, D., R.A. Monserud, and D.P. Dykstra. 2009. International bioenergy synthesis: Lessons learned and opportunities for the western United States. *Forest Ecol. Manag.* 257(8):1647–1655. doi:10.1016/j.foreco.2008.11.035.

Raison, R.J. 2006. Opportunities and impediments to the expansion of forest bioenergy in Australia. *Biomass Bioenergy.* 30(12):1021–1024. doi:10.1016/j.biombioe.2005.12.012.

Shackley, S., S. Sohi, P. Brownsort, et al. 2010. *An assessment of the benefits and issues associated with the application of biochar to soil.* Department for Environment, Food and Rural Affairs, London.

Sorensen, J. 2011. Pellet giant. *Can. Biomass.* February 10, 2011. Simcoe, ON, Canada. Available online at http://www.canadianbiomassmagazine.ca/news/pellet-giant-2286.

Stidham, M., and V. Simon-Brown. 2011. Stakeholder perspectives on converting forest biomass to energy in Oregon, USA. *Biomass Bioenergy* 35(1):203–213.

US Bureau of Labor Statistics. 2001–2016. Quarterly census of employment and wages. Available online at www.bls.gov/cew/datatoc.htm; last accessed March 6, 2017.

US Census Bureau. 2014. Population Estimates Program. Available online at www.census.gov/popest/; last accessed September 30, 2015.

US Energy Information Administration. 2012. Most states have Renewable Portfolio Standards. Today in energy. February 3. Available online at economic impact assessment.gov/todayinenergy/detail.cfm?id=4850; last accessed June 23, 2016.

Wiser, R., N. Christopher, M. Gielecki, and R. Smith. 2007. The experience with renewable portfolio standards in the United States. *Elec. J.* 20(4):8–20. doi:10.1016/j.tej.2007.03.009.

Whistance, J., W. Thompson, and S. Meyer. 2017. Interactions between California's low carbon fuel standard and the national renewable fuel standard. *Energy Policy.* 101:447–455.

Wüstenhagen, R., M. Wolsink, and M.J. Bürer. 2007. Social acceptance of renewable energy innovation: An introduction to the concept. *Energy Policy.* 35(5):2683–91. doi:10.1016/j.enpol.2006.12.001.

Qin, X., R.F. Keefe, and D. Daugaard. 2018. Small landowner production of pellets from green, beetle-killed, and burned lodgepole pine. *Energies.* 11:648. doi:10.3390/en11030648.

Zamora-Cristales, R., and J. sessions. 2016. Modeling harvest forest residue collection for bioenergy production. *Croat. J. For. Eng.* 37(2):287–296.