Biorefinery Site Selection

Using a Stepwise Biogeophysical and Social Analysis Approach

Natalie Martinkus^a, Sanne A. M. Rijkhoff^b, Season A. Hoard^c, Wenping Shi^d, Paul Smith^d,
Michael Gaffney^c, Michael Wolcott^a

Abstract

A key factor in the production of economically viable and environmentally sustainable biofuels is biorefinery site selection. Facility location analysis has traditionally been driven by access to feedstock, proximity to customers, and local incentives. While economic constraints will always be major factors in site selection, incorporating social metrics may further reduce the cost of constructing a biorefinery. A community's disposition toward a biorefinery project may significantly impact implementation success: grassroots support can lower implementation costs while opposition may increase the costs of permitting blockages and other scale-up delays. The proposed biorefinery siting tool improves upon previous research by incorporating site-specific biogeophysical measures and more complete and comprehensive social measures of community innovation and capacity for collective action. A refined biogeophysical analysis assesses pulp mills for their potential as repurposed biorefineries. The social asset components of site selection are greatly improved by enhancing and disaggregating key metrics through the use of multiple indicators of community collective action capacity and propensity for change. The refined measures are integrated into a biorefinery site-selection tool. Pulp mills that rank highly in both the biogeophysical and social asset measures may be considered more suitable candidates for repurpose into a biorefinery. This enriched methodology has been applied to biorefinery siting decisions in the U.S. Pacific Northwest region; however, it is suitable for applications to infrastructure development projects in any region of the U.S.

Keywords

Pulp Mills; Biorefinery; Social Assets; Decision Model.

a) Department of Civil and Environmental Engineering, Washington State University, natalie.martinkus@wsu.edu,
wolcott@wsu.edu

b) Mark O. Hatfield School of Government, Division of Political Science, Portland State University,
srijkhoff@pdx.edu

c) School of Politics, Philosophy and Public Affairs, Division of Governmental Studies and Services, Washington
State University, hoardsa@wsu.edu, mjgaffney@wsu.edu

d) Department of Agricultural and Biological Engineering, Pennsylvania State University, wxs191@psu.edu,
pms6@psu.edu

1.0 Introduction

In the United States' Pacific Northwest region (PNW), woody biomass residuals from logging operations are proposed as a potential feedstock for conversion into iso-paraffinic kerosene, or sustainable aviation biofuel [1, 2]. A key factor in the production of economically viable and environmentally sustainable biofuels is biorefinery site selection. The location of a facility is primarily driven by access to feedstock, proximity to customers, and local incentives [3]. While economic constraints will always be major factors in site selection, incorporating social measures may further reduce the cost of constructing a biorefinery. A community's disposition toward a biorefinery project may impact implementation success: grassroots support can lower implementation costs while opposition can increase the costs of permitting blockages and other scale-up delays [4].

Social measures are rarely incorporated into siting decisions due to the qualitative nature of the data and a lack of experience in applying the metrics. Acknowledging difficulties in adequately measuring social assets, Martinkus et al. [5] were the first to create a single metric to measure community capacity for collective action as an indicator for community support of a biorefinery project. The authors developed a facility siting tool that combined county-level biogeophysical assets with a single social score to identify communities in a region with the highest potential for successful biorefinery implementation. While this tool was the first to identify potential sites using biogeophysical *and* social assets, its measurement of communities' capacity for collective action remains incomplete and does not fully capture this important, yet under-utilized, resource. Given the demonstrated importance of social assets to economic development and successful environmental policy implementation [6-14], this study provides an improved facility siting tool by incorporating enhanced measures of both social assets and biogeophysical metrics.

Specifically, the goal of this research is to develop a biorefinery siting tool that incorporates both location-specific siting variables and social metrics that indicate a community's ability to implement a biorefinery project. The major objectives are to: (1) refine the biogeophysical analysis by including location-specific siting variables, (2) improve and disaggregate social asset components through multiple indicators of community collective action capacity and propensity for change, and (3) integrate the refined measures into a biorefinery site-selection tool. The improved methodological framework is tested in the PNW states of Oregon, Idaho, and Washington to identify existing pulp mills best suited both biogeophysically and socially for potential biorefinery projects.

Pulp mills are targeted for repurpose as their infrastructure is similar to that of a wood-based biorefinery, and many have closed or been decommissioned in recent years due in part to the "Great Recession" of 2007-2009 [15]. Repurposing pulp mills into wood-based biorefineries may provide a revitalization opportunity for communities traditionally dependent on forest products-based employment. Additionally, existing facilities may offer a trained workforce, feedstock connections, and local support for retaining jobs [16].

2.0 Literature Review

As noted by Hutchins and Sutherland [17], supply chain decisions traditionally focus on the economic measure of sustainability. Environmental considerations have gained strength through

life cycle assessments, yet social measurements remain ill-defined [17]. This is evident in biorefinery siting research. While community characteristics and social assets are acknowledged, the inclusion of these assets is often minimal and does not incorporate characteristics that adequately predict success of these projects.

Many facility siting studies have examined the impact of biogeophysical variables on site selection in the ethanol industry. Major siting factors were found to include: feedstock availability, access to biofuel and coproduct markets, utility costs and availability, government incentives, and absence of operating ethanol plants [18-20]. Additionally, access to multi-modal transportation, product markets, and producer credit can provide a comparative advantage in attracting ethanol plants [20]. Facility siting analyses using the aforementioned siting criteria have been performed using a combination of geographic information system (GIS) software and/or optimization routines to identify ideal locations for biorefinery siting [3, 21-24]. Other studies incorporated environmental constraints into facility siting analyses through measuring greenhouse gasses emitted along the supply chain [25, 26], or measuring soil erosion, nutrient loss, runoff, or pesticide movement off-site [27, 28]. All studies assume a Greenfield biorefinery will be constructed at the location identified as ideal.

Some used imprecise measures to either quantitatively or qualitatively assess social metrics in facility siting analyses. Van Dael et al. [29] developed bioenergy facility siting criteria and weights with the assumption that early stakeholder buy-in would result in increased acceptance of the final decision. They defined a society criterion as the willingness of communities to accept the project in their area. However, their measurement of this criterion included variables such as community acknowledgement of the local Kyoto protocol, total number of unemployed job seekers, and total free industrial area. Sultana and Kumar [30] assumed that social acceptability of establishing a plant was contingent on proper consideration for man-made, natural, and environmental elements. Fortenbery et al. [31] modeled biodiesel siting decisions through examining several biogeophysical resources, political resources, and socioeconomic variables, including proxies of market measures and community acceptance. They used percentage of houses owner-occupied and education level as indicators of potential opposition to the construction of a biodiesel refinery. Few facility siting analyses incorporate economic, environmental, and social criteria through quantifiable means. You et al. [32] and Perimenis et al. [33] approach facility siting differently, yet both incorporate quantifiable economic, environmental, and social measures through minimizing feedstock costs, measuring greenhouse gas emissions along the supply chain, and estimating the total number of jobs created through an installed biorefinery, respectively. Both also assume the communities surrounding the final location will be accepting of a new biorefinery. Using metrics such as the total number of jobs created, education-levels, or owner-occupied housing offers very poor proxies of the indicators needed to predict success of the biorefinery installation.

Martinkus et al. [5] developed the first biorefinery siting tool to incorporate social assets through quantitative measures for prediction of biorefinery implementation success. Their tool used a step-wise approach, first identifying and ranking suitable communities for a biorefinery through a city- and county-level assessment of biogeophysical siting measures. Next, county-level social assets (*social capital*, *creative leadership*, and *public health status*) were combined into a single score and applied to the ranked county list to identify communities with the highest potential for

biorefinery investment success. However, there are several limitations of this first biorefinery site selection tool, including incomplete measures of social assets and a lack of site-specific biogeophysical measures. Specifically, social capital measures excluded key indicators such as the number of non-profit organizations and associational groups; the creative leadership construct did not fully capture community adaptability and creativity; and, the human health measure relied on self-assessments of health rather than objective measures of community health. Additionally, the biogeophysical assessment was performed at the community level with the assumption that a valid biorefinery location could be found, rather than considering existing industrial sites for repurpose (Table 1). Pulp mills hold great potential as repurposed wood-based biorefineries due to their scale, infrastructure compatibility, and feedstock logistics [34-37], and may provide significant reductions in biorefinery capital expenditures. Using operational cost-based metrics in a facility siting analysis allows for identification of locations that provide reduced annual expenses. Together, consideration for capital and operational costs in a siting analysis may allow for production of a more competitively priced biofuel, which is highly important in this nascent industry. Our proposed model improves site-selection decision making and enhances the likelihood of success for these important biofuel infrastructure projects.

< INSERT Table 1. Comparison of 2014 City/County-Level Model [5] and Proposed Site-Specific Model>

3.0 Methodology

The Community Capitals Framework, developed by Emory and Flora [38], models community capacity using seven “capitals” that combine various resources, such as social, biogeophysical and financial assets (Figure 1). The decision tool presented in this paper incorporates six of the seven capitals in a step-wise process. First, a biogeophysical assessment is performed on selected pulp mills, addressing natural, built, and financial capital. Site-specific metrics are applied through a decision matrix to assess and score each facility. A ranked list of mills is developed from the decision matrix based on biorefinery repurpose potential. Second, improved county-level social metrics are applied to each facility to assess the collaborative and creative capacity of communities to accommodate a biorefinery by measuring cultural capital, human capital, and social capital. Facilities with high biorefinery repurpose potential and strong social assets are identified as having the greatest potential for implementation success.

< INSERT Figure 1. Community Capitals Framework. Based on work by Emory & Flora [38].>

3.1 Biogeophysical Siting Analysis

A list of pulp mills in the PNW was obtained from [39] and verified for current status. Pulp mills were assessed based the following biorefinery scenario:

- An annual feedstock demand = 760,000 bone dry metric tons (BDMt) of forest residuals to the biorefinery gate;
- Mild bisulfite pretreatment converts wood into pulp to produce approximately 133 million liters of biojet fuel per year; and,
- At least 61 hectares available for site development.

Of the 21 active pulp mills identified, eight were removed based on site development limitations (Figure 2).

<INSERT Figure 2. Pulp Mill Locations in the PNW (n=13)>

3.1.1 Facility Siting Decision Matrix

Multi-criteria decision analysis combined with GIS is a powerful tool in bioenergy projects [29, 40]. A decision matrix, similar in form to Wang et al. [41], is constructed based on criteria and weights to assess each pulp mill (Table 2). Criteria provide a means to compare facility assets against a design biorefinery scenario, and weights denote the importance of each criterion relative to all criteria. An integer scale value from 1 to 5 is assigned to each facility for each criterion based on its location-specific assets relative to the range of regional values. A ‘5’ indicates an asset that best matches that biorefinery component, and a ‘1’ indicates an asset that may add significant additional cost to the construction or operation of a biorefinery.

Siting criteria and weights are developed from the major capital and operational cost components that vary geospatially, as identified in a Greenfield biorefinery techno-economic analysis (TEA) [42]. Criteria include *total delivered feedstock cost*, *electricity rate*, *average weekly wage*, and *infrastructure retrofit potential*. A regional average annual cost is determined for each criteria and applied in the TEA for weight derivation (Equation 1), where c_i is the annual average cost of criterion i , n is the total number of criteria, and s_{max} is the maximum scale value. The last term is used to normalize the weights. In the siting analysis, facilities are assessed based on their infrastructure compatibility for retrofit into a biorefinery. Similar to others [21, 25, 43], the total capital expenditure to construct a greenfield biorefinery (C_k) is converted to an annualized expense (A_k) assuming a plant life (y) of 30 years and a discount rate (r) of 10% using the capital recovery equation (Equation 2) for inclusion in weight derivation as an operational expense.

$$w_i = \left(\frac{c_i}{\sum_{i=1}^n c_i} \right) * \frac{100}{s_{max}} \quad \text{Equation 1}$$

$$A_k = C_k * \frac{r(1+r)^y}{(1+r)^y - 1} \quad \text{Equation 2}$$

Each criterion’s range of regional values is used to determine the criterion-based value designation associated with each scale value. Where others translate facility-specific values into scaled values through linear transformation [29, 41], we use criterion-based “bin” values (B_i), determined by dividing the range of regional values ($a_{i,max}$, $a_{i,min}$) by the maximum scale value (s_{max}) for each criterion i (Equation 3).

$$B_i = \frac{a_{i,max} - a_{i,min}}{s_{max}} \quad \text{Equation 3}$$

In the decision matrix, the maximum scale value for each criterion is assigned to the minimum or maximum range value that denotes the most positive influence on facility siting, such as high

biomass availability or low electricity rate. The subsequent scale values are calculated by either adding or subtracting B_i , depending on the positive or negative influence of the criterion (Table 2). Where regional values are not available or possible, as in infrastructure assessments or delivered feedstock cost, bin values are determined from the range of facility values.

< INSERT Table 2. Biorefinery Siting Decision Matrix >

Overall facility scores are determined using the Weighted Sum Method [40] (Equation 4), where j represents a criterion, n represents the total number of criteria, s_{mj} is the assigned scale value based on the assets present at facility m , and w_j is the weight associated with criterion j . The facilities are then ranked from highest to lowest based on facility score.

$$F_m = \sum_{j=1}^n w_j s_{mj} \quad \text{Equation 4}$$

3.1.2 Criteria Development

Biomass availability is a measure of the risk associated with a facility's ability to procure feedstock in the face of feedstock shortages due to natural disasters or changes in market demand. The weighted average delivered feedstock cost to each facility at the biorefinery annual demand is determined using a Total Delivered Feedstock Cost Model [44]. This model combines GIS-based variable least-cost routes, V_{bj} , along a networked road dataset between biomass source points, b , and a pulp mill, j , with a fixed cost, F_b , to procure and process the biomass at each source point (Equation 5).

$$TC_{bj} = F_b + V_{bj} \quad \text{Equation 5}$$

The result is a table of total transport costs and associated volumes for all biomass source points supplying a facility. By sorting the total costs from least to greatest, a weighted average delivered cost can be determined for each facility at the annual demand of 760,000 BDMt. The facilities that procure sufficient feedstock at the least cost are best-situated to maintain annual production in low-yield years.

Electricity rate (averaged over 2010–2014) and weekly wage (averaged over 2012–2014) are county-level data derived from national datasets [45, 46]. Each facility's repurpose potential as a percent reduction from the Greenfield biorefinery is performed utilizing methodology presented by Martinkus et al. [47]. They present a factored approach to assign valuation to the major capital cost components of a Greenfield biorefinery. Existing facilities are assessed for their compatibility through an infrastructure and asset analysis to determine an estimated capital percent savings that may be realized through repurposing into a biorefinery.

3.2 Social Asset Analysis

Site-selection literature thoroughly addresses financial and biogeophysical resources; however, social resources remain inadequately addressed. This is problematic given the wealth of scholarly literature that supports the importance of social, cultural, and human capital in

community success and project sustainability. Following the Community Capitals Framework, the social assets in our decision tool consist of multiple indicators of community collective action capacity and receptiveness to change measured through social capital, cultural capital and human capital. To date, these measures are the most complete quantitative indicators of these key assets available across the United States.

Social capital refers to the number, strength, and type of social networks present within a community based on norms of trust, communication, and reciprocity. It has been found to increase the capacity for cooperation, promote economic growth, aid in city sustainability, and promote natural resource management [6, 7, 9-11, 48]. Scholars have argued that social capital predicts variation in environmental policy success [12, 13]; therefore, it is important to include complete measures of this concept in biorefinery siting models. Cultural capital, based on the attributes and traditions of a community that influence creativity and innovation [13], is an important component of success because highly technical projects require adaptability and creativity. Research has found that creativity contributes to successful sustainability programs [49]. Lastly, human capital, which includes several measures that analyze the skills and ability of a community [38], is included because of its importance in natural resource management, and its role in helping local economies [50] through identifying skills within a workforce.

Ideal data for each of these capitals is qualitative in nature (see also [33]); however, even the best qualitative measures lack precision and accuracy, are not widely available, and are expensive and time-consuming to obtain at the community level. To enhance the likelihood of success, key decision makers need more complete quantitative measures that can help them assess and compare various sites across the United States. Therefore, we use county-level data from nationwide databases as close proxies for the qualitative measures. Data developed by Rupasingha et al. [51] was used to measure social capital. Cultural capital was measured using the Creative Vitality Index from WESTAF [52], and human capital was measured using the County Health Rankings dataset [53]. For each capital, we created one scale by summing relevant indicators and providing a single score for the latest year available.

3.2.1 Enhancement of Social Assets

The measures provided here for social, creative, and human capital are more refined and accurate than the single social asset factor score provided previously by Martinkus et al. [5]. Following Martinkus et al. [5], we calculated reliability scores for a potential single social asset factor score based on their measures of the three capitals; however, the low reliability of the scale, with a Cronbach's α of 0.043, and the single indicators per capital were limitations of this work. For instance, the social capital score included only one component of social capital: the sum of political organizations, labor organizations, business organizations and professional organizations (known as Olson groups) divided by the population in 1997. This excludes components such as the "Putnam groups"¹ which include non-profit organizations, often viewed as the most important measures of social capital. Furthermore, the creative capital indicator consisted of only 40% of the Creative Vitality Index, and the human capital score combined the percentage of adults reporting to have fair or poor health, reported physically poor days per

¹ Olson or rent-seeking groups are political organizations, labor organizations, business organizations and professional organizations. Putman or non-rent-seeking groups are civic organizations, bowling centers, golf clubs, fitness centers, sports organizations and religious organizations and non-profit organizations.

month, and reported mentally poor days per month for 2012 into a single score without standardizing the original variables. These limitations decrease accuracy and predictive capacity to identify communities more likely to succeed at implementing biorefinery projects. The following model for developing social asset scores provides more inclusive and precise indicators for the three capitals, thus enhancing accuracy and predictive capacity.

3.2.1.1 Social Capital

The social capital analysis uses the most current indicators available from Rupasingha et al. [51], including organizations and associations, non-profit organizations, and voter turnout. To keep the model parsimonious, an aggregate social capital score per county is calculated. The social capital score consists of the aggregate of the count of organizations and associations, voter turnout, and the number of non-profit organizations. This scale is reliable (Cronbach's $\alpha = 0.67$) and an exploratory factor analysis resulted in a single factor solution (eigenvalue = 1.33) explaining 44.2% of the total variance. Factor loadings are acceptable ranging from 0.442 to 0.837. Each county score of the three indicators was multiplied by its factor loading and summed to represent one social capital score per county.

3.2.1.2 Creative Capital

Creativity and innovation can be difficult to measure and observe. Florida [54] argues that creative communities are the centers of diversity, innovation, and economic growth. Therefore, Florida [54] uses the creative vitality index (CVI) created by WESTAF, which measures the health of the creative economy as it compares to a national index. This multifaceted measure of community creativity includes indicators of level of arts participation (e.g. revenues of arts related goods and services) and occupational employment in the arts. Overall, the index reflects creative economy employment which involves creative thinking, originality, and fine arts. We use the index available for the most current year (2010).

3.2.1.3 Human Capital

Measures of community health are used to represent human capital, as health is an indicator of the ability and skills of a community's workforce. A healthy person is more reliable at work and less expensive for the biorefinery in terms of insurance and time off. The health score includes measures of obesity, low birth weight, premature deaths, adults reporting to have fair or poor health, and counts of physically and mentally unhealthy days per month. The data is from the 2013 County Health Rankings [53], from which we develop a scale reflecting health scores per county. This scale is measured by negative scores, thus lower scores indicate healthier counties overall.

The health scale consists of six indicators, of which three are measured by the National Center for Health Statistics while the other three come from the Behavioral Risk Factor Surveillance System. The six health indicators were found to form a reliable scale (Cronbach's $\alpha = 0.86$) and an exploratory factor analysis resulted in a single factor solution (eigenvalue = 3.17) explaining 52.8% of the total variance. Factor loadings are acceptable ranging from 0.584 to 0.916. For each county, the scores of the individual indicators were multiplied by their respective factor loadings and then summed for one health score per county.

3.2.2 Determining cutoff scores

To determine the levels of human capital, cultural capital, and social capital necessary to increase the likelihood of biorefinery implementation success, we previously conducted a retrospective analysis of community projects within the PNW region [55]. No discernable means were identified for comparing county scores within a category, therefore cutoff scores, or minimum values selected to denote positive capital attributes, were based on regional averages. Communities with values above the regional average are considered more likely to support a new biorefinery. Table 3 provides the average social asset scores by nation, the West, and the PNW. The National score includes all 3,007 U.S. counties, less 632 counties with missing data, located outside the PNW region. The West is a U.S. Census Bureau-designated region, and includes all states from the Pacific Coast, Hawaii, Alaska, Montana, Wyoming, Colorado and New Mexico. The PNW region includes Oregon, Washington, and Idaho, and the twelve forested counties in western Montana.

<INSERT Table 3. Social Capital Scores>

4.0 Results and Discussion

Table 4 presents the biogeophysical results and associated county-level social asset scores. The biogeophysical results indicate that Cosmo Specialty Fibers is best suited as a repurposed biorefinery. Cosmo is a magnesium sulfite mill with similar pretreatment equipment to the design biorefinery, and has a lower electricity rate and delivered feedstock cost than other pulp mills in the assessment. Weyerhaeuser and SP Fiber Technologies follow in rank; while both have reduced delivered feedstock costs and electricity rates, Weyerhaeuser has a higher repurpose potential due to additional infrastructure compatibility with the Greenfield biorefinery. The decision matrix weights heavily favor delivered feedstock cost and infrastructure repurpose potential, indicating that these are large annual expenses the design biorefinery must incur as compared to annual expenditures for electricity or labor. It must be noted that weights and siting criteria will change with biorefinery design.

The individual social asset standard deviations are reported to easily assess whether the capital score for each county meets or exceeds the regional benchmark (highlighted in grey). The human capital measure is a negative index score, with negative standard deviation scores indicating communities that perform better than the regional average. Cosmo and Weyerhaeuser score well in the biogeophysical analysis, yet score low in social asset measures. GP Wauna and Port Townsend Paper Mill have high social assets in all three capitals. While GP Wauna scores fourth due to its lower repurpose potential, the mill scores high in all social assets, thus making it the best location overall for repurposing into a biorefinery. The additional cost to retrofit the pulp mill may be offset by a faster permitting and construction process due to a more collaborative community and healthier workforce.

<INSERT Table 4. Combined Biogeophysical and Social Asset Analysis Scores. Capital Standard Deviations Are Shown in Parentheses. >

The social asset analysis informs stakeholders of the social, creative, and human capital present in a location; however, a biorefinery must procure its annual feedstock demand at a reasonable cost and have access to additional feedstock sources during low-yield years to be successful. Therefore, facilities with high social capital and high feedstock procurement costs, such as Port Townsend Paper Mill and Boise Wallula Mill, would not make good candidate sites for the proposed biorefinery. However, a smaller biorefinery with a lower annual feedstock demand may be successful in these areas. While Cosmo is theoretically the least-cost to repurpose, the top four sites procure biomass at less than \$71/BDMt. The additional cost to repurpose a different pulp mill type may be offset through a facility with high social capital, and thus, potentially lower start-up costs through a supportive community. The Georgia Pacific-Wauna mill may experience an easier transition into a biorefinery than other sites due to the collaborative and creative nature of the community in which it resides.

4.1 Sensitivity Analysis

4.1.1 Biogeophysical Asset Sensitivity Analysis

A biogeophysical sensitivity analysis was performed to determine the effect of feedstock and electricity costs on the criteria weights and resulting ranking of facilities. Feedstock cost is affected by variables such as market demand fluctuations, insect outbreaks, climate change, and advances in logging logistics. A high-feedstock cost scenario was run to determine the increase in feedstock cost each biorefinery may incur during years of low biomass availability. It was found that in regions of high biomass availability (west of the Cascade Mountain Range), feedstock procurement costs remained relatively stable while less productive biomass regions (east of the Cascade Mountain Range) saw an increase in delivered feedstock costs. A low-cost scenario was run assuming the use of a blower for loading ground chips into the chip van, which was found to increase payload by 25% over traditional gravity-fed loading methods [56] (Figure 3).

< INSERT Figure 4. Delivered Feedstock Cost Sensitivity Analysis by Pulp Mill >

The average electricity rate used in the techno-economic analysis (TEA) to determine annual expenses varies based on the defined region. The electricity rate averaged over the counties in which the pulp mills are located is \$0.056/kWh. When the region is expanded to include all counties in the study region, the average electricity rate increases to \$0.071/kWh. In the decision matrix, the regional range of values is used to set criterion bin values, which in turn influences the scale values assigned to a facility based on its location-specific assets. When the region is defined so broadly that all facility assets are grouped into one or two scale values, it reduces the strength of the decision matrix as a facility siting tool. The biogeophysical sensitivity analysis results (Table 5) indicate that variations in feedstock cost do not affect electricity and labor rate weights due to the large expense incurred for feedstock procurement. When a higher electricity rate is used, feedstock and infrastructure weights drop slightly, but are still significantly higher than electricity and labor. Additionally, the ranking of facilities did not change based on the variables assessed in the sensitivity analysis. Labor and infrastructure are not assessed as their values in the TEA are not based on rates or costs that vary geospatially.

<INSERT Table 5. Sensitivity Analysis of Weights for Select Siting Criteria >

4.1.2 Social Asset Sensitivity Analysis

To understand how the selected cut-off points developed from PNW region averages impact results, a sensitivity analysis was performed by adjusting cut-off points based on Census West and National averages. The averages for the West for social capital are lower than the Pacific Northwest region, and National averages are considerably lower than both (Table 3). Creative capital averages are higher for the West and lower nationally, while average scores for human capital are slightly lower in the West and considerably lower nationally.

When adjusting cut-off points based on West averages of each capital, facilities that meet or exceed social and human capital cut-offs do not change. Adjusting creative capital cut-offs reduces the facilities that exceed the cut-off to 4: Georgia Pacific Camas Mill and RockTenn no longer have the necessary cultural capital to be considered. Likewise, adjusting social capital assets based on National averages does not impact the facilities that meet or exceed these assets, while adjusting cultural capital cut-offs adds just one potential facility: Clearwater Paper Lewiston Mill. The human capital adjustment does add 5 facilities that exceed these scores: Rock Tenn, Cascade Pacific Pulp Mill, Clearwater Paper Lewiston Mill, and Ponderay Newsprint Usk Mill.

When utilizing cut-off points based on West or National averages, the facilities with the necessary levels of all three social assets remain unchanged: Georgia Pacific Wauna Mill and Port Townsend Paper Mill. These results show the strength of the measures utilized in the social asset analysis based on PNW averages, and highlight the importance of study region in assessing facilities. While the ranking of facilities in this analysis is not impacted using either the West or National averages as cut-off points, performance on these indicators vary substantially nationally and can considerably skew results. Using national averages could potentially lead to several additional facilities that meet or exceed national social asset performance, but substantially underperform communities based on regional assessment.

Further, initially the study region was divided geographically into the counties west of the crest of the Cascade Mountain Range (here called the C2P region) and the counties in eastern Washington, the panhandle of Idaho, and western Montana (here called the WMC region). These initial regional distinctions were developed based on differences in the regions' population densities: the C2P is more densely populated while the WMC is more rural. These differences impact regional cut-off values in cultural capital (higher in the C2P) and social capital (higher in the WMC). While these regional cut-off values allowed for comparison between facilities in each respective region, it hindered adequate comparison of facilities located in different regions. Cultural capital tends to be higher in densely populated regions due to its focus on creative occupations, while social capital can be higher in rural regions due to the inclusion of non-profit organizations and social organizations, such as churches, which tend to be higher per capita in rural counties. Therefore, regional cut-offs need to be selected that allow for nuanced and robust comparative analysis, while still adequately reflecting the study region of interest. Since few active pulp mills exist in the WMC, we selected the PNW as the study region for all facilities. The social asset scores utilized in this analysis allows for better comparison and assessment of potential facilities while still accounting for regional differences that are better indicators of success between facilities in the region of interest.

5.0 Conclusion

Sustainable and economically viable aviation biofuel supply chains require careful consideration of several assets to make siting decisions that increase the likelihood of success. The proposed biorefinery siting tool improves previous research by incorporating site-specific biogeophysical measures and more comprehensive social measures of community innovation and capacity for collective action. The result is a new, innovative and integrated decision tool that is tested within the PNW and can be applied to other infrastructure projects throughout the U.S.

Social capital represents a community's ability to work together on contentious issues and influence a resolution; creative capital represents a community's ability to develop creative solutions to a problem; and, human capital represents a community's ability to be effective employees. Together, these capitals provide a county-level measure of potential community willingness to accept a new biorefinery through their ability to develop creative solutions to contentious issues surrounding the installment of a biorefinery. When combined with a biogeophysical analysis, it provides insight into each candidate site's potential for added implementation costs due to extra community education or delays from litigation conflicts.

Martinkus et al [9] identified two counties in the WMC region with the combined assets necessary for successful biorefinery implementation: Missoula and Flathead. However, incomplete indicators and the assumption that a site could later be identified within those counties limits these findings. This paper improves that work through more complete biogeophysical and social measures. Thirteen active pulp mills were assessed for their repurpose potential as a lignocellulosic biorefinery through cost-derived geospatial siting criteria. The highest scoring facilities theoretically are the least cost to repurpose and provide the least risk in terms of operational expenses.

Additionally, the social asset components were greatly enhanced by adding additional measures that more fully capture each of the key assets, and disaggregating to individual asset scores which more reliably reflects these assets. Our model more precisely depicts the county-level measures of these capitals, and more accurately predicts implementation success based on these assets. Through this analysis, we narrowed the 13 initial pulp mill sites to one site that possesses the optimal combination of biogeophysical and social assets for siting a biorefinery: Georgia Pacific –Wauna Mill (Clatsop County, OR).

The model presented here uses social asset regional averages as cutoff values for assessing the strength of each capital present in a county, and is one of the first studies to develop robust quantitative measures of these social assets that are available nationally. These measures have been validated through retrospective analysis of multiple community-level projects in the Pacific Northwest [53], and enhance predictive capacity of implementation success for highly technical projects necessitating community collaboration and support. We incorporated standard deviations to illustrate varying degrees of strength. Future work will utilize standard deviations in a retrospective analysis of multiple biofuels-related projects to determine if more refinement can be achieved in assessing a cutoff value for each capital. While full model validation is beyond the scope of this analysis, research is underway to further examine and refine model

assets utilizing biofuel related projects in the PNW and other regions of the United States. Some adjustments will occur when examining other U.S. regions due to differences in feedstocks and facilities examined for potential retrofitting; however, the components of the current model are well-suited to siting decisions in the Pacific Northwest, and only slight adjustments will likely be necessary for projects in other regions. Additionally, a biorefinery siting model that incorporates economic, environmental, and social metrics will be created in a decision matrix form, which will provide a more holistic approach to biorefinery siting.

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Table 1. Comparison of 2014 City/County-Level Model [5] and Proposed Site-Specific Model

Community Assets	City/County Model	Site-Specific Model
Biogeophysical (Natural & Built Capital)	Cities selection criteria: Population greater than 1,000; located within 1.6 km of major road and rail; near large quantities of biomass; near petroleum terminals	Pulp mill assessment criteria: delivered feedstock (biomass) cost; average electricity rate; % reduction in Greenfield construction cost through infrastructure assessments; average weekly wage
Social Capital <ul style="list-style-type: none"> Rupasingha et al, 2006 2009 data used 	# Rent-Seeking Groups: political, labor, professional and business organizations	# Rent-Seeking Groups: political, labor, professional and business organizations # Non-Rent Seeking Groups: civic organizations, bowling centers, golf clubs, fitness centers, sports organizations and religious organizations # Non-Profit Organizations % Voter Turnout
Cultural Capital <ul style="list-style-type: none"> WESTAF 	\$ Average annual revenues of arts-related goods and services based on all revenues between 2002 and 2010	# Arts related organizations # Arts related business # Occupational employment in the arts \$ Revenues of arts related goods and services
Human Capital <ul style="list-style-type: none"> County Health Ranks 	% Self-reports of poor health condition (physically and mentally)	Health: <ul style="list-style-type: none"> % Low birth-weight % Premature deaths % Obese (BMI >30) % Self-reports of poor health condition (physically and mentally)
All counts (#) and amounts (\$) are calculated as a rate of the population per 10,000		

Table 2. Biorrefin

ery Siting Decision Matrix

	<i>Natural Capital</i>	<i>Built Capital</i>	<i>Built Capital</i>	<i>Human Capital</i>
	Total Delivered Feedstock Cost (\$/BDMt)	Electricity (\$/kWh)	Infrastructure: % Reduction from Greenfield Cost	Avg. Wage (\$/week)
Scale				
5	67.8	0.047	45.2	558
4	74.3	0.051	43.4	617
3	80.8	0.055	41.5	675
2	87.2	0.058	39.7	734
1	93.7	0.062	37.9	792
<i>Weight</i>	7.9	2.3	7.6	2.2

Table 3. Social Capital Scores

Asset	National	West	Pacific Northwest (PNW)
	<i>N = 3,108</i>	<i>N = 413</i>	<i>N = 128</i>
Social Capital			
<i>Avg. Score (2009)</i>	0.00	0.04	0.08
Minimum score	-4.29	-3.06	-2.51
Maximum score	23.08	7.88	3.52
Missing counties	40	35	0
Creative Capital			
<i>CVI score (2010)</i>	0.49	0.69	0.57
Human Capital			
<i>Avg. Health (2013)</i>	0.08	-1.43	-1.59
Minimum score	-7.66	-7.66	-6.11
Maximum score	12.50	6.21	2.71
Missing counties	632	82	15
Note: missing values are mostly all counties in Alaska and Hawaii, plus seven counties in Georgia			

Table 4. Combined Biogeophysical and Social Asset Analysis Scores. Capital Standard Deviations are Shown in Parentheses

Biogeophysical Assessment				Social Assessment		
Rank	Site name	Facility Score	County and State	Social Capital	Creative Capital	Human Capital Health
1	Cosmo Specialty Fibers	97.8	Grays Harbor, WA	-0.30 (-0.30)	0.31 (-0.60)	1.49 (1.72)
2	Weyerhaeuser - Longview Mill	75.4	Cowlitz, WA	-0.66 (-0.59)	0.33 (-0.55)	1.67 (1.82)
2	SP Fiber Technologies	71.9	Yamhill, OR	-0.68 (-0.61)	0.51 (-0.14)	-2.88 (-0.72)
4	Georgia-Pacific – Wauna Mill	63.8	Clatsop, OR	0.64 (0.45)	0.99 (0.93)	-2.61 (-0.57)
5	KapStone Kraft Paper Mill	59.6	Cowlitz, WA	-0.66 (-0.59)	0.33 (-0.55)	1.67 (1.82)
6	International Paper - Springfield Mill	56.8	Lane, OR	-0.15 (-0.19)	0.96 (0.88)	-1.62 (-0.01)
7	Georgia-Pacific – Camas Mill	54.8	Clark, WA	-1.29 (-1.09)	0.60 (0.06)	-2.40 (-0.45)

8	Cascade Pacific Pulp Halsey Mill	54.4	Linn, OR	-0.46 (-0.43)	0.30 (-0.62)	-0.71 (0.49)
9	Port Townsend Paper Mill	46.2	Jefferson, WA	1.47 (1.11)	1.51 (2.11)	-2.45 (-0.48)
10	RockTenn	42.5	Pierce, WA	-1.10 (-0.94)	0.66 (0.19)	-0.91 (0.38)
11	Ponderay Newsprint Usk Mill	41.3	Pend Oreille, WA	0.11 (0.03)	0.26 (-0.71)	-0.10 (0.84)
12	Clearwater Paper Lewiston Mill	31.6	Nez Perce, ID	-0.08 (-0.13)	0.53 (-0.11)	-0.79 (0.45)
13	Boise Wallula Mill	29.2	Walla Walla, WA	-0.56 (-0.51)	0.69 (0.26)	-2.25 (-0.37)

Table 5. Sensitivity Analysis of Weights for Select Siting Criteria

	Siting Criteria			
	Feedstock	Electricity	Labor	Infrastructure
High Yield (Low Cost) Delivered Feedstock	7.5	2.4	2.2	7.9
Average Yield Delivered Feedstock	7.9	2.3	2.2	7.6
Low Yield (High Cost) Delivered Feedstock	8.2	2.3	2.1	7.4
High Electricity	7.6	2.9	2.1	7.4

Figure 1

Figure 2 basemap

Figure 4. Delivered Feedstock Cost Sensitivity Analysis by Pulp Mill