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Title: The "Great Hope": Bioenergy in Eastern Oregon and Its Implications for Dry Forest Restoration

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Oregon has been moving forward with biomass energy development. Large-scale biomass power and cogeneration (producing heat and electricity) have been the focus of the last twenty-five years, while small-scale thermal bioenergy installations (producing heat) have dramatically increased during the last decade. In eastern Oregon, bioenergy is closely linked to restoration objectives for dry mixed conifer forests at risk of uncharacteristic high-severity fire. Bioenergy is frequently identified as potentially able to facilitate fuel reduction treatments, while creating renewable energy and rural economic development. However, the relationship between existing bioenergy installations and restoration activities in the region is not well understood, especially through differences of bioenergy types and scales. To fill this knowledge gap, we explore what factors and conditions have enabled the adoption of thermal and cogeneration bioenergy systems in eastern Oregon within the context of regional forest restoration activities. Our study suggests that this "great hope" for bioenergy is dependent on site-specific attributes that interact to influence project outcomes, frequently in ways that complicate forest restoration objectives. While thermal bioenergy systems appear to be more financially, socially, and environmentally feasible, they are limited in their ability to act as a meaningful mechanism to accomplish fuel reduction treatments because of attributes related to scale. In contrast, cogeneration is better able to create an immediate demand for low-quality biomass on the scale that some suggest is needed for restoration,

but is limited in its development because of attributes related to financing and potentially social acceptance. We use a case study approach, focusing on Grant County and drawing selectively from Wallowa and Harney Counties for a regional context.

The “Great Hope”: Bioenergy in Eastern Oregon and
Its Implications for Dry Forest Restoration

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Meagan Louise Nuss, Author

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1 Introduction

> "The great hope was that ultimately we could reduce our dependence on other types of energy, use this renewable resource of energy... [get] 50-100 times less of the particulate pollution parts if you burn it in a facility as opposed to out in the woods... have more jobs, more people working, utilizing, getting this stuff... and if somehow as a miracle... maybe it could even pay for itself and somebody could make a living at a facility."
>
> –id24, conservation advocate

Oregon has been moving forward with biomass energy development. Large-scale biomass cogeneration (producing heat and electricity) and biomass power have been the focus of the last twenty-five years, while small-scale thermal bioenergy installations (producing heat) have dramatically increased during the last decade (Nicholls *et al.* 2008). In fiscal years 2011 and 2012 the US Department of Agriculture's (USDA) largest competitive grants program awarded two $40 million grants to research teams based in the Pacific Northwest to develop liquid fuels sourced from woody biomass (National Institute for Food and Agriculture Newsroom 2011). The state-coordinated Forest Biomass Working Group and several non-profit and forest products organizations also advocate for further development of multiple types and scales of bioenergy across the state (e.g., OFRI 2006; Forest Biomass Working Group 2012; SNW 2013; RVCC and CEFC 2011).

Globally, motivation for bioenergy variously includes rural development, forest products industry diversification, energy independence, and low-carbon energy alternatives (e.g., Domac *et al.* 2005; Nicholls *et al.* 2008; Lippke *et al.* 2011); however, bioenergy's potential contribution to forest restoration has increasingly been highlighted as a primary benefit of such developments in the dry mixed conifer region of the US West (OFRI 2006; Stidham and Simon-Brown 2011; Nicholls *et al.* 2008; Evans and Finkral 2009). One conservation advocate active in the region described bioenergy as representing a "great hope," potentially able to address pressing restoration needs while stimulating rural economies and creating clean renewable energy.

The risk of uncharacteristic high-severity fire events has increased in this region, due to changes in stand structure, density, and species composition (Powell 2011; Hessburg *et al.* 2005; Rainville *et al.* 2008). Fuel reduction treatments that alter stand conditions (e.g., thinning from below or prescribed fire) are common prescriptions to mitigate high-severity fire risk and restore forests to more historic conditions (Stephens *et al.* 2009; Hessburg *et al.* 2005; Brown *et al*. 2004; ERI 2013; Martinson and Omi 2013; Powell 2011). The woody biomass that results from mechanical fuel reduction treatments typically has low commercial value, and is either left on-site to decompose or be burned. The appeal of bioenergy is to stimulate a market demand for this material, thus offsetting the costs of restoration (Nicholls *et al.* 2008; Wynsma *et al.* 2007; Evans and Finkral 2009).

Bioenergy is an umbrella term that encompasses biomass systems with a variety of characteristics, including energy conversion technologies, feedstocks, scales, and end products (McKendry 2001; Buchholz and Volk 2008). Whether a bioenergy project is able to accomplish perceived benefits is dependent on such system characteristics, in addition to contextual site-specific attributes (Cook and Beyea 2000; McCormick 2005). Despite the recent interest in bioenergy as a tool for restoration, few authors have considered how existing bioenergy installations and their conditions in the mixed conifer region relate to high-severity fire risk reduction objectives (for an exception, see Becker *et al.* 2009a). Failure to closely examine current developments will serve to confuse future bioenergy ambitions, and contribute to a poor understanding of what "great hope" bioenergy truly offers to restoration and other regional objectives. Given this knowledge gap, we sought to understand what has enabled the particular types of existing bioenergy installations in eastern Oregon, and what their relationship has been to regional restoration objectives. To these ends, we ask: What factors influence thermal and cogeneration bioenergy adoption in eastern Oregon, within the context of forest restoration objectives in the region?

We use a case study approach for our analysis, focusing on Grant County and drawing selectively from Wallowa and Harney Counties. In the Background section below we introduce bioenergy system characteristics and policies, the ecological setting, restoration considerations and rural economies of the Blue Mountains region in eastern Oregon, and the case of interest. Next, we explain our methodology. In the first Results and Discussion section, we identify five primary factors that influence both thermal and cogeneration bioenergy adoption in the region. In the Factor Interactions and Implications section, we next examine how thermal and cogeneration bioenergy attributes within the five factors relate to each other, and interact to shape implications for restoration and project feasibility. Finally, in the Scaling Up Thermal Bioenergy Results and Discussion section, we extend our analysis to address a question that emerged from study participants and the factor interactions regarding the potential impact aggregated TBE systems could have on restoration. We conclude with Summary and Conclusions. Our study results suggest that the "great hope" bioenergy seems to offer is dependent on site-specific attributes related to the type of bioenergy being developed, and that the five factors interact to influence project outcomes in ways that frequently complicate implications for forest restoration objectives.

2 Background

Due in part to the wide spectrum of bioenergy characteristics and contexts, the literature addresses a variety of factors that influence economic, environmental, and social outcomes of bioenergy projects. Our interest in restoration provides sideboards that focus our attention on specific environmental outcomes, although these are entangled with other types of impacts to an extent. Here we provide a brief background on important bioenergy system attributes, emission considerations, and relevant policy mechanisms. We then focus on dry forest ecosystems in the Blue Mountains of eastern Oregon, restoration trends, and rural economies of the region. Within each of these sections, we highlight aspects of bioenergy attributes and the regional context that the literature suggests are relevant for project implications. Finally, we introduce the case we use to illustrate the relationship between bioenergy developments in eastern Oregon and dry forest restoration.

2.1 Bioenergy Development

Biomass can be converted into useful energy through thermal, biological, or mechanical conversion pathways (McKendry 2001; Bridgwater 2006). Combustion is one of three primary thermal processes, and is widely employed at domestic, small industrial, and utility scales to produce heat and/or electricity. Liquid fuels such as ethanol are primarily produced through biological processes (Solomon *et al.* 2007). In this study we focus on two combustion systems: thermal bioenergy (TBE) and cogeneration (also known as cogen, combined heat and power, or CHP). We also discuss district heating (DH) as a form of distributing thermal energy, primarily addressed in the Scaling Up Thermal Bioenergy section. Our feedstock of interest is woody biomass, which the U.S. Forest Service (USFS) defines as a “byproduct” of restoration and/or management, e.g., tops, limbs, and small-diameter material (Wynsma *et al.* 2007). Below we summarize relevant issues pertaining to bioenergy systems, their emissions, and supportive policy.

2.1.1 Bioenergy Systems

TBE systems burn densified wood pellets, wood chips, or firewood in high-efficiency boilers to heat residential homes, institutional, and commercial buildings (see **Figure 1**)(Emhofer 2012; Nicholls *et al.* 2009; McCormick 2005). Biomass CHP systems produce thermal energy, which is directed through turbines to also generate electricity (see **Figure 2**)(Nicholls *et al.* 2008; ORNL 2009). CHP systems can double the efficiency of a standalone power plant by utilizing excess heat instead of rejecting it (Dovetail 2009). Both TBE and CHP can be designed to provide district heating. Biomass DH distributes heat (and sometimes cooling) to a network of users through insulated piping systems, eliminating the need for a boiler installation in every building (see **Figure 3**)(Vallios *et al.* 2008; Rezaie and Rosen 2012). As a component of CHP, excess thermal energy is distributed to the network while electricity is sent to the grid.

Because TBE boilers only deliver heat on-site, these systems are the smallest form of bioenergy, ranging from less than one million British thermal units per hour (MMBtu/hr) to less than 10 MMBtu/hr (Egger *et al.* n.d.; Nicholls *et al.* 2008). The scale of biomass cogeneration can overlap that of TBE, typically ranging from approximately 3.4 MMBtu/hr to more than 300 MMBtu/hr, or 100 MW. The Biomass Energy Data Book (ORNL 2009) lists 300 MW as an upper capacity limit for biomass electrical generation, but gives examples of greater than 1000 MW when biomass is co-fired with another fuel. Despite such a wide range of CHP applications, constructed facilities tend to be between 20 and 50 MW in the US (ORNL 2009; Cameron *et al.* 2007; McNeil Technologies 2003). DH systems have a wide range of installed capacity; for example, Austria has biomass DH systems that range from small to large (100 kW to greater than 1 MW)(Madlener 2007). Sweden installs more large-scale systems, with approximately 400 wood-fired DH networks with capacities greater than 5 MW (Dovetail 2009; Salomon *et al.* 2011).

While TBE and CHP exist on a spectrum of scales, large-scale bioenergy is more frequently the subject of peer-reviewed literature (Nielsen-Pincus and Moseley 2009; Buchholz and Volk 2008). However, Nielsen-Pincus and Moseley (2009) observe that knowledge about the impacts of project scale is “weak at best” (p.10). Buchholz and Volk (2008) argue that negative bioenergy impacts are more often associated with large-scale systems. They suggest that a systems approach to assessing bioenergy can more accurately reveal tradeoffs related to scale. For example, they note that large and small systems differ in energy consumer locations (regional versus local), financing entities and owners (international versus national), and likely employment (international or regional versus national or local). Larger projects are more complex and subject to uncertainty and risks, and higher investments might suggest a reliance on proven (rather than innovative) technology. Others have also observed that small-scale renewable energy systems in general are more ecologically and socially beneficial, while large-scale systems are typically more economically feasible (Burton and Hubacek 2007; Mirata *et al.* 2005; Mangoyana and Smith 2011). Some note that while more emphasis should be placed on smaller-scale developments, this should be complementary to larger systems (e.g., Johansson *et al.* 2005; Mirata *et al.* 2005; McCormick 2010).

Importantly, there is no defined capacity for what counts as “small” bioenergy. While TBE is the smallest on the spectrum of bioenergy systems, it also exists in a range of applications. CHP can be designed for various capacities as well, and has been referred to as “small” in multiple conflicting contexts. For example, Cameron *et al.* (2007) refer to biomass CHP less than 70 MW as small, while Brown and Mann (2008) consider those less than 20 MW to fit this category. Others discuss CHP at scales substantially smaller than those referenced above; Dong *et al.* (2009) refer to “small-scale CHP” as having electrical power less than 100 kW (3.4 MBtu/hr) and “micro-scale CHP” as systems with electrical capacity less than 15 kW.

2.1.2 Emissions

Like other energy systems using combustion conversion processes, TBE and CHP produce both greenhouse gas (GHG) and air pollutant emissions. GHG emissions are of concern for their contribution to global climate change, while other air pollutants can create adverse health and environmental affects (EPA 2013).

Of the greenhouse gasses, carbon dioxide (CO_2) is the most relevant and contentious for bioenergy. An in-depth analysis of bioenergy carbon impacts is beyond the scope of this paper; however, below we summarize a few salient points regarding this topic. The lower energy density of biomass compared to fossil fuels necessitates that more biomass be combusted to produce an equivalent unit of energy, which results in more CO_2 emitted per unit of energy (Mitchell *et al.* 2009; Cherubini and Strømman 2011). However, ultimate assessments of bioenergy carbon impacts depend largely on research assumptions. The combustion of biomass for energy is frequently considered carbon neutral if the feedstock is sourced from sustainably managed forests, because the same amount of emitted CO_2 is assumed to be re-sequestered during continued vegetation growth (Cherubini and Strømman 2011; Gunn *et al.* 2011; Zhang *et al.* 2010; McCormick 2005). Life cycle assessments (LCAs) with this assumption frequently find bioenergy to be more beneficial than energy sourced from fossil fuels in terms of GHG emissions, even with included emissions from harvest operations such as collecting, grinding, and transporting biomass (e.g., Zhang *et al.* 2010).

However, others argue that assuming carbon neutral combustion ignores harvest impacts to carbon stored in forests, where reductions can significantly outweigh benefits gained from replacing fossil fuels (Mitchell *et al.* 2009; Gunn *et al.* 2011; Hudiburg *et al.* 2011; McKechnie *et al.* 2011). For example, McKechnie *et al.* (2011) integrated an LCA approach with an assessment of forest carbon for the production of cellulosic ethanol and the use of wood pellets for electricity, replacing coal. The authors found that without the calculation of forest impacts, each scenario showed reductions in CO_2 compared to the fossil fuel alternative. In contrast, all scenarios showed an initial excess of CO_2 emissions when harvest-related forest carbon losses were accounted for, only contributing to reduced emissions after a period of time had elapsed for the regrowth of biomass resources. For pellet-generated electricity, emissions were not reduced relative to coal for 16-38 years (depending on whether the biomass was sourced from forest residue or standing trees), while cellulosic ethanol did not lead to reduced emissions for 74-100 years.

While several studies find bioenergy harvests to negatively impact overall carbon stores when forest carbon is included, considerable uncertainty exists with regard to bioenergy sourced from fire-adapted regions. For example, some studies suggest that carbon emissions are minimal to negative in fire-adapted regions like eastern Oregon, where fuel reduction treatments may improve the site's carbon storage capacity (Mitchell *et al.* 2009; Hudiburg *et al.* 2011). In these cases, overall long-term carbon flux depends on the probability of uncharacteristic high-severity fire, the extent and efficacy of fuel reduction treatments, and the likelihood that a state change will occur (e.g., see Restaino and Peterson 2013; Campbell *et al.* 2012; Stephens *et al.* 2012). Disagreement remains regarding the ultimate carbon effect of these and other interactions. Campbell *et al.* (2012) contend that improved carbon storage via fuel reduction treatments is highly unrealistic, regardless of most site details. Others suggest that the role of future disturbance, climate change, and other uncertainties have not been adequately considered to determine carbon impacts (Restaino and Peterson 2013; Stephens *et al.* 2012). Hurteau and Brooks (2011) acknowledge that mitigating high-severity fire events through fuel reduction treatments often generates carbon emissions, but that this represents a tradeoff between short-term maximization of carbon stocks and long-term forest carbon stability.

Bioenergy's contribution to air pollutant emissions results from a complex interaction of several factors, as both the particle size and chemical composition of emissions are affected by the chemical composition of the feedstock, physical properties of the fuel (e.g., moisture content, surface area), type of combustion equipment, and emission reduction controls (Villeneuve *et al.* 2012; Johansson *et al.* 2003; Sippula *et al.* 2009). Consequently, a range of air pollutants can be recorded, depending on site-specific conditions. Bioenergy is typically more advantageous than fossil fuels in terms of sulfur and nitrogen oxide emissions because of low sulfur and nitrogen content in biomass feedstocks (Villeneuve *et al.* 2012; Sippula *et al.* 2009; Zhang *et al.* 2010). However, bioenergy has been criticized for particulate matter (PM) emissions, which can vary (Johansson *et al.* 2003; Sippula *et al.* 2009). For example, Sippula *et al.* (2009) found that fine PM was higher in wood-fired TBE systems than in heavy fuel oil (HVO) boilers, but that HVO systems produced smaller PM. In their comparison of biomass combusted in a TBE system and biomass combusted in harvest slash piles, Jones *et al.* (2010) found the former to have substantially lower CO_2, methane, and PM emissions. Both studies found PM levels in wood-fired boilers to improve with the use of air pollution controls. In addition to air pollution controls, the standardization of wood fuels contributes to improved emissions by enabling more precise boiler designs and combustion (Villeneuve *et al.* 2012).

2.1.3 Supportive Policy

While biomass energy provides more than ten percent of global energy demands, its consumption varies significantly between countries (McCormick 2005). According to Nicholls *et al.* (2009), Finland, Sweden, and Austria lead in bioenergy production internationally. Twenty percent of Finland's total energy production comes from bioenergy, due both to policy instruments (i.e., carbon tax, renewable energy targets, and government-backed research initiatives) and the presence of a strong forest sector. High taxes on fossil fuels have also been key to Sweden's development of bioenergy. The most substantial use of bioenergy in Austria is in domestic heating (i.e., residential and district heating systems), supported by government-backed investment subsidies (Nicholls *et al.* 2009).

In the US, wood energy consumption has fluctuated since the 1970s, responding in part to alternative energy prices and supportive policy instruments (Aguilar *et al.* 2011). By 2007, biomass (including biofuels, waste, and woody materials) contributed 53% of all renewable energy consumption in the country, and 3.7% of total energy consumption (ORNL 2009). Most national renewable energy policy instruments have targeted power generation, primarily through tax incentives, bonds, and state Renewable Portfolio Standards (RPS)(Aguilar *et al.* 2011). Becker *et al.* (2011) evaluate policy instruments that target biomass utilization by what stage in the supply chain is addressed, and find that most target manufacturing and consumer markets through a diversity of mechanisms similar to those identified by Aguilar *et al*. (2011). The authors list Oregon as among the states with the most biomass-related policy instruments, which include cost-share and grants, technical assistance, bonds and loans, procurement mandates, rules and regulations, and tax incentives. Oregon's RPS was established in 2007, and mandates an incremental increase in renewable energy up to 25% total energy consumption in 2025 (ODOE n.d.-b). Notably, while a renewable energy mandate has also been established for liquid fuels on the national level (e.g., US Department of Energy 2011), no such equivalent exists in Oregon or nationally for thermal energy. New Hampshire became the first state to establish a renewable energy standard for thermal energy with Senate Bill 218 in 2012 (BTEC 2012).

In Oregon, TBE systems have seen the most growth among bioenergy projects over the last decade, jumping from two school installations in 2009 to nineteen facilities by 2013 (ODOE Energy Plan 2013). Systems include installations in schools, hospitals, commercial buildings, and a USFS building, all but one fuelled by wood pellets. About half of these projects are located east of the Cascade Crest (ODOE n.d.-a). Nineteen biomass cogeneration facilities exist in the state, all co-located with a forest products manufacturing site and primarily located west of the Cascades (Biomass Project List 2011; ODOE n.d.-a). Of the nineteen facilities, ten are operational (as of fall 2013), and six were constructed in the last decade. Oregon also has one standalone biomass power facility.

2.2 Forest Restoration in the Blue Mountains

Forestland in eastern Oregon lies primarily in the 5.5 million acres of the Blue Mountains, which is composed of the Wallowa-Whitman, Umatilla, and Malheur National Forests (Rainville *et al.* 2008). As shown in **Figure 4**, these National Forests cover substantial portions of Grant and Wallowa Counties, less so in Harney County. We introduce the forested ecosystems of the Blue Mountains National Forests and discuss biomass utilization as a restoration tool to frame the regional environmental context of existing bioenergy developments. In addition, we include a discussion of rural economies in relation to natural resource utilization in the US West as a background for the socioeconomic characteristics relevant to our case.

2.2.1 Ecological Setting

The Blue Mountains are home to grasslands, woodlands, and mixed conifer forests across a gradient of elevation and moisture availability (Powell 2011). Dry mixed conifer forests occur at low to moderate elevations and are the most common in the region (Powell 2011; Rainville *et al.*

2008; Hessburg *et al.* 2005). These forests represent a range of cover types, including ponderosa pine (*Pinus ponderosa*), grand fir (*Abies grandis*), white fir (*Abies concolor*), and Douglas-fir (*Psudotsuga menziesii*); however, they are well-documented as historically dominated by ponderosa pine through the presence of frequent low- to mixed-severity wildfire (Hessburg *et al.* 2005; Agee 1993; Powell 2011; Franklin and Johnson 2012; Brown *et al.* 2004). Agee (1993) defines low- and mixed-severity fire as occurring every 1-25 years with less than 20% basal area mortality and every 25-100 years with 20-70% basal area mortality, respectively, although Hessburg *et al.* (2005) note that dry western forests tend towards the low end of mixed-severity fire behavior. The Blue Mountains Forests Revised Land and Resource Management Plan (BMF Revised Plan 2010) categorizes 60% of the three national forests as dry forest, which falls within Rainville *et al.'s* (2008) estimation of 40-75% for the same region.

Of the mixed conifer forests, dry forests have had the greatest departure from historic conditions (Powell 2011; Hessburg *et al.* 2005; Brown *et al.* 2004; Stephens *et al.* 2009). Fire suppression, grazing, timber harvesting, and plantation establishment during the late 19th and early 20th centuries have contributed to a transformation of the open park-like landscape characteristic of the dry forests into dense multi-storied stands, typically composed of fire-intolerant species (Powell 2011; Hessburg *et al.* 2005; Rainville *et al.* 2008). The BMF Revised Plan (2010) establishes desired conditions for the three national forests based on the historic range of variability according to a variety of criteria, and observes significant changes in forest structure, composition, and available fuels (see **Table 1**). The vertical and horizontal structural arrangement of vegetation influences wildlife habitat, insect and disease susceptibility, wildfire hazard, scenic integrity, and potential social and economic potential (BMF Revised Plan 2010). In forests, structural stages are represented by stand initiation, stem exclusion, understory re-initiation, old forest multi-story, and old forest single-story. The BMF Revised Plan states that the existing level of understory re-initiation (multi-layer stands from 5 to 20 inches diameter breast height [DBH]) is substantially higher than desired conditions, while the extent of the old forest single-story structural stage (single-layer stands with an overstory generally greater than 20 inches DBH) is substantially less than desired conditions.

Similarly, dry forests have exhibited the most dramatic shift in species composition, with an increased dominance of grand fir on sites historically dominated by ponderosa pine. Finally, higher levels of multi-layered stands have contributed to increased stand density and decreased average tree diameters compared to historic conditions. As wildfires in the US West have increased in size, frequency, and severity (Westerling *et al.* 2006; Miller *et al.* 2009), current stand conditions make dry forests increasingly vulnerable to high-severity fire events (Powell 2011; Hessburg *et al.* 2005; Rainville *et al.* 2008; Franklin and Johnson 2012; Stephens *et al.* 2009; Agee 1993). While dry forests likely historically experienced high-severity fire behavior at small scales (Hessburg *et al.* 2005; Stephens *et al.* 2013; Stephens *et al.* 2012), the BMF Revised Plan (2010) observes that the risk of stand-replacing wildfire has increased from a desired state of 5-15% of the dry forest landscape to 40-60%.

2.2.2 Biomass Utilization as a Restoration Tool

Given the state of dry mixed conifer forests and the increasing risks of uncharacteristic stand-replacing fire, the US Forest Service has explicitly aimed to "increase the pace and scale of restoration on the national forests" (USDA FS 2012, p.3). The agency estimates that more than 65 million National Forest acres are at high or very high risk of stand-replacing wildfire, of which 12.5 million require mechanical treatments (USDA FS 2012). Fuel reduction treatments that alter stand conditions are common methods to reduce the risk of high-severity fire (Stephens *et al.* 2009; Hessburg *et al.* 2005; Brown *et al*. 2004; ERI 2013; Martinson and Omi 2013; Powell 2011). Such treatments aim to remove small-diameter trees that have encroached in the understory of dry forests in the absence of frequent fire. Creating a market demand for biomass utilization, such as supplying a bioenergy facility, is commonly cited as critical to expanding the scale of restoration treatment by offsetting treatment costs (Becker *et al.* 2009b; Aguilar and Garrett 2009; Nicholls *et al.* 2008).

The literature suggests a number of factors that are important in biomass to energy projects within this restoration context. For example, the Oregon Forest Resources Institute (OFRI 2006) highlights eight barriers to development: supply issues, lack of supportive public policies, public acceptance and trust, institutional issues within the federal agencies, market access, technical issues, costs, and potential negative environmental impacts. Below we briefly discuss issues related to accessing biomass supply.

Several bioenergy assessments conducted in Oregon begin with estimates of physically available biomass, often calculated by referencing fuel reduction treatment levels (e.g., OFRI 2006; McNeil Technologies 2003; Rainville *et al.* 2008; Nicholls *et al.* 2008). These studies vary in their areas of interest, assumptions of yield, and other parameters, but generally conclude that a large amount of biomass material physically exists. OFRI (2006) reviewed literature on woody biomass supply at national, regional, state, and sub-state scales, and found that 0.8 – 12.7 million bone dry tons are annually available as a byproduct of fuels reduction treatments. That study also developed its own analysis of biomass availability based on fuel reduction treatments across 20 eastern and southern Oregon counties that are classified as having high fire risk. They found that 20 million bone dry tons is available from 4.25 million acres of eligible forestland, more than 70% of which is publicly owned. In an analysis of biomass available from current fuel reduction treatments on forestlands in the three most northeastern Oregon counties, McNeil Technologies (2003) determined that more than 200,000 bone dry tons could be supplied per year.

Physically available biomass is further constrained by the economic feasibility of accessing the material. Costs associated with biomass harvesting, collecting, and transportation have been identified as one of the most significant barriers to utilization (Becker *et al.* 2009b; Aguilar and Garrett 2009; Nicholls *et al.* 2008). For example, Rainville *et al.* (2008) filtered their assessment of available biomass from treating overstocked stands in the Blue Mountains by the amount that would be commercially viable to remove, including an assumption of harvested saw-logs alongside biomass residuals. Under their basic assumptions, the authors found that only about 10% of the overstocked acres could be profitably treated. Nicholls *et al.* (2008) observe that the value of biomass rarely pays for the cost to harvest and transport the material. They note that energy and chip markets have historically paid $25 – 35 per ton, while thinning small-diameter material typically costs $70 per ton. Davis *et al.* (2012) suggests hand thinning, piling, and burning costs $300 – 900 per acre, Becker *et al.* (2009b) estimates that average costs of mechanical harvesting can exceed $1000 per acre, and Han *et al.* (2004) state that in general, mechanical harvesting costs increase as tree diameter size decreases. Longer transportation distances are also conventionally considered to financially hamper biomass utilization projects, although these costs are not necessarily prohibitive (Becker *et al.* 2009b; Evans and Finkral 2009). Some cite this transportation factor as motivation to build decentralized systems closer to supplies (e.g., Gold and Seuring 2011; Becker *et al.* 2009a; Aguilar and Garrett 2009; Dovetail 2009)

The social availability of biomass, in addition to the social acceptance of bioenergy as a form of biomass utilization, creates another constraint on biomass supply. While the physical availability of biomass may be known, its social availability more often is not (Becker *et al.* 2013; Shindler 2009). Becker *et al.* (2013) define social availability as “that portion of total physical availability accessible in the marketplace after accounting for social factors influencing landowner propensity to harvest” (p.83). While the authors investigate the social availability of biomass from non-industrial private forestlands, the notion holds for harvests on public lands as well. Shindler (2009) explains that social acceptance of activities on public lands matters because “objective science” rarely is the sole driver of decisions; rather, individual and collective values play an important part. Additionally, all American citizens have a right to affect federal land management because they are the ultimate owners, and unsatisfied stakeholders can – and often do – resort to litigation (e.g., Brown and Webb 2012). The lack of long-term supply agreements has also been linked to a lack of socially available biomass and trust among stakeholders, which can limit utilization by constraining industry’s capacity to invest in new markets (Stidham and Simon-Brown 2011; Becker *et al.* 2009a and b; Moseley and Davis 2010; Nicholls *et al.* 2008).

Utilizing biomass for bioenergy involves another layer of social acceptance. McCormick (2010) warns that local communities can organize to prevent the implementation of even technically, economically, and environmentally robust projects, and also argues that the wider “political legitimacy” of bioenergy can be damaged by public concerns and popular media. Similarly, Upreti (2004) documents public opposition as one of the major obstacles to promoting biomass power plants in the United Kingdom. In their case study of stakeholder perspectives on biomass harvesting for energy in Oregon, Stidham and Simon-Brown (2011) found general support for bioenergy. Notably, "virtually all" respondents discussed bioenergy in terms of forest restoration rather than energy generation. These authors and Nielsen-Pincus and Moseley (2009) both observe that environmental organizations are likely the most cautious towards bioenergy developments.

Collaborative processes and stewardship contracts are two mechanisms that have been identified as facilitating biomass supply for market utilization (e.g., Schultz *et al.* 2012; Stidham and Simon-Brown 2011; Shindler 2009; Moseley and Davis 2010; NFHR 2012). According to Schultz *et al.* (2012), the increasing costs and frequency of fire was the primary driver of the Collaborative Forest Landscape Restoration Program (CFLRP), which was established by Congress in 2009. Objectives of the CFLRP include promoting ecological, economic, and social sustainability, leveraging local resources, reducing the risk of uncharacteristically severe fire, and supporting local economies (Schultz *et al.* 2012). Projects that qualify for federal funds through the program must be based on a landscape restoration strategy, be developed and implemented through a collaborative process, and demonstrate how restoration byproducts will be utilized to support local economic development. Collaborative groups have been fairly successful in Oregon; eight currently operate east of the Cascade Crest, including one each in Grant, Wallowa, and Harney Counties (NFHR 2012). Becker *et al.* (2009a) observe that collaboratives take many shapes, and that formal organizations are needed "when the challenges to [biomass] utilization are significant and complex" (29).

Stewardship contracts have also been cited as a tool to accomplish active restoration and stabilize supply to encourage industrial investment (Moseley and Davis 2010; Schultz *et al.* 2012; Stidham and Simon-Brown 2011). Moseley and Davis (2010) provide an extensive review of the variety of stewardship contracts and their implementation in western national forestlands, and suggest their use is still new and rapidly evolving. Stewardship contracts are aligned with collaborative objectives to facilitate forest restoration while providing economic benefit for local communities. In their various forms, such contracts have enabled more flexible projects that are awarded based on "best value," and provide for reinvestment back into restoration services. The authors additionally emphasize that stewardship contracts do facilitate biomass availability, albeit without a guarantee of supply.

2.2.3 Rural Economies

Importantly, each of the strategies to overcome active restoration barriers described above prioritizes benefits to local rural economies alongside ecological objectives (e.g., USDA FS 2012; Moseley and David 2012; Schultz *et al.* 2012; Becker *et al.* 2009a; NFHR 2012). A growing body of literature suggests that the rural western United States is a shifting landscape, and describe a heterogeneous pattern of declining extractive industries, mobile amenity-seeking migrants, and opportunities for new ways to utilize natural resources (Robbins *et al*. 2009; Winkler *et al.* 2007; Power and Barrett 2001; Slee 2009; Hibbard *et al*. 2012). Implications for rural community wellbeing remain complex and varied. For example, Power and Barrett (2001) challenge the common assumption that declining production-oriented industries (e.g., mining, logging, and agriculture) have wrought economic disaster on communities. They point out that while such industry declines have been apparent since at least the 1970s, overall employment, income, and population in the Mountain West during the same period has increased; in fact, it was the fastest growing multi-state region during the last half of the twentieth century in the entire country. The authors argue both that depressed earnings in the region largely reflected trends in the national economy, and that individuals were moving into the region for an improved quality of life. They conclude that the shortfall in pay is offset by attractions like high amenities of rural living, lower cost of living, scenic beauty, and recreation, and that these amenity-seeking migrants represent a new economic relationship to natural resources. Winkler *et al.* (2007) also acknowledge that quality of life motivations seemed to dominate migration decisions during the last two decades, however they note that places with attractive settings tended to fare better (e.g., adjacent to national parks, along waterways, and near mountain peaks). They conducted a spatial analysis of communities based on the degree to which they exhibited qualities of an amenity-oriented economy (dubbed "New West"), and confirmed that employment in extractive industries (an "Old West" characteristic) was inversely related to these. While they found that the New West phenomenon was widespread throughout the region, about two-thirds of the communities they assessed scored as Old West. Their results suggest that a substantial number of rural communities in the region remain linked to traditional production-oriented natural resource use.

Other studies have also reported diverse effects on communities as a result of declining production-oriented industries. For example, Charnley *et al.* (2008) studied socioeconomic impacts of declines in federal harvests instigated by the Northwest Forest Plan (NWFP). They found that effects varied based on a number of factors, but that between 1990 and 2000, communities within five miles of a federal forest scored the lowest on their socioeconomic wellbeing index. Weber and Chen (2012) complicate this data in their analysis of communities adjacent to NWFP-affected forests, in which they classify communities as “non-logging” (less than 5% employment in farming, forestry and fishing), “intermediate” (5-10%), and “logging” (greater than 10%). They found that intermediate and logging communities were negatively affected during the 1990s, but that this effect disappeared in the 2000s.

These mixed results suggest both that the presence of traditional industries is not unwaveringly tied to rural community wellbeing, and that some communities are more dependent on them than others. Despite his critique of the industry/wellbeing relationship, Power (2005) notes that communities isolated from metropolitan areas with limited transportation infrastructure and reliant on industries with declining employment opportunities confront serious economic challenges. Hibbard *et al.* (2012) argue that most resource-dependent communities are struggling with losses of primary production in conjunction with continued degradation of natural resources. These authors suggest a middle ground, positing that rural communities require (and are creating) “new natural resource economies” (or NNRE) that embrace production-, consumption-, and protection-oriented economic activities. They share perspectives documented elsewhere that insist mechanisms to sustain healthy communities can coexist with those that sustain healthy forests (e.g., Kelly and Bliss 2009; Nielsen-Pincus and Moseley 2013). For our purposes it is notable that the authors specifically include biomass energy within the NNRE, and cite Grant County as representative of some NNRE elements.

2.3 The Case: Bioenergy in Grant County

We chose Grant County in which to situate our case study for its relevance to bioenergy and dry mixed conifer restoration in the state. We also drew from Wallowa and Harney Counties for a regional perspective. Grant, Wallowa, and Harney Counties share several similarities in these and other regards (see **Table 2**). Public land ownership composes a large portion of each county's land base. In addition, each county has substantially fewer people per square mile than the state average. Furthermore, each county is losing population; Grant and Harney are two of three Oregon counties categorized as having high outmigration for the last two decades (defined as 10% or higher population loss from net migration) (USDA ERS 2014). The three counties are all older than the state and national average, and whiter. Unemployment and poverty rates are higher, while medium household income and college graduates are lower. Percent employed in agriculture, forestry, fishing and hunting, or mining is substantially higher than in the rest of Oregon and nationally. Finally, they are more isolated. The USDA Atlas of Rural and Small-Town America created an Urban Influence Code as a 12-scale classification based on metro/micro/nonmetro status, location, commuter trends, and size of the largest place in a given county (USDA ERS 2014). Grant, Wallowa, and Harney Counties are designated as 12, 10, and 11 on that scale, respectively, indicating their low degree of connectivity to metropolitan centers.

These counties have led the state in bioenergy installations. Grant County's experience in particular has been referenced as a "successful model" of bioenergy developments in Oregon (Dovetail Partners 2013). Beginning in 2009, four TBE systems have been installed in the county: at a new county airport, one hospital, and two public schools. A pellet manufacturing plant built in 2010 by the last sawmill in the county complements these projects, as well as a recently idled 10 MW CHP facility. Harney and Wallowa Counties have also been front-runners of bioenergy adoption in the state, with the first TBE system in Oregon installed in a Harney County hospital in 2008, and the first TBE system in an Oregon school installed in Wallowa County later that same year. Additionally, one small CHP integrated with a forest products manufacturing facility is near completion in Wallowa County.

In addition to their advancements in bioenergy, Grant, Wallowa, and Harney Counties each have established collaboratives that work to enhance forest and watershed health while benefitting local economies. The Blue Mountain Forest Partners (BMFP, established in 2006) is based in Grant County, and together with the Harney County Restoration Collaborative (HCRC) was awarded funds through the CFLRP in 2012 (BMFP n.d.). The study identifying Grant County as a "successful model" of bioenergy in the state additionally refers to BMFP as crucial to the success of the biomass cluster, further indicating the connection between biomass utilization for energy and active restoration activities in the region (Dovetail Partners 2013). However, the study does not elaborate on this relationship beyond documenting the collaborative's role in securing a biomass supply for the local pellet plant on critical occasions.

Figure 1: Example of a thermal bioenergy system, which produces heat. In this example, an auger feeds densified wood pellets into the combustion chamber. TBE systems are the smallest form of bioenergy, and are designed to burn very efficiently.

Image: hargassner.net.

Figure 2: Example of a biomass cogeneration system, which produces heat and electricity. Thermal energy is directed through turbines to generate electricity. Utilizing excess heat can double the efficiency of a standalone power plant.

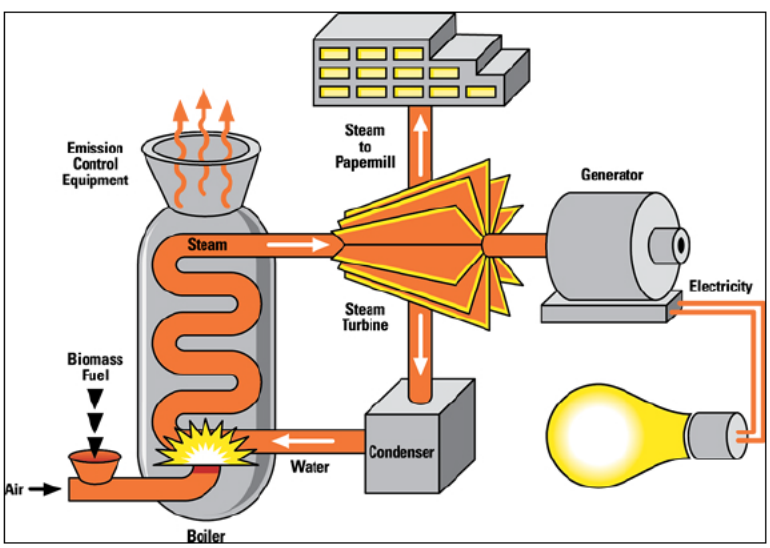


Image: www.we-energies.com.

Figure 3: Example of a district heating system. District heating distributes heat (and sometimes cooling) to a network of users through insulated piping.

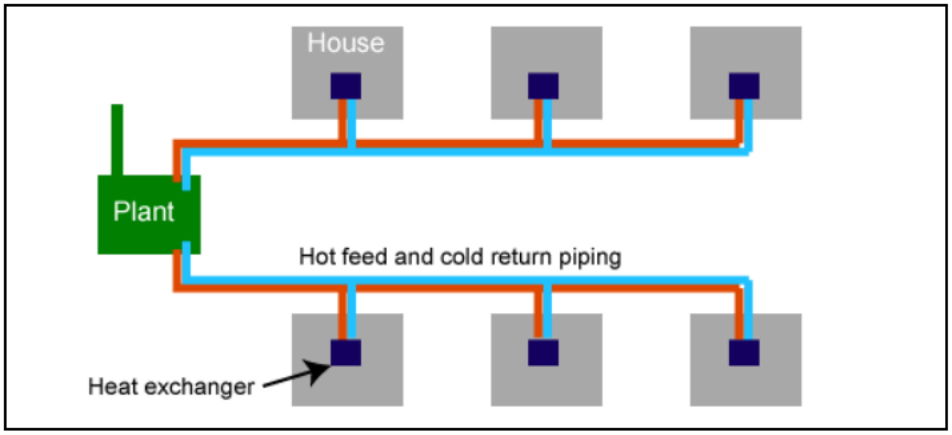


Image: http://www.greenspec.co.uk/biomass.

Figure 4: National forests in the Blue Mountains of eastern Oregon. Grant, Wallowa, and Harney Counties are outlined.

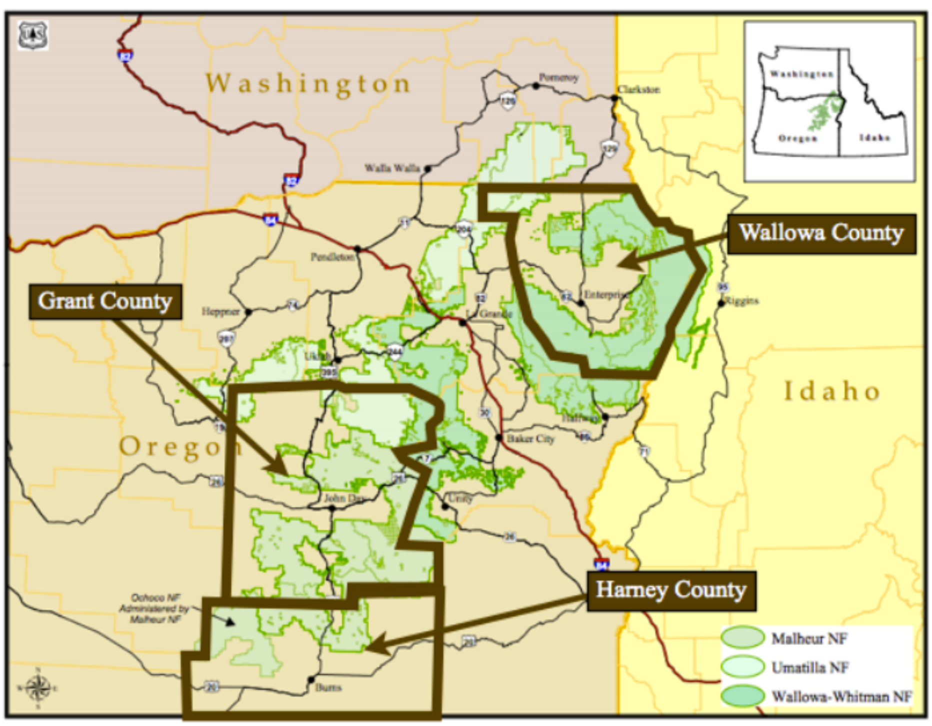


Table 1: Current conditions of the dry forest group in the Blue Mountains compared to desired conditions. Here the Blue Mountains include the Wallowa-Whitman, Umatilla, and Malheur National Forests.

Select Characteristics of the Dry Forest	Desired[a]	Current[a]
Old forest single-story	40-60%	<5%
Understory re-initiation	5-15%	52%
Abies grandis dominated forest type	1-10%	51%
High stand density[b]	5-15%	54%

Source: Adapted from BMF Revised Plan (2010).
[a]Desired and current conditions are expressed as the percent of the landscape.
[b]High stand density is classified as greater than 60% of the maximum stand density index, which can also be equated to about 40% canopy closure in the dry forest group.

Table 2: Select socioeconomic data for Grant, Wallowa, and Harney Counties in comparison to Oregon and the United States. All data are for 2012 unless otherwise noted.

Variable	Grant	Wallowa	Harney	Oregon	US
Population size	7,317	6,821	7,212	3,831,073	308,747,508
Population density (persons per square mile)	1.6	2.2	0.7	39.9	87.4
Population change 2000-2010	-6.1	-3.0	-2.4	+12.0	+9.7
Percent of population under age 18	18.5	18.2	21.6	22.1	23.5
Percent of population 65 or older	25.5	25.1	20.8	14.9	13.7
Percent Non-Hispanic White	92.5	94.2	88.9	77.8	63.0
Unemployment rate	13.4	10.2	12.6	8.1	8.5
Poverty rate, 2011	17.2	16.0	19.1	15.5	14.9
Median household income, 2000-2010	$34,337	$40,204	$39,674	$50,036	$53,046
Percent college graduate or higher, 2008-2012	17.5	22.3	15.7	29.2	28.5
Percent employed in agriculture, forestry, fishing and hunting, and mining 2006-2010	15.0	14.9	18.9	3.4	1.9

Source: USDA ERS 2014, United States Census Bureau 2014, and United States Census Bureau 2006-2010.

3 Methodology

Case studies aim to develop a well-rounded understanding of a current phenomenon in its real-world context by investigating an illustrative case (Yin 2003; Berg and Lune 2012; Creswell 2007). Our phenomenon of interest is development of bioenergy in eastern Oregon, and we purposefully selected bioenergy projects in Grant, Wallowa, and Harney Counties collectively as our illustrative case. Case studies can and often do rely on quantitative and qualitative data triangulation, in which multiple data collection methods and data sources are cross-referenced to develop a more objective "compelling whole" (Creswell 2007, p204; Berg and Lune 2012; Yin 2003). We collected empirical evidence using participant observation and key informant interviews, and additionally drew from existing secondary sources such as Census data and available national forest assessment data. Our data analysis includes transcribing interviews and observations, coding transcriptions and inductively developing factors of adoption through data themes, and using secondary sources to analyze potential forest impacts of scaling up TBE applications in Oregon.

By nature of our research approach, our findings are as much a representation of our own interpretation of data as they are reflective of study participant perspectives (Creswell 2007). While the purpose of triangulation is to ensure study dependability, it is useful to provide a brief explanation of our own interests inasmuch as they are relevant to the genesis of this research. The first author has studied bioenergy-related topics for more than four years, focused primarily on cellulosic ethanol and thermal bioenergy, and more recently on biomass cogeneration. She relates to rural economies through her own childhood visiting family in northeastern Oregon, where her father was raised. Her original interest in eastern Oregon bioenergy developments stemmed from excitement at the potential opportunity for previously conflicted stakeholders to find common ground through forest restoration. This early perspective shaped initial research objectives to explore what has enabled bioenergy development in the region. It was not until mid-way through data collection that it became clear bioenergy's relationship to forest restoration is not straightforward, which prompted a more in-depth investigation into the different types of bioenergy and their respective implications. We offer this evolution of our own understanding of bioenergy's role in the region because it is representative of the reflexive approach we have taken to check the biases and frameworks that we bring to this work.

3.1 Data Collection

Participant observation is a data collection method most frequently used in ethnographic studies (Yin 2003; Creswell 2007). The researcher may act in a range of roles, from an outside observer to an active inside participant. The method enables researchers to gain insights that would otherwise be difficult to observe from a distance. Relationships with study participants provide both insider information, and a closer experience to the actual phenomenon of interest. Qualitative research values the deeper and "thicker" understanding that accompanies being embedded in the study's context (Creswell 2007). Being so positioned also creates challenges; for example, the investigator may lose sight of broader research objectives and take on an advocacy role, which can undermine scientific integrity (Yin 2003). A researcher may also become so busy participating, that s/he has little time to make observations. These and other challenges require researchers to consistently practice reflexivity, and to depend on the triangulation process. For our study, participant observation data was collected between summer 2012 and winter 2013. During this time, the lead author attended more than a dozen community and educational events relevant to the research topics, including collaborative meetings and field trips, a town hall meeting, bioenergy and renewable energy conferences, and workshops. She also rented a room and lived in Grant County for 4.5 months. Observation notes were written and audio recorded daily.

Interviews are another important form of data collection in qualitative research (Yin 2003; Berg and Lune 2012; Creswell 2007). Interviews can be effective at gaining information that other methods cannot accurately capture; for example, when a topic of interest is nuanced or not well defined, a survey composed of predefined and closed questions is not likely to uncover useful data (Berg and Lune 2012). Yin (2003) describes interviews as more of a "guided conversation" than a structured query (p.89). Interview questions can be formally structured and consistently asked, semi-structured with leeway to adjust to the content of each conversation, or unstructured with no set order or form to questions (Berg and Lune 2012).

We purposively selected our interviewees using a snowball sampling technique, whereby we began with known individuals and learned of more potential interviewees as the study progressed (Yin 2003; Berg and Lune 2012). A Portland-based non-profit organization working in the region provided an initial list of stakeholders involved in bioenergy developments. These individuals were contacted for study participation, and were asked to suggest additional potential participants who might represent different opinions from their own. Interviews were semi-structured around participant perspectives of bioenergy context (e.g., economic, environmental, and social drivers, existing obstacles), distributed economies (e.g., the role of scale, the dissemination of bioenergy as a concept), and accomplished objectives (e.g., bioenergy's role in objectives, possible ideal futures). We adapted our interview guide to the particular expertise of each interviewee, and adjusted questions over time to refine our data collection and respond to current events in our area of interest. Interviews took place in offices, coffee shops, restaurants, and homes, and lasted between 45 minutes and 3 hours. Interviewees signed a consent form permitting audio recording and providing the option to have their identities remain confidential. Although only three participants opted for confidentiality, we refer to all interviewees by an assigned identification number and title based on their self-described position.

Twenty formal interviews were conducted and recorded with individuals from the Blue Mountain Forest Partners (BMFP) collaborative, forest products industry, project champions, non-profit organizations, county government, US Forest Service (USFS), conservation groups, Oregon Department of Forestry (ODF), community members, and one bioenergy developer (see **Table 3** and **Appendix A**). "Project champion" refers to primary advocates for TBE installations. Interviewee experience with bioenergy in the region was varied, some heavily involved with TBE or cogeneration research or implementation, and others more indirectly involved through their participation in forest management issues. This range of experience was solicited to gain depth in understanding bioenergy adoption from different perspectives. However, we interviewed more individuals representing the local collaborative and the forest products industry, which may bias our results towards these groups.

3.2 Data Analysis

Data analysis had both an on-going and concentrated element (Creswell 2007; Berg and Lune 2012). Throughout the study, the primary author engaged in a reflexive process of questioning and ground-truthing her observations and interpretations within the context of the case. This involved heavy note-taking, conversations with individuals in the field, and reference to existing peer-reviewed and secondary data. Following data collection, interviews and researcher notes were transcribed and uploaded into the data management software NVivo (QSR International, Version 9). In NVivo, transcripts were first coded using and open coding method, by which segments of text are labeled with nodes (or tags) that reflect aspects of the text content (Strauss 1987; Berg and Lune 2012). The NVivo program designates a "node" as a noun, and "code" as a verb. The central purpose of open coding is to find meaning in the text content by making a wide, unrestricted inquiry of the data (Strauss 1987). Assigned nodes were aggregated into a preliminary database that organized text evidence within a tentative framework. Coding was primarily conducted inductively, and was also deductively informed by literature regarding distributed economies, new natural resource economies, and scale. Following the open coding of all interview transcripts, we refined the preliminary node framework by conducting multiple intensive coding iterations for all transcript sources. Our final node framework had over one hundred nodes categorized under four primary content topics: bioenergy development, community development, forest health, and markets (see **Appendix B**).

We analyzed the detailed node framework for underlying themes by using computer software query tools. We began by running queries that pulled data coded as "driver" or "challenge" to identify key aspects of a bioenergy project. This text was manually analyzed for co-occurring nodes and relevant themes. Queries were expanded based on additional identified nodes. Retrieved text evidence was manually sorted under primary themes and sub-categories in Microsoft Excel, represented as factors that influence bioenergy development. This process generated a list of primary factors and supporting attributes linked to data evidence, refined through many iterations of queries and manual analysis. The final result identified five factors that directly and indirectly influence bioenergy adoption in eastern Oregon. These five factors were ranked according to the number of times each factor was referenced, which was calculated by summing the number of references each factor attribute was referenced (including both interview and participant observation sources). We also counted the number of interviewees (out of twenty) who referenced each factor. See **Appendix C** for a more detailed explanation of this coding analysis process.

Table 3: Representative categories of interviewees.

Representative Category	Number of Interviewees
Blue Mountain Forest Partners collaborative	10
Forest products industry	5
Project champion	4
Non-profit organizations	3
Local government	3
US Forest Service	2
Conservation organizations	2
Oregon Department of Forestry	2
Community	1
Bioenergy developer	1
TOTAL*	20

*Total does not add because study participants fall into multiple categories.

4 Results and Discussion

For many in eastern Oregon, bioenergy represents a synergy of possible benefits that revolve primarily around the facilitation of fuel reduction treatments for restoration (Stidham and Simon-Brown 2011). One conservation advocate active in the region described bioenergy as representing a "great hope," potentially able to address pressing restoration needs while stimulating rural economies and creating clean renewable energy. Our study suggests that this "great hope" for bioenergy is dependent on site-specific attributes that interact to influence project outcomes, frequently in ways that complicate forest restoration objectives. To understand these dynamics, we first identify five primary factors that influence thermal and cogeneration bioenergy adoption in eastern Oregon in the Factors of Adoption section. In Factor Interactions and Implications, we discuss how attributes both shared and unique to the two types of bioenergy interact to shape implications for restoration and project feasibility. Finally, we use available secondary data to extend our analysis in the Scaling Up Thermal Bioenergy section, addressing a question that emerged from study participants and factor interactions regarding the potential impact that aggregated thermal bioenergy systems might have on regional fuel reduction targets.

4.1 Factors of Adoption

We identified five factors that contribute to the adoption of thermal and cogeneration bioenergy in eastern Oregon: supply availability, social acceptance, financing, forest sector considerations, and scale (defined in **Table 4**). While the data suggests all factors are relevant to both TBE and CHP projects, attributes of each factor differentiate the two types of bioenergy and ultimately influence their implications for forest restoration. The data also indicate that the five factors are highly interrelated, so delineating boundaries between them is to some extent arbitrary. However, we address each factor individually to aid in clarifying the components suggested by the case as important in bioenergy adoption in eastern Oregon. We discuss them below in order of most mentions by study interviewees.

4.1.1 Available Supply

Available biomass supply refers to the magnitude and accessibility of raw biomass material. This factor received the most number of mentions, from every interviewee. The factor applies to both TBE and CHP inasmuch as they both ultimately rely on biomass availability as a raw material.

4.1.1.1. Magnitude

Our study participants widely agreed that a large quantity of biomass is generally available in Oregon. An ODF Stewardship Forester, for example, perceived federal forests to have "just an untold vast supply out there that we seem to be burning up every summer in wildfires" (id16). Similarly, a private forestry consultant who is also involved with the BMFP collaborative said that supply is not a problem for cogeneration facilities: "it's not a supply issue at all, we've got the supply" (id22). The timber manager of a pellet plant in Grant County acknowledged supply as a potential challenge for biomass markets, but expressed little concern over it:

> "The other [concern] is raw material, supply. But in reality there is plenty of it on the national forest. Raw material supply, even if we put another [pellet] machine in, would not be a problem." –id02, timber manager

A few study participants described biomass availability in Grant County by referring to an assessment conducted by the Blue Mountain Forest Partners in collaboration with local USFS staff for the Malheur National Forest (BMF 2010). The study used stand structure as a proxy for forest health, and calculated the effect that various levels of treatment would have on future fire impacts and stand conditions. According to the study, 40,000 to 60,000 acres would need to be treated on the Malheur National Forest (MNF) per year to get ahead of continued structural change and degrading conditions, or 20,000 to 30,000 acres on the ground (assuming 50% of project acres are actually treated). At this level, 100,000 to 150,000 green tons of biomass would be produced per year. One interviewee described the inadequacy of the current level of active restoration on the MNF, based on the study's findings:

> "If...we've got a 1.7 million acre forest out there, with maybe 1.2 million forested acres, and we're only actively managing at 10,000 acres a year on the ground,

> we're going backwards, essentially. We'll never get there. We'll never effectively restore this forest." –id18, collaborative participant member

4.1.1.2 Accessibility

The previous section describes interviewee perspectives on the extent to which biomass material exists in Oregon and our region of interest. However, as noted by Becker *et al.* (2013), not all physically available biomass is accessible. Our study participants referred to several mechanisms that assist in making biomass accessible, including social acceptance and collaborative and stewardship contracting tools.

4.1.1.2.1 Social Acceptance of Active Restoration

The social acceptability of active restoration in dry mixed conifer forests on public lands represents one relationship between the social acceptance and supply factors. We discuss this attribute here as it reflects the social availability of biomass supply. Nearly two-thirds of our study participants expressed support for fuel reduction treatments aimed at restoration. Additionally, while references were made to individuals who prefer that no action be taken on federal lands, none of our interviewees personally advocated that position. As found in other studies, this support was widely predicated on an understanding of degraded forest conditions and a risk of high-severity fire (e.g., McCaffrey and Olson 2012; Stidham and Simon-Brown 2011). For example, a county commissioner opened our interview by stating his fear of an imminent stand-replacing fire as a result of the extent of forests at high fire risk:

> "I'm scared to death... The potential of a catastrophic fire anywhere in our forest is extreme... if we have a fire it's gonna be catastrophic. And that will do no one any good. And I'm concerned." –id07, County Commissioner

More than half of our interviewees also favored fuels reduction treatments for economic values. For example, the manager of a non-traditional mill integrated with a small CHP unit described active management and biomass utilization as beneficial for avoiding both environmental and social waste:

> "...[I]n the sense of a wasted opportunity to have natural resource utilization that creates jobs and energy and other things, but also the potential waste of our watershed health, whether it's creating fire danger or reduced wildlife [habitat]... And so to me when you look at those environmental issues and then tie it to the societal issues of the waste... it's easy to become way more passionate about it because all a sudden you have five different things that are all drivers, that are all related." –id12, manager of non-traditional mill

Endorsement of active restoration was not without qualification and criticism. For example, two conservation advocates were among a few interviewees who emphasized that they considered active management to apply to specific ecological circumstances. One such individual took issue with what she saw as an overgeneralization of all eastern Oregon forests as historically having frequent fire regimes, and therefore requiring biomass removal for restoration. She emphasized that biomass removal is:

> "...a unique situation for dry ponderosa pine-dominant sites, I don't think it's appropriate for the moister mixed conifer... The majority of the forest is actually mixed severity fire regime mixed conifer... and then there's areas as you move further north, clearly moist mixed conifer that's naturally a stand-replacement, infrequent fire regime. Those sites are completely inappropriate to do biomass as far as I'm concerned." –id14, director of conservation non-profit

In the fuels treatment literature, it is often noted that guidance for appropriate restoration is less clear where interactions of fire, weather, and fuels are more complex, as in moist mixed conifer and mixed-severity fire regimes (e.g., ERI 2013; Martinson and Omi 2013; Hessburg *et al.* 2005). The least is known about these ecosystems, owed in part to classification challenges and broad effects of mixed-severity fire (Agee 1993; Hessburg *et al.* 2005; Brown *et al.* 2004; Merschel *et al.* in press). Further complicating the issue, recent research suggests much of what is now considered moist in the mixed conifer region likely shared many functional characteristics with dry sites, e.g., frequent low- to mixed-severity fire events and low-density stands (Hagmann *et al.* in press; Merschel *et al.* in press). While only a few of our study participants highlighted this issue, they represent a view likely held by other conservation-oriented groups (Nielsen-Pincus and Moseley 2009); as such, it is a critical perspective to consider when focusing on biomass utilization from public lands.

Study participant views about dry forest conditions and active management informed their opinions regarding a need for a biomass utilization market, which was favored by almost all our interviewees. More than half of these mentions specifically referenced a market as a mechanism to offset costs and help finance restoration activities. As described by the former county judge, it became "increasingly clear if we want to do what we need to do on the federal lands, we need to create a market [for biomass] and develop capacity" (id27). Similarly, a US Forest Service staff member for the Malheur National Forest explained that getting involved with bioenergy:

> "[W]as really about the economics of doing fuels treatments on national forests lands, and that there was no market for a lot of that, and it was in some cases very expensive to get out of the woods. And yet it was really needed for restoration."
> –id23, MNF staff member

Notably, a handful of interviewees pointed out that it didn't matter to them how the biomass was used – it only mattered that it be utilized. These comments seem to support Stidham and Simon-Brown's (2011) observation that "at its foundation, forest biomass utilization is a forest restoration issue in Oregon, rather than an energy issue" (p.204).

4.1.1.2.2 Collaborative and Stewardship Contracting Tools

In addition to a biomass market, another US Forest Service employee at the Malheur National Forest identified both collaborative and stewardship contracting tools as necessary to make bioenergy work:

> "Gotta have a foundation, a collaboration. You've gotta have creative stewardship contracting tools, the tools with which to be able to cut and remove and deliver that material to industries. And then you have to have industries that are viable, such as a pellet plant, a shaving plant, compressed wood bricks or whatever, that can utilize that material and make a profit from it." –id10, MNF staff member

Several of our interviewees (most involved with the BMFP) viewed stewardship contracting and collaboratives together as tools to mitigate budget, policy, and litigation constraints imposed on normal USFS operations. The USFS staff member quoted above said their Forest was recently able to bring fuels reduction treatment costs from $1,000 or $1,300 to $97 per acre because of available biomass markets and stewardship contracting – which, he added, was "just unheard of" (id10). A recent case study assessing the benefits of utilizing harvested small-diameter biomass material rather than piling and burning it showed a similar, though less dramatic, cost reduction (Davis *et al.* 2012). The study found that treatments with biomass utilization cost $296 per acre, just shy of the low end of the estimated cost for typical hand thinning, piling, and burning ($300-900). The authors note that the demonstration project would work well where stewardship contracting can be applied.

More than half of our interviewees described collaboratives as facilitating active management on public lands by building common ground and increasing capacity. Common "zones of agreement" were valued by a number of interviewees for contributing to increased trust and relationships. For example, the director of an environmental non-profit expressed value in the collaborative process, despite no longer being a member:

> "We've been improving relations and understanding between people substantially. So I still go to meetings and try to influence them, and I still get a lot of respect from even timber industry people, and do have some influence."
> –id14, conservation advocate

The local collaborative was also credited with increasing the accessibility of biomass supply through streamlining the project implementation process, conducting or participating in forest and market assessment initiatives, and gaining regional and national exposure for the county. Like other anecdotal evidence (e.g., NFHR 2012; Nielsen-Pincus and Moseley 2013), one collaborative member told us "there's no question about it that the collaboration process has been a very important and valuable contributor of improving the efficiency and productivity of the planning phase" (id18). However, study participants also noted the limits of stewardship contracting and collaborative tools. Prominent among these were their limited ability to make systematic changes. For example, the collaborative member quoted above went on to note that efficiencies gained in project implementation were still "not near enough" to facilitate the needed level of activity (id18). USFS budgets, delegated by Congress, were also recognized as constrained beyond the influence of either mechanism.

4.1.2 Social Acceptance

Attributes that affect the acceptability of bioenergy production, in addition to active restoration as discussed above, compose the social acceptance factor. This factor had the second highest number of mentions, and was also referenced by every interviewee. Study participants identified a number of bioenergy attributes as contributing to or detracting from their perceptions of bioenergy acceptability, with little differentiation between TBE and CHP energy generation. Here we address study participant perceptions about bioenergy acceptance as it relates to education and awareness, carbon and air quality impacts, and scale of utilization.

4.1.2.1 Education and Awareness

Perhaps reflecting their positions as state employees, both ODF study participants commented the most on the role of government initiatives in promoting bioenergy education and awareness. The Stewardship Forester, who had helped initiate the Biomass Working Group, said that "education [is] paramount... you could have the best mousetrap in the world but if nobody's buying into it, you're not going anywhere" (id16). At a lecture series on biomass energy, a senior policy analyst for the Oregon Department of Energy (ODOE) also described the need for better education on bioenergy systems because of their unique and complex interactions with land management (Krumenauer 2013). Interviewees who discussed bioenergy awareness often suggested that if people had a fuller understanding of the multiple potential benefits of bioenergy (e.g., facilitating fuel reduction treatments and contributing to local economies), they would be more apt to support development. For example, the ODF Biomass Specialist suggested that people don't generally understand biomass, but would support it if they did:

> "One of my operating principles is that if people understood it more [and] better, they would support it. Hence why I do what I do." –id32, ODF Biomass Specialist

Additionally, one conservation advocate said that if people understood the "premise" of bioenergy, they would be more likely to say "why not utilize [biomass] if we can? And make some energy out of it, and maybe it offsets some other energy source" (id24).

Finally, half of our interviewees discussed the importance of increasing the number and distribution of successful TBE models to encourage bioenergy awareness. The ODF Biomass Specialist noted that with almost twenty systems now installed across the state, the "densification of examples" has helped spread the concept to more people (id32). Indeed, each of the project champions we spoke to either referred to existing TBE systems as influencing their decision to pursue a project, or to others inquiring about their system to learn more about conversion options. These individuals described the value of being able to see for themselves TBE systems in action that were generating savings. The bioenergy developer responsible for the four systems in Grant County called this effect "social proof," in which would-be project champions can "kick the tire" of an operating installation (id05). Another project champion's comment that "you'd be stupid not to do [a TBE conversion]" is powerful evidence that successful projects can create a cultural impact as adoption spreads (id17). Conversely, as observed by two of our interviewees, models that have been less than successful can be challenging to overcome. One of the project champions of the first wood chip TBE system in the state acknowledged that the early challenges they experienced have made some people "a little gun shy" to move forward with bioenergy projects, despite their system generating immediate and substantial energy savings (id03).

4.1.2.2. Carbon and Emission Impacts

One conservation advocate observed that, in addition to understanding the "premise" of bioenergy, considerations of carbon impacts and sustainable supply would also need to be clarified to facilitate widespread social acceptance. In our case, there was little agreement among study participants about whether bioenergy has a positive, negative, or neutral affect on carbon (regardless of energy type). As discussed in the Background section, the literature also offers conflicting reports on the topic (e.g., McKechnie *et al.* 2011; Zhang *et al.* 2010; Campbell *et al.* 2012; Hudiburg *et al.* 2011; Hurteau and Brooks 2011). Regardless of the prevailing consensus, it was noted by a few individuals that public opinion about carbon impacts could stymie future bioenergy development. The non-profit executive director expressed his concern that the positive potentials of bioenergy could become lost in higher-level debates about climate change and carbon:

> "I think too often... the specifics are lost in generalities [in] things that can be nationally legislated, and then the fact that we have all these unhealthy stands, we've got this massive increase in wildfire, we've got this massive slash burning program, and so we have uncontrolled emissions that far exceed what we would do, and we could convert a lot of that into controlled emissions, you know with much much much more benign emissions profile – that's all gonna get lost, possibly, in these big national policy discussions about the Clean Air Act and climate change and carbon. I think [that] would be terrible."
>
> –id03, non-profit executive director

At the time of our data collection, the National Emissions Standards for Hazardous Air Pollutants for Area Sources (NESHAP) was being reviewed for boilers, including those using biomass fuels. While a few interviewees expressed some concern that standards might be overly strict for TBE, they also acknowledged this was unlikely for systems of their size. NESHAP was finalized December 2012, and is summarized as it concerns bioenergy in **Table 5**. According to the rules, boilers smaller than 10 MMBtu/hr (which covers all TBE systems in this study) are only required to conduct biannual tune-ups; larger systems such as new CHP will additionally have to meet particulate matter emission standards (US EPA n.d.). This likely reassures TBE enthusiasts like the executive director above, at least regarding air quality associated with bioenergy. Social and scientific opinion on carbon, however, is still uncertain, and the executive director may be right to be concerned. For example, despite his long-time efforts to promote certain bioenergy applications for their role in fuel reduction treatments, the conservation advocate quoted above acknowledged that:

> "[I]f peers and the science papers and everything show yeah [bioenergy is] bad because of this, this and this [carbon impact], and this is so bad that it's gonna offset any kind of other positives, than fine... I would change my position."
>
> –id24, conservation advocate

The individual's comments suggest that even those who have promoted bioenergy in the past might retract their support depending on outcomes of the carbon debate.

4.1.2.3 Scale of Utilization

A final aspect of social acceptability relates to an acceptable scale of biomass energy utilization. Several interviewees described a general preference for small-scale biomass facilities, believing these to be more flexible and sustainable while being less financially risky. For example, the same conservation advocate quoted above described smaller facilities as better able to respond to fluctuations in supply:

> "Because that way, to me if you did overdue it, you wouldn't have to shut down a 30 MW thing, you could just shut down a 5, or a 7 MW. Or, [if you've] got a whole bunch more [biomass], you can add a 5 MW, but... there's not enough to add another 35 MW." –id24, conservation advocate

Implicit in the above comment is a concern for overbuilding a bioenergy industry and overextending demand. Acknowledging these fears, the ODF Stewardship Forester commented that some in the environmental community think of bioenergy as "a black hole in space, just sucking every cell of wood fiber off the landscape." He went on to say that this characterization has some merit, "if we're not intentional and deliberate about what we're doing" (id16). In their review of social issues of woody biomass utilization, Nielsen-Pincus and Moseley (2009) also suggest that environmental groups are likely to be skeptical of bioenergy development and only cautiously supportive. Indeed, of the references to this topic, the two conservation advocates interviewed provided the most input. The director of a conservation non-profit active in forest management issues described her concerns in terms of the eventual tradeoff between the supply required to maintain a large facility and increasing costs as supply is located further away:

> "I'm very concerned about if there's a biomass plant sited somewhere and it's too big, very soon it will have stripped the available material that we would want removed, which is a lot of small trees in the case of dry ponderosa pine that have grown in since the last logging... And after a certain amount of going around in a radius around that site,... it no longer is energy efficient to bring in material from beyond that circle. So then you'd wanna come back to that area again, and I'm

afraid that it would be depleted too fast, and then depleted too much."
–id14, director of conservation non-profit

Becker *et al.* (2009a) also observed a preference for smaller facilities for both increased flexibility and a reduced likelihood of depleting the resource. The authors noted that smaller facilities were thought to create more benefits for the local community, and would be generally more acceptable to a wider array of stakeholders. Notably, concerns raised in this research regarding bioenergy scale were not about prohibiting all development, but rather about what the appropriate scale of utilization is. For example, the interviewee quoted above identified the pellet plant in Grant County and the presence of one or two cogeneration plants in central Oregon as "not a big risk" and "probably ok," respectively, regarding the demand they place on natural resources. "The problem," she went on to say, "is there's a whole bunch of other [CHP plants] on the books now that would compete" for supply (id14).

4.1.3 Financing

Financing received the third highest number of mentions, and was discussed by all but one interviewee. Like any development project, financing bioenergy facilities involves considering costs and potential sources of funding, including available policy instruments. Here we classify these attributes as 1) capital and operating costs and 2) funding mechanisms. Thermal and cogeneration bioenergy largely differed in their financing factor attributes.

4.1.3.1 Capital and Operating Costs

Several interviewees observed that high upfront costs of both types of bioenergy installations can be a deterrent to implementation, particularly for TBE systems. Of the six operating TBE systems included in this study, capital costs were just under $300,000 to over $1.5 million, with a range of boiler capacities, technologies, and additional energy efficiency renovations included (see **Table 6**). A review of other TBE facilities in the state with publically available funding data indicates that this price range is typical (see **Appendix D**). TBE installation costs can range from three to ten times more than a fossil fuel commercial boiler installation (A. Haden, pers.

communication, 12/13/13), which can be daunting for rural communities with shrinking populations and uncertain futures.

Unappealing high upfront costs were also attributed to cogeneration facilities. Sessions *et al.* (2013) suggest capital costs for biomass cogeneration facilities range from $2 to $5 million per MWh. A recently constructed 20 MW CHP plant in western Oregon falls within this range at $60 million, 25% of which went to emission control technology (Payne 2013). A smaller 1.5 MW facility in southern Oregon cost $6 million in capital costs, on the high end of the spectrum (Phillipi 2012).

Tradeoffs between capital efficiency and transportation costs limit the optimal scale of a biomass utilization facility (Cameron *et al.* 2007; Jenkins 1997; Dornburg and Faaij 2001). A facility with larger volume requirements must travel further to secure adequate supply, which can drastically affect costs (Becker *et al.* 2009b; Aguilar and Garrett 2009; Han *et al.* 2004). Several of our interviewees highlighted this constraint on raw material procurement, noting that costs increase as the distance traveled increases. They suggested that one method to mitigate transportation costs is to develop distributed or decentralized facilities in close proximity to the supply, and frequently included scale as a consideration. For example, one private forestry contractor who had been involved with a business strategy to develop a cogeneration plant in Wallowa County cited transportation costs as motivation to distribute biomass plants across the region:

> "The closer [a biomass plant] can be located to the source of material, the better. So the material in Wallowa County needs a plant here to absorb it. We could maybe... truck it to [the next county over], but if you get transportation too far, I think it's better off having another small plant there. So keep them community-ized I guess is how you'd want to say it." –id13, private forestry contractor

Similarly, a staff member for the Malheur National Forest posited that "to-scale" cogeneration facilities could be strategically situated in communities "where you have a close proximity of biomass that could be utilized to decrease the haul distances" (id10). In their analyses of forest sector professionals' perspectives on biomass utilization, both Aguilar and Garrett (2009) and

Becker *et al.* (2009a) confirm that local and decentralized processing facilities are often cited as structural strategies to minimize transportation costs.

The same distance limitations do not appear to apply to a TBE consumer and their fuel provider. While three interviewees did suggest that some upper limit exists in which it is no longer cost effective to ship pellets, a few others observed that energy cost savings can far outweigh the cost of transporting processed wood fuel. The bioenergy developer responsible for the four TBE systems in Grant County explained that sourcing fuel from a county or two away might result in a $20 or $30 increase per ton; "but that's only, say, 10 or 15% of an increase in your fuel bill. Not a 150% increase, which would be if you go back to propane" (id05). The project champion of the first Oregon TBE system illustrated the insignificance of transportation costs compared to energy cost savings by calculating an extreme case of fuel procurement:

> "We just did the 'lets get really stupid' calculation and we were going to use 40-lb sacks of pellets imported from Connecticut, so instead of $200 it's $400/ton...That means that your heating bill goes from $10,000 a year to $20,000 a year. It's nothin. It's nothin. [Because we were spending] probably about $100, $150,000 a year." –id11, project champion

Decentralized fuel processing and energy generation facilities were not without their caveats, particularly in relation to scale. As described by a few interviewees (including both the owner and the timber manager of two different pellet manufacturing plants), processors focused on local markets require adequate local demand to remain viable. Commenting on the limited number of pellet customers in the region, the timber manager told us:

> "If you're going to concentrate on trying to have smaller local production facilities like ours, than you need [TBE customers] clustered around them to help support that facility." –id02, timber manager for forestry products facility

4.1.3.2 Funding Mechanisms

According to our data, TBE and CHP funding options differ markedly. Both, however, are strongly driven by the cost and availability of competing energy options, which determines the extent to which they are each dependent on favorable policy mechanisms.

4.1.3.2.1 Alternative Energy Options

As was expressed by many of our study participants, TBE is unable to compete with the low price of natural gas. In contrast, interviewees cited rising and volatile costs of petroleum-based fuels as creating conditions where biomass is economically attractive. Three project champions and a bioenergy developer made the most references to this factor in relation to TBE. The executive director of a non-profit that helped to instigate the first TBE installation in an Oregon school described the role of alternative energy options in eastern Oregon as follows:

> "You know these are all places that natural gas is not being delivered to, I'm pretty sure. And so in the absence of having access to natural gas, and if you're burning oil, the price of heating oil has gone up astronomically. So that has to be a motivator for people." –id03, project champion and non-profit executive director

Natural gas supplies over half of Oregon's heating needs across all sectors, while petroleum-based fuels provide 10.3% (Remington *et al.* 2012). Remington *et al.* (2012) note that while petroleum-based fuels are a relatively small source of thermal energy in the state, it is likely that the bulk of their consumption occurs outside of natural gas utility service territories. As shown in **Figure 5**, this tends to encompass rural areas away from major travel corridors, including much of eastern Oregon. The competing energy trends described by our study participants can be clearly seen in **Figure 6,** which shows the price of no. 2 heating oil, propane, and natural gas for residential use in the U.S. between 1991 and 2013 (reported in 2014 US dollars). Since 2000, the price of heating oil and propane has increased by over 100% and 40%, respectively, while natural gas price has decreased slightly (US EIA 2014). Heating oil and propane have fluctuated in price by as much as 26% since 2008. In 2009, the price of wood pellets was between $16 and $20 per MMBtu, just below the lowest price of heating oil (Reeb 2009). Additionally, according to one TBE annual report, the price of biomass wood chips has declined by 24% since 2008

(McKinstry 2012). This comparison of alternative energy trends illustrates the cost benefits of utilizing biomass when replacing petroleum-based fuels for heating.

In addition to the rising cost of petroleum-based fuels, a few study participants cited the long-term risk of fossil fuel availability as a motivating factor in considering a TBE conversion. The project champion of the first TBE system in the state framed his decision to explore biomass heating in terms of this long-term risk assessment:

> "[We] would talk about the future of energy. The future of stuff. And I came away from those conversations convinced that, you know, oil wasn't gonna last, and if it was gonna last it was gonna be more expensive, and if it was more expensive, than all other conventional sources would be expensive."
> –id11, project champion and hospital CEO

The ODF Stewardship Forester discussed a similar perspective he shared while talking to a university president about converting their facility from natural gas to biomass:

> "I said everything about this university is based on natural gas. What happens if the pricing gets out of hand? What happens if something happens to the supply? And two, three, four, five years ago before 9/11 or any of that stuff, everybody thought every day we'll flip the switch, the price will always be good, the supply will always be there. That might not always be the case."
> –id16, ODF Stewardship Forester

These last sentiments speak powerfully to bioenergy's potential to contribute to energy security, especially in isolated areas where biomass is widely available. It also ties to the value interviewees placed on utilizing local resources, which we discuss in the Forest Sector section.

Biomass CHP systems market both heat and electricity, both of which can be particularly challenging sales. In a study commissioned by the Energy Trust of Oregon, for example, all respondents of wood burning bioenergy facilities reported that the price of power and the power purchase agreement (PPA) were a difficult or severe problem (n=6, Itron 2004). This finding was largely confirmed in our case. Several study participants were quick to point out that biomass-sourced electricity cannot currently compete with the region's cheap electricity rates, which presents a stark contrast from TBE's market opportunities. The Northwest Electric Region has historically had the lowest electricity rates in the nation, with an average cost of $35.24/MWh in 2009 (FERC 2012; PNUCC 2010). Historically low natural gas prices have compounded the region's typically cheap electricity, with relatively low electric rates experienced nation-wide since 2009 (FERC 2012). In contrast, a 2007 International Energy Agency (IEA) factsheet on cogeneration estimates biomass electricity rates at $40-90/MWh, noting that costs can vary widely because of a range of feedstock characteristics and conversion technologies. The 2006 OFRI report projects biomass power to cost $.09 – 0.13/kWh when sourced from forest residues versus $0.03 – 0.07/kWh when sourced from mill residues; both cases were deemed not competitive with wholesale electricity prices of $0.03 – 0.06/kWh at the time. Nicholls *et al.* (2008) also observe that biomass electricity is relatively inefficient when compared to hydropower or wind, contributing to higher prices. One community member, who was intimately involved with attempts to locate another cogeneration plant in Grant County, sums up many study participants' views on selling biopower with the following statement:

> "You've gotta be able to sell your electricity at a price which, off the top of my head, is like eight or nine cents a kilowatt-hour or something like this. And you ain't got a snowball's chance of doing that." –id18, community member

Given the challenging electricity market described above, nearly half of our interviewees emphasized the importance of securing a heat demand with an appetite large enough to consume a facility's excess energy. A private forestry consultant who had come close to constructing a CHP plant in Wallowa County said the cheap price of power necessitated an adequate heat user:

> "The trick to making [a bioenergy] plant successful is you had to have another plant or some kind of a factory or facility next to it that would buy the heat. Because the heat is the by-product. If you think you're gonna build one of these plants and generate electricity and pay for it, in my personal opinion and what I found out, it won't work." –id13, private forestry consultant

Many of these individuals noted that co-locating a CHP facility with a forest products processing site could often provide such a demand. In the words of a former county judge involved with researching cogeneration options in Grant County, "it becomes a lot more cost effective as you look at is as a complement to a timber mill, a sawmill, because of the steam and the power needs that they can use" (id27). This relationship seems to hold in Oregon, where only one standalone biomass power plant is in operation. We elaborate on the relationship between bioenergy and the forest products industry in the Forest Sector section.

Interestingly, four individuals suggested that electricity generated from biomass ought to be valued at a higher rate because of the associated benefits that could come from it. For example, one conservation advocate reasoned that if CHP can accomplish restoration goals by facilitating fuel reduction treatments, than paying more for electricity generated from such facilities should be viewed as reinvesting in forest health after decades of degradation:

> If "the preponderance of the people think [biomass cogeneration is] a good thing to do, and we have our way, then I don't mind putting a little money into it. It just seems like that's kinda reasonable, we invest back in the forest we took so much from." –id24, conservation advocate

Similarly, the ODF Biomass Resource Specialist argued that the appropriate price for biomass energy should internalize the externalized benefits that can come from active management in the woods:

> "The [best-case scenario]... is some sort of reliable, stable price signal that incorporates the ecological and carbon benefits of biomass energy into the price. And a price signal that understands that the active management of forests provides a significant number of common goods and public goods which have a value, which raise the price of that energy product."
> –id32, ODF Biomass Resource Specialist

Finally, the former county judge of Grant County described paying higher prices for cogenerated biomass electricity as getting out of the "consumer mentality that cheaper's always better," and into "the ecosystem sort of conversation" that recognizes a synergy of benefits arising from one action (id27).

Mason *et al.* (2006) demonstrate a similar perspective as these four individuals in their quantitative analysis of the public costs and benefits of hazardous fuel reduction treatments. After accounting for such variables as firefighting costs, fatalities, timber resources, community risk reduction, and wildlife habitat, the authors approximate net benefits of treatments as greater than $1,400/ac for forests at high risk of fire, and $600/ac for forests with moderate risk. Like our interviewees above, the authors conclude that a full accounting of costs and benefits would place a higher value on fuel reduction activities, and mechanisms that facilitate them.

4.1.3.2.2 Policy Instruments

The economic competitiveness of thermal bioenergy at least where natural gas is not available suggests that such projects are not necessarily dependent on favorable policy funding mechanisms. Their high up-front costs relative to conventional boiler systems, however, do warrant a closer inspection of project payment schemes.

According to our case data and available information on other TBE systems across Oregon, policy instruments have played a variable role in financing TBE projects in the state. **Table 6** shows that three of the six projects in our case relied substantially on grant or tax incentive funding, while two of the remaining three have received smaller grants after project completion. Of the six additional facilities included in **Appendix D**, all but one project reportedly received a large portion of funding through grants or tax incentives. The federal American Recovery and Reinvestment Act (ARRA) stimulus package and state Business Energy Tax Credit (BETC) stand out as dominant funding sources, both of which have since sunsetted (see ARRA 2014; Kuehl 2010).

TBE project champions interviewed in this study most frequently identified energy cost savings as a mechanism to mitigate high capital costs. For example, one project champion and school board member recently involved in converting her school to biomass explained that the school was projected to realize savings between $75,000 and $80,000 per year compared to heating with propane, which would “more than make the payment on the biomass [loan]” (id17). **Table 6** shows that the TBE systems included in this study reported savings ranging from $10,000 to

$100,000 per year, slightly higher than those included in **Appendix D**. Potential energy cost savings is a product of the magnitude of the heat demand (higher use indicates higher savings compared to expensive fuel sources), and the selected wood fuel (wood chips are cheaper than wood pellets).

In addition to grants, incentives, and energy cost savings, a few interviewees explained that "creative financing" was sometimes used to pay for a project. In our case, this usually meant securing a Qualified Zone Academy Bond (QZAB) and private equity contribution. The US Department of Education provides QZABs, or noninterest-bearing bonds, to school districts with eligible low-income populations (United States Department of Education 2005). The two schools that converted to pellet systems in Grant County both depended primarily on QZAB loans and a 10% match from the local mill in the form of a long-term reduced pellet price, rather than substantial grants or incentives. One case example and five of the additional six installations leveraged a low-interest QZAB loan along with grants and incentives (see **Appendix D**).

These examples of TBE funding mechanisms indicate that policy instruments have been helpful, and potentially essential, for several projects in the state. Paying for high up-front costs may be particularly challenging for rural communities struggling with high poverty rates and declining populations. However, the most recent TBE conversions suggest that policy instruments may not be critical. This would be especially true if heat demand is high, and potential project champions are willing and able to locate low interest bonds or loans.

In contrast to thermal bioenergy, the region's rich electricity resources force CHP facilities to rely on favorable policy to be financially feasible. However, many of our interviewees described current policy instruments as inadequate to support CHP development, especially compared to other renewable energies like wind and solar. As discussed in the Background section, Oregon established a Renewable Portfolio Standard (RPS) in 2007 that includes biomass as an eligible feedstock. An ODOE website documenting Oregon's mix of power sources, however, reports that the two largest electricity providers secure only 0.56% and 1.6% of their energy from biomass (ODOE n.d.-c). Oregon's third largest power provider lists biomass as fulfilling 12.6%

of its RPS obligations in its first compliance report (EWEB 2013). Confirming study participant suspicions, wind energy had a substantially larger market share in these power mixes than bioenergy (although EWEB may be an exception). These conditions also confirm observations elsewhere that national RPS programs tend to advance wind and solar generation more than biopower, and that biopower is less economically competitive than wind (Aguilar *et al.* 2011; Nicholls *et al.* 2008). Furthermore, study participants frequently noted that another limitation of the RPS mechanism is its success. A senior ODOE policy analyst reported that regulated utilities have fulfilled their obligations up to the year 2021 (Krumenauer 2013), which suggests the policy-driven market for renewable energy is saturated. A Malheur National Forest staff member described the limited RPS market in conjunction with the lack of a traditional market as a significant roadblock for biomass cogeneration development in Oregon:

> "As long as power is cheap in the Pacific Northwest, I think it's the biggest challenge we have going. Oregon state Renewable Portfolio Standards, those have been capped out. Our projections are it'll be 10 years before we hit a window of opportunity again where those can be expanded or utilized again."
>
> –id10 MNF staff member

The recently passed California Senate Bill 1122 may offer a model for adjusting existing policy mechanisms to better accommodate biomass, particularly as an element of forest restoration. The Bill requires that 50 MW of electricity in the state be procured from new small-scale bioenergy plants that specifically source material from fuel reduction treatments in areas deemed at high fire risk (see DSIRE 2012). Eligible facilities will fetch a higher price for their generated electricity under California's RPS rules. Additionally, as suggested by Becker *et al.* (2011), alternative policy mechanisms may be pursued or developed further along different stages of the bioenergy supply chain.

4.1.4 Forest Sector

The forest sector includes a wide range of industries, ownerships, and jobs related to forest resources, products, and manufacturing. All our interviewees described the industrial and economic infrastructure of the forest sector as relevant to various attributes of bioenergy projects, which together composed the fourth largest number of mentions. Here we focus on the integration of bioenergy products within the forest products industry (FPI), and the role of this relationship in accessing biomass supply. We also discuss study participant perspectives on bioenergy's impact for local economies. Thermal and cogeneration bioenergy shared several fundamental attributes within this factor because of their shared reliance on raw biomass inputs at some point in the supply chain. However, they appeared to have important differences related to their potential impact on local economies.

4.1.4.1 Integration and Capacity

The process of generating energy from woody biomass is embedded within the forest products industry (e.g., logging, manufacturing, and a skilled workforce) to varying degrees. For example, both TBE and CHP systems require fuel that has been processed into an acceptable quality (e.g., moisture content, particle size, and ash content), presupposing a role for forest sector manufacturing (Smith *et al.* 2012). More than half of our interviewees referred to bioenergy products (energy and wood fuels) as a means to diversify the FPI, particularly as an integrated component with other forest product manufacturing. The ODF Stewardship Forester described such FPI diversification as a more efficient use of forest resources and a strategy to maintain market viability:

> "The thing about diversification and integration is it allows you to be nimble. It allows you to not be a slave to limited markets. And what limited markets mean is that if all you're producing is chips and lumber and the housing market goes down... you're pre-positioned to weather some of those swings."
>
> –id16, ODF Stewardship Forester

The above quote refers to the niche benefit that low-value woody biomass can bring to a manufacturing company; conversely, many of our interviewees described the necessity of high-value products in enabling the collection and utilization of woody biomass. For example, the timber manager of a forest products facility in Grant County explained their pellet plant's reliance on their sawmill operation for shared costs:

> "...[S]o much of the overhead and operating costs for the pellet mill are also shared with the sawmill. Just taking something as simple as unloading the log trucks. We have a guy out there full time with a great big piece of equipment,

> brand new, it's 8 or $900,000... You can't have a guy sitting around all day, or a piece of equipment at that expense sitting around just unloading six or seven loads a day of fiber... Maintenance, electricians, millwrights, administration, office – you know, that's all shared. And as soon as you take away the sawmill and burden the pellet plant with so many of those costs, it would be not good."
>
> –id02, timber manager

The ODF Biomass Specialist made a similar statement regarding CHP dependence on higher-value products in the FPI:

> "The reason why [cogeneration] facilities are functional is because they have the demand for the heat to dry their lumber, or the demand for the heat to dry their veneer. Those things go away, then the cogeneration part goes by with them."
>
> –id32, ODF Biomass Specialist

Finally, another level of integration exists through supply. Like most pellet manufacturers in the United States, ten of the eleven producers in Oregon use mill residue for their raw material (Spelter and Toth 2009); only the plant located in Grant County chips whole logs sourced from fuel reduction treatments. Similarly, as discussed in the Financing section, most CHP facilities in Oregon are co-located with a forest sector industrial site. In addition to providing a heat demand for generated energy, a products manufacturer can offset costs of CHP supply through the provision of mill waste (Sessions *et al.* 2013). For example, a CHP facility in western Oregon sources 75% of its supply from the co-located sawmill, and purchases the remaining 25% as forest residuals (Payne 2013).

In addition to the interdependence of bioenergy products and conventional forest product manufacturing at a single facility, many of our study participants considered the FPI infrastructure as critical to bioenergy development at a larger regional scale. To these individuals, the equipment and skilled workforce in the forest sector provides the capacity to do active restoration in the woods, and to generate even the small volumes of feedstock necessary for TBE installations. For example, the bioenergy developer interviewed for this study emphasized that he could not envision bioenergy establishing without an existing FPI infrastructure:

> "You need to have an active forest... I can't imagine, especially for pellets, coming in to some kind of community that had zero logging operations and everything and just starting from scratch." –id05, bioenergy developer

A non-profit executive director working in Wallowa County shared a similar view when he described the biggest risk to restoration-focused biomass utilization as the continued decline in timber harvests and sawmilling infrastructure:

> "There's nothing today that generates value back to the landowners or to the forest contractors but sawlogs. And if we lose that, and we lose all of the hard infrastructure and trucking and equipment and processing capacity related to the sawmills and lumber production, we may not have any capacity left to get this. It may be out there, but nobody can bring it in."
> –id03, non-profit executive director

The preceding discussion suggests the FPI enables the supply of bioenergy products through financial integration and infrastructure capacity. To the extent that this is true, this relationship ties all forms of residual woody biomass utilization to the fate of sawlog harvests and removal, in addition to the tools discussed in the Available Supply Accessibility subsection. Notably, Becker *et al.* (2009a) also found that a bioenergy industry would be difficult to establish without the FPI, or without a sawlog market.

4.1.4.2 Bioenergy and Local Economies

As discussed in the Background section, the forest sector has historically been an important source of employment for rural communities such as those in our study. While the notion of community wellbeing as tightly coupled with timber extraction has been challenged during the last two decades, the literature also indicates that this relationship varies across the rural landscape (e.g., Winkler *et al.* 2007; Power 2005; Weber and Chen 2012; Charnley *et al.* 2008). Isolated communities that lack high-amenity features tend to remain tied to more traditional industries (Winkler *et al.* 2007; Power 2005; Hibbard *et al*. 2012), and face unique challenges as environmental resources degrade and industries restructure. It's within these circumstances that local economic benefit is explicitly prioritized alongside increasing active restoration and biomass utilization in the region (e.g., USDA FS 2012; NFHR 2012; Nielsen-Pincus and Moseley 2013).

Grant, Wallowa, and Harney Counties share declining populations, high unemployment and poverty rates, high presence of traditional industries, and geographic isolation (see **Table 2**). Furthermore, the USDA Atlas of Rural and Small-Town America classifies Grant County as having low natural amenities (USDA ERS 2014). Several of our study participants described their communities as in "desperate" need for any type of employment; indeed, one conservation advocate considered biomass removal for bioenergy development to be driven by "an awful lot of economically desperate people in Grant County and Harney County" (id14). She suggested that these motivations ran the risk of simply perpetuating exploitative extraction, and challenged rural communities to shift away from traditional industries. Yet, many study participants were skeptical that the region could transition away from traditional extractive industries. For example, nearly a third of our study participants named Grant County's geographic isolation and considerable public land ownership as prominent limitations to such a shift. A county commissioner stressed the importance of transportation costs to potential industries:

> "We don't have rail, no access to freeways. We got it – 75 miles away. So... it limits us for competing [to attract industry] on other levels."
> –id07, county commissioner

Interestingly, bioenergy seemed to exist as a sort of hybrid economic activity, connected to but distinct from the traditional forest products industry. As described by study participants, bioenergy's primary reliance on low value biomass (as opposed to high value timber) was its main differentiating characteristic. This was identified as both limiting and appealing to the burgeoning industry. For example, the Economic Development Coordinator for Grant County said that embracing bioenergy would require a philosophical "paradigm shift," that "it's not just about getting logs off the woods" (id20). Similarly, an ODF Stewardship Forester suggested that the forest products industry required a "paradigm shift" to embrace the smaller profit margins that might come from merchandizing low value material versus higher value material (id16). The manager of a Wallowa County mill that primarily utilizes small-diameter material, however, reported that he had received positive feedback from both traditional timber- and conservation-oriented individuals. He viewed the extension of the FPI into markets that facilitate dry forest restoration as creating the possibility that timber harvests and conservation “don’t have to be mutually exclusive” (id12).

The ODF Stewardship Forester quoted above described bioenergy as a form of extraction, clarifying that a shift in paradigm is needed simply in “how we look at [extractive industries], how we do it,” rather than away from any kind of it (id16). The former Grant County judge shared a similar view, describing the diversification into bioenergy production as “right for a community like ours,” inasmuch as it complements rather than replaces the removal of sawlogs (id27). These comments seem to support the inclusion of bioenergy in a “new natural resource economy,” as suggested by Hibbard *et al.* (2012). Under this framework, bioenergy may represent both a production- and protection-oriented activity, which may offer unique economic benefits to communities with limited alternative options. Certain aspects of bioenergy may even create inroads for otherwise skeptical individuals. For example, despite her suspicions, the conservation advocate quoted previously was in favor of bioenergy that is “local, small-scale, sustainable,” even describing the facilities in Grant and Harney Counties as “visionary” (id14).

Our study participants prioritized the potential economic development opportunities that could be generated through bioenergy. For example, one project champion of a TBE installation in a Grant County public school emphasized that, next to being financially viable, it was essential that their project be a model for economic development by and for their community. This individual felt strongly that if the school didn’t invest in its own community, they couldn’t expect anyone else to do so (id33). Nearly all of our study participants described similar attitudes towards supporting the local economy. The ways in which they viewed bioenergy as meeting these objectives, however, differed somewhat between TBE and CHP applications.

More than two-thirds of our interviewees observed or anticipated economic impacts of bioenergy applications in general to originate from the use of local resources. Most of these individuals valued local biomass utilization for fuel simply because of its apparent abundance. For example, one TBE project champion who was raised in the Grant County area described biomass as a fuel readily available on the nearby national forests, compared to conventional energy sources that had to be imported:

> "The resource is here. The [other energy sources] have to be brought in. If we can continue to get [biomass] off of the Malheur, the Wallowa-Whitman, the Umatilla, the Ochoco, all those forests, it's right here. We're surrounded by it."
> –id17, project champion

Nearly half of our interviewees described the use of local resources for TBE applications specifically as injecting value into the local economy, referring to both pellets and the biomass to produce them. These comments focused on 'keeping money local,' supporting local businesses, and creating opportunities for future business opportunities. A few individuals also attributed a measure of self-reliance to locally fuelled TBE systems. The primary mechanism at work was described as the replacement of an (expensive) imported fuel with local (or almost local) supplies, thus retaining and circulating money in the local and regional economy. The owner of a pellet manufacturing business, who has been involved in lobbying for community-scaled bioenergy policy, credited the use of local resources as valuable on multiple fronts:

> "It's one of the ways you can get more wealth, growth, and capital wealth capture in a community because the energy's not being paid for out of the area, it's all of those jobs, infrastructure, energy, everything can be sourced closer to its use."
> –id01, owner of pellet manufacturing business

Sourcing fuel locally was also seen as supporting existing businesses, and creating opportunities for future businesses to take advantage of inexpensive thermal energy. One project champion described a scenario where, if enough TBE systems were installed, further business development could be instigated:

> "At some point you might build enough business to sustain an investment in a new production facility. So if you really converted a lot of buildings, if you were able to convert everybody who's currently on heating oil or propane over to woody biomass-fired systems, you create a really strong demand for a local processing business to get into that."
> –id03, TBE project champion and non-profit executive director

A few of our study participants also described a less tangible social value associated with supporting local businesses. For example, the project champion for the first TBE system in Oregon explained that the final decision to install the boiler was about something other than the money:

> "Our Board was persuaded by the fact that they liked sort of the local angle, where there would be relatively local supplies. That there was the potential for more employment in the wood industry. And so... they weren't going through the math. That wasn't the way they made the decision."
>
> –id11, project champion and hospital CEO

The developer of the TBE systems in Grant County observed a similar relationship in his clients:

> "[T]he schools and the hospitals [that have converted to TBE], I think they've made the connection really clearly – that they serve the mill workers and their kids... And the families of the mill workers are really who their clients are at the hospital, and the same of course at the school. So they're totally connected that way, they see that." –id05, bioenergy developer

Interestingly, the bioenergy developer went on to suggest that increasing the use of woody biomass for a daily need, as opposed to the occasional use of traditional wood products like lumber, has the additional potential to redefine the relationship between the forest products industry and consumers by becoming "a much more integrated piece of the whole fabric of the economy and the communities" (id05).

While interviewees described the positive repercussions of using local resources as the primary TBE benefits to local communities (in addition to the personal savings discussed in the Financing section), CHP was usually referenced as creating or retaining jobs in the forest products industry. About a third of our study participants either explicitly made this connection, or more broadly identified positive community benefits of creating jobs. A self-employed forestry consultant said that one point of entry for her interest in CHP bioenergy was about "keeping the industry here":

> "I've been here twenty-three years... when we moved here we had three sawmills, we had the cogeneration plant in Prairie City, we had a chip plant; in that twenty

> years now after this recent announcement [of the last mill closing], we're down to nothing... It's a huge issue... So demographically we're losing our workforce, we're losing our skilled workforce for the woods."
>
> –id22, self-employed forestry consultant

Another private forestry consultant also described local interest in his involvement to locate a CHP facility in Wallowa County as motivated by the potential to create more forest sector jobs:

> "The main reason that people were interested in [a CHP facility] was it was going to create jobs. And when you start saying that you're going to create thirty jobs in a facility, and another thirty jobs in the woods, the major gets excited. The stores get excited. Because these are gonna be good jobs, that are supposedly gonna pay a good wage. And so there was quite a bit of support when I looked at it."
>
> –id13, private forestry consultant

4.1.5 Scale

The scale factor refers to capacity or magnitude, and can apply to several aspects of a bioenergy project. In previous sections, characteristics of scale have been invoked in relation to available biomass, the level of perceived need for active forest restoration, and expressed preferences and concerns for biomass utilization. Here we focus on scale as the energy capacity of a bioenergy facility, and its implications for available supply. This factor was widely referenced by 18 of our 20 key informants, and had the lowest number of mentions.

As discussed in the Background section, scale is a fundamental attribute of a biomass energy facility. Our study participants acknowledged and elaborated on the differences between TBE and CHP systems with regard to how each system is scaled, and associated differences in annual biomass demand. For example, the president of the bioenergy business responsible for the four TBE installations in Grant County explained that TBE is "almost by definition smaller scale" relative to other forms of bioenergy, because it is scaled to match (and thereby limited to) the on-site or nearby heat demand (id05). This characteristic translates to a lower volume of needed supply, including both raw material and fuel product. The five pellet boilers included in this study use between 40 and 400 tons of pellets per year, a typical range for TBE elsewhere in the US (see **Table 6** and **Appendix D**). The only chip boiler in Oregon uses around 600 tons of wood chips annually. The bioenergy developer quoted above explained that the heating needs of a typical downtown core in eastern Oregon could be met with 2,000 tons per year (id05).

Biomass CHP facility scale is typically defined in terms of the tradeoff between decreasing capital costs and increasing delivered fuel costs as scale increases (Jenkins 1997; Kumar *et al.* 2003; Cameron *et al.* 2007). In our case, however, almost three times as many references were made to scaling CHP to match available biomass supplies than to economic efficiency. Only one interviewee suggested such facilities be scaled to match energy demand. One conservation advocate who had worked to develop cogeneration biomass facilities in central and eastern Oregon described operational scale as first based on supply, paired with a precautionary approach:

> "What we've always said is... figure out maybe how much material you think you're really gonna have, after you take out environmental or ecological needs. Then take that and maybe cut it in half and see if it would be economically feasible to do [bioenergy]." –id24, conservation advocate

The range of possible CHP facility scales is also associated with a range of supply requirements, although all substantially larger than TBE required volumes. McNeil Technologies (2003) estimate that a 5 MW biomass cogeneration facility requires 123,000 green tons per year, and a 50 MW facility requires 723,000 green tons per year. According to estimates in the Southern Blues Restoration Coalition (MNF 2011), a 10 MW facility requires 200,000 green tons per year.

The conservation advocate quoted above and a non-profit executive director both associated the phrase "appropriately scaled" with this method of matching the scale of a biomass utilization facility to the assessed biomass supply. The non-profit executive director, also a TBE project champion, described how he had seen the phrase evolve over time:

> "['Appropriately scaled' references] whether or not the scale of all of the activities around biomass exceeds the capacity of the forested landscape to provide it sustainably... And 'appropriate' got substituted for 'small'...There's a tremendous amount of material out there, so it's gonna be relatively large-scale,

> but it will still be appropriate for what could sustainably be removed from the forested landscape." –id03, non-profit executive director

As described by the above quote, "appropriately scaled" is a phrase used to portray industries that utilize biomass as reflecting the quantity of supply that is available – no more, and no less. It suggests both that such activities be designed to not overburden the resource, and that they effectively utilize the resource. This notion has been invoked elsewhere as a link between bioenergy and fuel reduction treatments. The 2006 OFRI report states that appropriate development means "the needs for forest restoration should determine the scale of the forest biomass energy industry" (p.1-v). An assessment of biomass utilization potential in three northeastern counties of Oregon notes that project feasibility rests in part on "sizing the facility appropriate to the volume of material available on a long-term, sustained basis" (McNeil Technologies 2003, p.i). Oregon's Forest Biomass Strategy (2012) calls for woody biomass utilization done "at the appropriate scale" to facilitate more fire resilient forests. Finally, in their assessment of biomass utilization 'conventional wisdoms' in the United States, Becker *et al.* (2009a) define appropriately scaled processing as optimizing "the size of the facility with the volume of biomass sustainably available within an economically defined region" (p.21).

4.2 Factor Interactions and Implications

Our examination of the existing bioenergy industry in eastern Oregon suggests that these developments have been influenced by five primary interrelated factors, which we identify as available supply, social acceptance, financing, the forest sector, and scale. While our factors share similarities with those discussed in bioenergy literature elsewhere (e.g., OFRI 2006), our approach is unique in its explicit detailed treatment of both thermal and cogeneration bioenergy (although see Becker *et al.* 2009a; McCormick 2005). We found that each of these five factors is relevant to both thermal and cogeneration bioenergy systems in the region, and that each system has common and distinct factor attributes. Our data suggests that the two types of bioenergy share factor attributes that pertain to raw biomass material, because this is the basic input on which each system depends. They also share most attributes relevant to social acceptance, as our study participants did not tend to differentiate between TBE and CHP regarding issues like active restoration, biomass utilization, education and awareness, and carbon impacts. In addition, they share forest sector attributes; many study participants described supply chains for both types of energy as financially integrated with other forest products manufacturing, and also suggested that conducting work in the woods for all kinds of end products relies on a functioning forest products industry.

These issues provide important context for both types of bioenergy in eastern Oregon, which is also evident in the literature. For example, physically available biomass material can be quantified regardless of end use (see OFRI 2006; McNeil Technologies 2003; Rainville *et al.* 2008), and arguments for active restoration in dry mixed conifer forests frames any biomass utilization effort in the region (Stidham and Simon-Brown 2011; Becker *et al.* 2009a; Hessburg *et al.* 2005). Literature on carbon impacts of bioenergy tend to focus on carbon neutral assumptions and complex disturbance dynamics rather than the type of bioenergy system (e.g., McKechnie *et al.* 2011; Campbell *et al.* 2012); however, substantial differences between carbon implications of various bioenergy uses have been documented (e.g., Manomet 2010). In addition, study participant perspectives about shared forest sector attributes support Becker *et al.*'s (2009a) observations regarding the necessity of a forest products industry to enable a bioenergy industry.

Other factor attributes are distinct between the two systems. Funding mechanisms was perhaps the most differentiating factor attribute, stemming from the cost and availability of alternative energy options. TBE systems tend to be economically competitive with petroleum-based fuels such as heating oil and propane, although this limits their potential market development to areas where natural gas is not available. Furthermore, data from TBE facilities in our case and others across Oregon indicate that while grants and tax incentives have been important to cover high up-front costs, they have not always been essential to project feasibility (e.g., see Resource Innovations n.d.). In contrast, our study confirms other reports detailing biomass cogeneration's difficulty competing with inexpensive electricity rates in the Pacific Northwest region (e.g., see OFRI 2006; Itron 2004). As a result, CHP is reliant on favorable policy instruments to create a demand for generated electricity. Most study participants referred to the state Renewable

Portfolio Standard as the avenue through which cogeneration could be advanced, while citing the current conditions of the RPS as largely inadequate in practically doing so.

The data also suggest the two systems have different implications for local economies, which we categorized within the forest sector factor. TBE project champions and the bioenergy developer described energy cost savings from replacing petroleum-based fuels with biomass as creating economic benefits at the site-level, which can be reinvested into the community. Such systems were also described as creating value for local economies by keeping money local instead of importing fossil fuels, using products that support local businesses, and creating potential opportunities for future businesses. These characteristics seem to support other literature that has highlighted small-scale systems as better able to generate particular benefits for local communities, compared to large-scale systems (Burton and Hubacek 2007; Becker *et al.* 2009a; Johansson *et al.* 2005). For example, Burton and Hubacek (2007) found that large-scale renewable energy systems were more financially efficient over time, while small-scale systems were better at keeping money in the local area through the provision of local jobs. Becker *et al.* (2009a) observed preferences for small-scale bioenergy systems because they were viewed as contributing to a more diverse economy with benefits more likely to stay within the community.

Economic impacts of cogeneration were referred to as job creation and maintenance in general, as well as specifically within the forest sector. The emphasis on jobs associated with CHP may imply a perceived tighter interdependence between CHP and the forest sector than that of TBE. CHP appears to be more economically feasible when co-located with other forest products manufacturing facilities because of decreased supply costs and embedded heat demand, which suggests that jobs at a CHP plant may also secure jobs at a sawmill. Additionally, as facilities are typically scaled larger than TBE, cogeneration development may reasonably suggest more substantial job creation than thermal bioenergy.

4.2.1 Social Acceptance and the Scale Mismatch

In eastern Oregon, bioenergy is frequently referenced as a tool to accomplish forest restoration by facilitating fuel reduction treatments with a market demand for biomass (Stidham and Simon-

Brown 2011; Nicholls *et al.* 2008; OFRI 2006; Evans and Finkral 2009). Our case sought to understand this relationship by investigating what factors and conditions have enabled bioenergy development in the region. However, while perspectives about active restoration contribute substantially to social acceptance and supply factors, the impact of existing bioenergy facilities on restoration objectives is not straightforward. Rather than inherent in a particular bioenergy attribute, bioenergy implications for restoration in the region can be best understood as arising from the interactions of multiple factors that are differentiated between thermal and cogeneration. We discuss these below as factor relationships related to social acceptance and a scale mismatch.

First, the relationship between social acceptance and scale revolves around concerns for overbuilding a bioenergy industry. The social acceptance factor indicates that this apprehension depends on the scale of a biomass utilization facility, and suggests that there is some size above which would likely attract resistance from some stakeholders. For example, the project champion for the only wood chip TBE boiler in the state called its 600 green ton annual demand for biomass "peanuts" compared to the 150,000 tons of annual pulp loads or 400,000 tons of slash piles he estimated as coming from Wallowa County's largest private industrial timber company. He went on to explain that he has little concern that the bioenergy systems he's worked with will generate fears that the forest resource will be overburdened:

> "At some level of scale, people will get concerned that [biomass utilization] exceeds our capacity to provide it on a sustainable basis. I think, again, knowing what I know of the systems here and about the volume that's currently burned in slash piles and exported as low-value products, I'm not concerned that we're ever gonna hit that in my lifetime."
>
> –id03, project champion and non-profit executive director

In contrast, one timber manager suggested that while the small pellet plant he operated was socially acceptable, a particular scale of a CHP facility would not be:

> "If we were to slam some huge combined heat and power plant here that needed fifty loads a day of fiber, then the environmental community's gonna throw their hands up and say 'whoa, we're not supporting this anymore'"

–id02, timber manager

With an average of 25 tons per truckload, the individual's comment above suggests that a CHP facility around 25 MW or more would be unacceptable to the environmental community. This suggests that the inherently small scale of thermal bioenergy makes such systems more easily acceptable. Becker *et al.* (2009a) similarly observe that persistent supply challenges contributed to an eventual shift away from large-scale systems and towards small-scale. However, because CHP can be scaled to match biomass supply, for financial efficiency, or to match electricity demand, the associated range of annual biomass requirements may or may not trigger concerns about overbuilding the industry. That cogeneration can be scaled to match available biomass – to be "appropriately scaled" – suggests that these systems could be developed to explicitly prioritize restoration objectives over other considerations. Regardless, cogeneration's potential impact is especially uncertain because our data and the literature doesn't identify an absolute scale that is "good" or "bad" in terms of its level of social acceptance. As noted in the Background section, a wide range of CHP facility scales have been referred to as small (e.g., Cameron *et al.* 2007; Brown and Mann 2008; Dong *et al.* 2009).

The second set of factor relationships is between scale and available supply, and results both in a scale mismatch between TBE and perceived forest restoration needs, and a preference for CHP where restoration is prioritized. Both systems share the context of assessed degradation of dry mixed conifer forests, and the need for a biomass utilization market to help finance fuel reduction treatments (e.g., Becker *et al.* 2009b; Aguilar and Garrett 2009; Nicholls *et al.* 2008). Becker *et al.* (2009b) refer to the scale of biomass utilization as a fundamental aspect of fuel reduction treatments. However, while TBE's inherently small scale may make such systems more easily acceptable to some, it also seems to indicate TBE's role as a market mechanism for biomass removal at a landscape scale is limited. Several interviewees spoke to this aspect of TBE, often recognizing its benefits for communities while expressing disappointment in its limitations of scale. For example, one conservation advocate described TBE systems in the region as "fantastic," but when asked whether he saw those installations as hitting his objectives for forest restoration, his response was:

> "No, no, they're not, there's not enough of them. We have more material out here at least from what we're doing right now than those can utilize."
>
> –id24, conservation advocate

Similarly, a private forestry consultant compared TBE demand to the amount of biomass material left as waste after regular harvest operations, saying "every little bit helps, small-scale's how you get to big-scale, but... have you seen any of those [slash] piles, they're staggering in size!" (id22).

This scale constraint of TBE led a few study participants to specifically advocate for cogeneration as a tool to accomplish restoration in the region. As explained by the ODF Biomass Specialist, the higher volume use of biomass cogeneration is "a real benefit when you look at the quantities of material that are available across the state, and even the quantities that are available on the east side" (id32). The former county judge included in this study was one interviewee who spoke the most to this view, explaining that "scale and biomass are intimately linked. You can't do one without the other if you're serious about a scale that makes a difference in the next thirty years." He went on to say that this scale necessitates a cogeneration facility, because of the demand it would create for low-value biomass (id27). **Figure 7** portrays the scale mismatch as it refers to the amount of biomass that would be available on the Malheur National Forest if restoration targets for that forest were accomplished (see BMFP 2010). The Figure clearly demonstrates that one CHP facility would create a market demand immediately meaningful for the available biomass. In contrast, a single wood chip TBE installation is barely noticeable. Even if the pellet plant currently located in Grant County were operating at peak capacity, it would only create a small demand for the available biomass.

The factor interactions of scale, social acceptance, and supply create a tension around the appropriate type and scale of bioenergy, depending on project objectives. The financial feasibility of a bioenergy facility further complicates development outcomes, as TBE facilities appear to have opportunities where they are economically competitive while CHP faces serious financing obstacles. To our knowledge, this conundrum is not explicitly addressed elsewhere, except by Becker *et al.* (2009a). In their analysis of biomass utilization conventional wisdoms, the authors describe several instances in which small-scale or thermal biomass utilization applications have been pursued because prior large-scale ambitions met with challenges. They also note that strong arguments for large-scale bioenergy remain, and that some suggest small-scale bioenergy is potentially a stepping stone to larger applications in the future. In our case, these circumstances inspired a few study participants to speculate as to the potential restoration impact of many aggregated small-scale TBE systems. We address this question in the next section.

4.3 Scaling Up Thermal Bioenergy

The factor attributes and their interactions revealed in our analysis of bioenergy adoption in eastern Oregon suggest troubling implications for forest restoration objectives. While the data indicate that TBE systems may be more financially, socially, and environmentally feasible for their attributes related to financing, scale, and social acceptance, they also suggest that attributes of scale limit the relevance of TBE as a mechanism to accomplish fuel reduction treatments at the level some regional assessments call for (e.g., BMFP 2010; USDA FS n.d.). Conversely, while CHP is better able to create this kind of demand for low-quality biomass, such developments are limited by their attributes related to financing and potentially social acceptance.

Given these circumstances, a few study participants speculated about the potential impact TBE could have on regional restoration objectives if scaled up to meet a larger heat demand. As put by an ODF Stewardship Forester, "what about the sum total of a lot of a little? A lot of a little can be a lot" (id16). We extended our analysis to include an investigation of this question, as we considered it a logical next step in exploring the implications of bioenergy for restoration. Below we describe our methodology to complete this exercise, followed by the results and a discussion.

4.3.1 Scaling Up Methodology

To examine the extent to which thermal bioenergy installations might create a demand for biomass that would be meaningful on a landscape scale, it is necessary to identify the potential demand for thermal energy that could be met with woody biomass. To do this, we use state-level thermal energy consumption as documented by Remington *et al.* (2012). Our case suggests that TBE is the most economically attractive when replacing petroleum-based fuels, which supplied 13.2% and 7.6% of Oregon's commercial and residential sectors in 2009, respectively (see **Tables 7** and **8**). The largest potential would be to replace natural gas consumption, which supplied around 50% of Oregon's commercial and residential sector heat demand in 2009. We designate eight heat demand scenarios based on these energy profiles, which range in the proportion of petroleum-based fuels and/or natural gas replaced with woody biomass in the commercial and/or residential sector (see **Table 9**).

We use the higher heating value common to Pacific Northwest conifer species (calculated for 50% moisture content; see Wilson *et al.* 2010) to convert the energy demand of each scenario from trillion BTUs to total required green tons (GT) of biomass per year. We use a low (5 GT per acre) and high (20 GT per acre) biomass yield for each scenario to convert total biomass per year into number of acres that could receive fuel reduction treatments, based on regional data (McNeil Technologies 2003; Rainville *et al.* 2008). We do not examine more specific prescription details, such as reduction of basal area, diameter limits, or effect on fire behavior; rather, we aim to develop a back-of-the-envelope assessment of potential demand effects. Additionally, we use the 30,000 targeted treatment acres for the Malheur National Forest (BMFP 2010) as a gauge to determine whether any of our scenarios stimulate active restoration on the scale identified as necessary for this particular national forest.

We also calculate the number of individual TBE facilities that would be required to meet each scenario. Thermal demand at the state level can be met with various types of heat-producing bioenergy systems. While alternative conversion technologies are being explored (e.g., gasification, see Difs *et al.* 2010), we focus this exercise on three types of combustion TBE systems: wood chip commercial boilers, pellet commercial boilers, and wood chip district heating. Wood chip and pellet TBE systems have been the focus of this paper thus far, reflecting the current bioenergy developments in the state. We include district heating (DH) in this exercise because such systems distribute thermal energy to a network of users rather than on-site demand alone, and thus might be a more accurate illustration of aggregated TBE development. As discussed in the Background section, biomass DH is common in European countries, and is less developed in the US (see Madlener 2007).

To estimate the number of individual TBE facilities that would be aggregated to meet each heat demand scenario, we divide the required annual biomass volume by average annual biomass needs of each system. TBE systems are designed for site-specific circumstances, so using an average is a coarse means of measurement; nevertheless, we average our case data with six additional pellet boilers in Oregon and five additional wood chip boilers in the nation using available secondary data (see **Table 10**, and **Appendix E**). Doing so provides an average wood chip TBE system of 3.67 MMBtu/hr with an annual demand of 687 GT, and an average pellet system of 1.6 MMBtu/hr with an annual demand of 380 GT. District heating systems also have a wide range of capacities and fuel requirements, based on local population density and climate (Madlener 2007; Vallios *et al.* 2008). The bioenergy developer included in this study is familiar with sizing such systems, and in the absence of any local district heating examples, we use his estimate of 2,000 GT as the annual fuel demand for a typical rural downtown core in Oregon (id05). To convert tons of pellets to green tons, we consulted existing life cycle analyses for pellet manufacturing (Katers *et al.* 2012; Dwivedi *et al.* 2011; Sikkema *et al.* 2010; Zhang *et al.* 2010). Green wood input required for pellet production varies based on the moisture content of the starting feedstock and ending pellet, the type of feedstock, and whether wood is used in the drying system. In general, the literature suggests that 2.0 to 2.4 green tons are needed to produce one ton of pellets, so for this exercise we use 2.2.

Finally, we make two additional assumptions in this exercise: first, that all new biomass demand initiated by thermal energy conversions will be sourced from fuel reduction treatments; and second, that all fuel reduction treatments will occur within the Blue Mountains region. Both of these assumptions are liberal, which suggests that our results will be overestimates of the possible effect aggregated thermal energy conversions will have on restoration activities. We perform a second calculation on generated biomass demand and associated harvests to gain a better understanding of the effects the first assumption. According to the ODF Biomass Resource Specialist, Oregon currently exports half of the 500,000 tons of pellets produced in the state. This suggests that 250,000 tons of new pellet demand (or approximately 550,000 GT of biomass) could be met by redirecting exported pellets for domestic use, without requiring any new harvests whatsoever. We subtract 550,000 GT from the quantity of biomass calculated to meet each heat demand scenario, and adjust the number of acres that would require fuel reduction treatments to produce those volumes. By doing so, we account for the potential that new biomass demand be met by redirecting existing pellet production in the state that is currently exported, before instigating new production sourced from fuel reduction treatments. While another set of assumptions is implicated with this analysis (e.g., competition with international markets and effects on price), it provides a more conservative, and perhaps more realistic, assessment of potential impacts.

4.3.2 Scaling Up Results

This analysis yielded a range of results. Without redirecting exported pellets, one scenario at low yield and two at high yield would instigate fuel reduction treatments at a scale relevant to the restoration targets on the Malheur National Forest (close to 30,000 acres) (see **Figure 8**).The volume of biomass required for these scenarios could be utilized in approximately 240 – 1,000 individual wood chip boilers, 400 – 1,800 pellet boilers, or 80 – 350 district heating systems. If currently exported pellets were redirected to meet new demand before generating new pellet production, two low and two high yield scenarios would meet this criteria (see **Figure 9**). These scenarios would require approximately 1,000 – 1,500 wood chip boilers, 1,700 – 3,200 pellet boilers, or 300 – 600 district heating systems,

4.3.3 Scaling Up Discussion

This exercise is broadly illustrative of how TBE might be scaled up to impact fuel reduction treatments in the Blue Mountains region. We see that indeed, “a lot of a little” can add up to a lot; that is, there does exist substantial untapped demand for woody biomass through thermal energy consumption currently using petroleum-based fuels or natural gas in the commercial and residential sectors. Even when accounting for thermal demand that could be met by existing pellet production in the state, there are scenarios that would be beneficial to restoration objectives in our area of interest. Whether a scenario assumes low or high biomass yield has a strong impact on the number of aggregated individual TBE facilities. Approximately four times as many facilities are required in high yield scenarios compared to low yield; this demonstrates that fuel reduction treatments that generate higher yields entail larger biomass utilization markets to treat the same number of acres.

However, our assumptions and other conditions suggest that the realistic implications of this exercise may be limited. Constructing hundreds or even a few thousand individual TBE systems may require substantial resources of time and funding. This alone is not impossible; over the course of fifteen years, 3,300 small- and medium-scale (100 kW – 1 MW) TBE systems were installed in Austria, as well as 460 systems larger than 1 MW (Madlener 2007). Of these, more than 800 were biomass district heating systems. Literature providing European examples of bioenergy typically cite strong policy instruments (e.g., carbon tax, shared capital costs, and incentives) and, especially in the case of Austria, motivated farmer and forestland owner entrepreneurs as bioenergy drivers (e.g., Madlener 2007; Rezaie and Rosen 2012; Nicholls *et al.* 2009). It's likely that similar supportive mechanisms would be required to generate this level of construction in eastern Oregon.

While this scale of heat demand does exist in the state, another challenge may be locating demand adequately distributed to warrant development. For example, DH systems are the most economically feasible when supplying thermal energy to high-density populations in cold climates (Vallios *et al.* 2008; Rezaie and Rosen 2012; Schmidt *et al.* 2010), and we have seen that TBE does well when replacing expensive fossil fuel alternatives. In eastern Oregon counties where natural gas is the least accessible, only forty-one incorporated towns are located, and many boast only a few hundred people (United States Census Bureau 2006-2010; Oregon Blue Book 2014). Such statistics suggest that simply locating more than a few dozen optimal locations where DH could be economically applied might be a constraint, especially within the Blue Mountains region.

Finally, our assumptions that all pellet production will be sourced from fuel reduction treatments and all fuel reduction treatments will occur in the Blue Mountains region underlie additional limitations to scaling up TBE into large aggregates. First, the majority of pellets manufactured in Oregon (and elsewhere) use mill waste as their feedstock (Spelter and Toth 2009); only one pellet plant in the state sources material directly from fuel reduction treatments. Thus, even accounting for redirected exports vastly overestimates the number of acres that would be treated to supply pellets. Smith *et al.* (2012) observe that biomass energy advocates have been disappointed by the prevalence of pellet TBE systems versus wood chip, because the latter creates more opportunities to directly impact active restoration. This suggests that aggregated TBE would be most meaningful to restoration if the majority is utilized in wood chip systems. Secondly, most petroleum-based thermal energy consumption in the state likely occurs outside of natural gas territories, which tends to be in rural areas away from major travel corridors (Remington *et al.* 2012). As shown in **Figure 5**, this includes parts of the Cascades and Coast Range in addition to the Blue Mountains. While a preference might reasonably be established to source biomass from the Blue Mountains to mitigate high-severity fire risk, it is likely that new demand on the west side of the state would procure some portion of biomass from that area.

While such logistical constraints limit the realistic application of this exercise to some extent, it is useful to explore the potential impacts of aggregated small-scale systems. Building many individual small systems can be viewed as a development model distinct from building a few individual large systems. Our case has demonstrated that all bioenergy is not created equal, and that both thermal and cogeneration systems have benefits and drawbacks depending on project objectives. Tradeoffs include, but are not limited to, implications for dry forest restoration (Buchholz and Volk 2008; Becker *et al.* 2009a). Thus while aggregated TBE may still create less than the desired biomass demand, such a strategy may be valuable in other ways. From our case, this might include more flexibility to variations in supply, more social acceptance, and more money kept in local communities. Buchholz and Volk (2008) add that small-scale systems are able to be economically sustainable (e.g., achieve financial payback) quicker than large-scale systems, are less likely to have a prolonged development stage due to permitting or acceptance complications, and may support more local ownership. Finally, as suggested by Becker *et al.* (2009a), smaller-scale systems may pave the way for larger applications in the future.

Table 4: Primary factors of TBE and CHP bioenergy adoption, their definitions, number of study participant mentions, and number of interviewees who referenced each factor.

Primary Factors	Definition	Number of Mentions	Interviewees (#/20)
1. Available Supply	Perceived magnitude and accessibility of biomass.	453	20
2. Social Acceptance	Attributes that affect the social acceptability of active restoration and bioenergy production.	342	20
3. Financing	Costs and funding mechanisms for thermal and cogeneration bioenergy facilities.	292	19
4. Forest Sector	Bioenergy relationship to existing forest sector industrial and economic infrastructure.	247	20
5. Scale	Characteristics of thermal and cogeneration bioenergy related to facility capacity.	188	18

Source: Data based on key informant interviews and participant observation conducted between summer 2012 and fall 2013.

Table 5: Summary of biomass boiler National Emission Standards for Hazardous Air Pollutants (NESHAP) area source emission limit and work practice requirements.

Boiler Size and Construction Date	Fuel Type	Summary of Requirements
Other New and Existing Small boilers (<10 MMBtu/hr)	Oil, Biomass, and Coal	• Tune-up every other year or every 5 years
Existing[a] Large boilers (≥10 MMBtu/hr)	Biomass and Oil	• Tune-up every other year • One-time energy assessment
New[b] Large boilers (≥10 MMbtu/hr)	Biomass and Oil (excluding limited-use, seasonal, and new oil-fired boilers)	• Emission limit for particulate matter[c] • Tune-up every other year or every 5 years

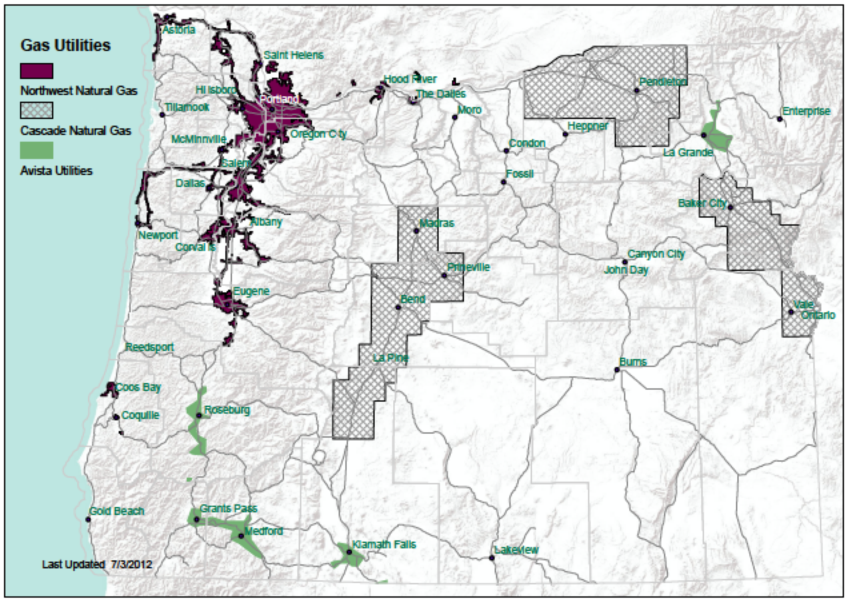
Source: Adapted from US EPA (n.d.)
[a]Commenced construction or reconstruction of the boiler on or before June 4, 2010.
[b]Commenced construction or reconstruction after June 4, 2010.
[c]PM limit: 0.03 lb/MMBtu (≥30 MMBtu/hr); 0.07 lb/MMBtu (≥10 to <30 MMBtu/hr)

Table 6: Select characteristics of six TBE systems included in this case study.

Project Name	Feed-stock	Capacity MMBtu/hr (kW)	Approx. Demand (tons/yr)	Capital Costs ($)	Approx. Savings ($/yr)[¥]	Funding Sources
Enterprise School District[a,d]	Wood chip	2.5 (733)	600[†]	1,519,586	76,141 (guaranteed) 104,000 (realized)	• USDA grant (pre-feasibility study) • ODF funding (energy audit) • ODOE BETC ($448,000) • QZAB low interest loan
Harney County District Hospital[a,d]	Pellet	0.5 (147)	45	269,000	73,000	• ODOE BETC ($80,000 after completion) • USDA and bank loans
Grant County Regional Airport[b]	Pellet	0.75 (220)	50	325,000	10,000	• 2 USDA grants ($177,350 total) • Connect OR II grant ($147,650)
Blue Mountain Hospital[b,c]	Pellet	1.8 (528)	380	450,000	84,000	• ARRA and BETC ($339,923) • Bank loan
Grant Union Jr/Sr High School[b,c]	Pellet	2.0 (586)	180	532,000	40,000	• QZAB 0% interest loan • DOE grant ($32,000 after completion) • Ochoco Lumber 10% match
Prairie City School[b]	Pellet	2.6 (762)	240	675,000	65,000	• QZAB 0% interest loan • Ochoco Lumber 10% match

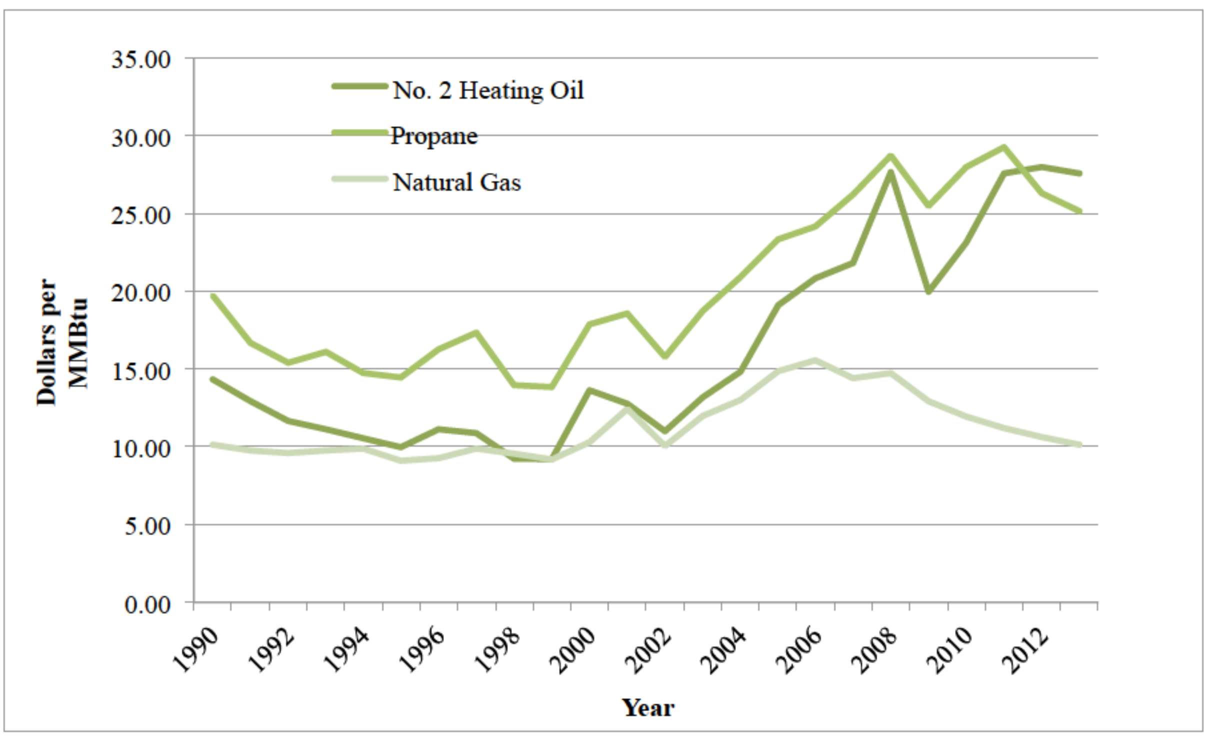
[†]GT/yr
[¥]Savings represent prior heating costs less heating costs with biomass. Does not include deductions for loan payments.
[a]Resource Innovations (n.d.)
[b]Haden (2013)
[c]Dovetail Partners, Inc. (2013)
[d]Interviewee data.
Acronyms: ARRA is American Recovery and Reinvestment Act; BETC is Business Energy Tax Credit; ODF is Oregon Department of Forestry; ODOE is Oregon Department of Energy; QZAB is Qualified Zone Academy Bond; USDA is United States Department of Agriculture.

Figure 5: Oregon natural gas utility service territories.



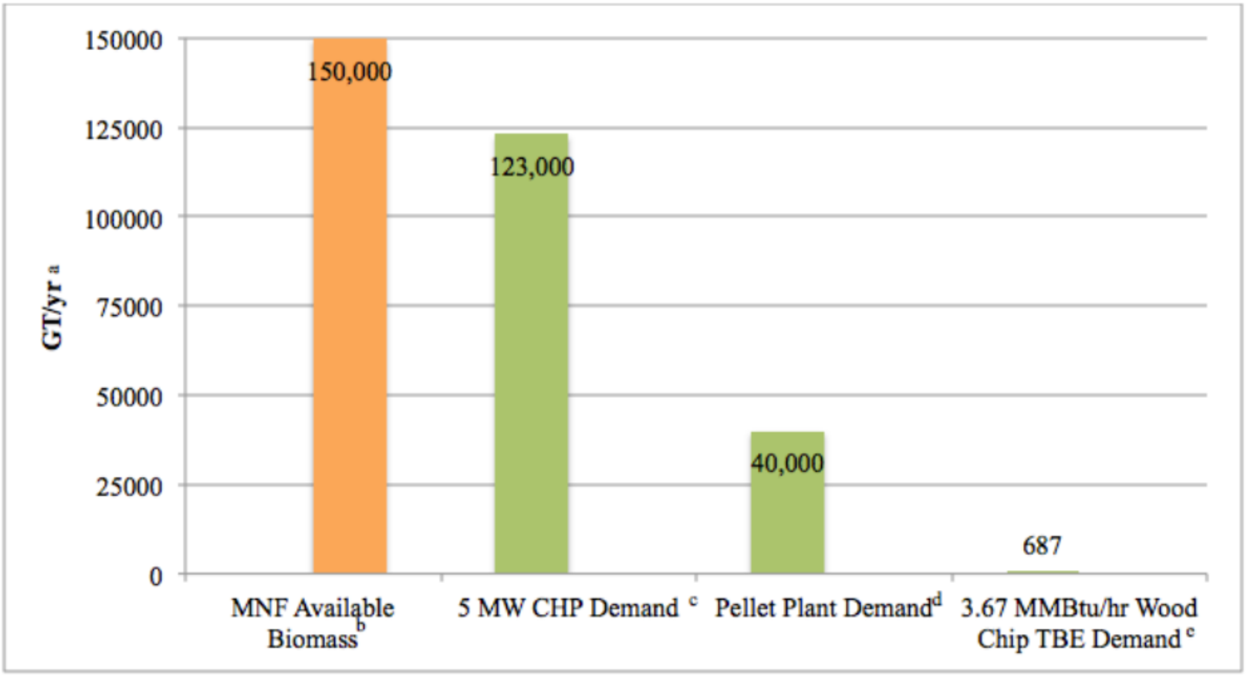
Source: Remington *et al.* (2012)

Figure 6: U.S. annual no. 2 heating oil, propane, and natural gas prices for residential use, 1990-2013. All prices are reported in 2014 U.S. dollars.



Source: US EIA (2014)

Figure 7: Annual biomass demand across different types of utilization compared to one estimate of biomass supply from the Malheur National Forest (MNF). The scale mismatch between both a single wood chip TBE demand and a pellet manufacturing plant and the available supply from targeted fuel reduction treatments is apparent.



[a]Green tons per year.
[b]Available biomass from the MNF if target fuel reduction treatments were accomplished (BMFP 2010).
[c]Annual demand adapted from McNeil Technologies (2003).
[d]Annual demand estimated from capacity of pellet plant in Grant County. Assumes 2.2 GT per 1 ton of pellets.
[e]Annual demand averaged from six wood chip TBE systems (see **Appendix E**).

Table 7: Oregon thermal energy consumption in the commercial sector by source in 2009.

Fuel Source	Percent	TBTUs*
Natural Gas	56.6	25.64
Electricity	24.9	11.28
Petroleum	13.2	5.98
Biomass	4.2	1.903
Geothermal	1.1	0.498
Total	*100*	*45.3*

Source: Remington *et al.* (2012)
*Trillion British thermal units.

Table 8: Oregon thermal energy consumption in the residential sector by source in 2009.

Fuel Source	Percent	TBTUs*
Natural Gas	46.2	38.9
Electricity	31.8	26.776
Petroleum	7.6	6.399
Biomass	11.8	9.936
Geothermal	0.3	0.253
Solar	2.3	1.937
Total	*100*	*84.2*

Source: Remington *et al.* (2012)
*Trillion British thermal units.

Table 9: Heat demand scenarios replacing a proportion of petroleum-based fuels and/or natural gas in the commercial and residential sectors with woody biomass. Each scenario also has two assumptions of biomass yields per acre.

Scenario	Description	Biomass Yield (GT/ac)	
		low	high
Scenario D1	Replace 25% commercial thermal energy consumption of petroleum-based fuels in Oregon with wood chips (50%mc).	5	20
Scenario D2	Replace 50% of commercial thermal energy consumption of petroleum-based fuels in Oregon with wood chips (50%mc).	5	20
Scenario D3	Replace all commercial thermal energy consumption of petroleum-based fuels in Oregon with wood chips (50%mc).	5	20
Scenario D4	Replace all commercial thermal energy consumption of petroleum-based fuels, AND 10% of commercial thermal energy consumption of natural gas in Oregon with wood chips (50%mc).	5	20
Scenario D5	Replace all commercial thermal energy consumption of petroleum-based fuels, AND 20% of commercial thermal energy consumption of natural gas in Oregon with wood chips (50%mc).	5	20
Scenario D6	Replace all commercial thermal energy consumption of petroleum-based fuels, AND 50% of commercial thermal energy consumption of natural gas in Oregon with wood chips (50%mc).	5	20
Scenario D7	Replace 50% commercial thermal energy consumption of petroleum-based fuels, AND 50% of residential thermal energy consumption of petroleum-based fuels in Oregon with wood chips (50%mc).	5	20
Scenario D8	Replace all commercial thermal energy consumption of petroleum-based fuels, AND 50% of residential thermal energy consumption of petroleum-based fuels in Oregon with wood chips (50%mc).	5	20

Table 10: Average capacities and fuel use for three TBE systems. See text for discussion of average values.

TBE System	Capacity MMBtu/hr (kW)	Fuel Use GT/yr
Wood chip boiler	3.67 (1,080)	687
Pellet boiler	1.6 (469)	380
District heating	*Variable*	2000

Figure 8: Heat demand scenarios that would stimulate fuel reduction treatments relevant to restoration targets for the Malheur National Forest (close to 30,000 acres per year) if currently exported pellets *are not* redirected to meet new demand, with low (5 GT/ac) or high (GT/ac) biomass yield. Number of individual thermal bioenergy facilities that would be required to account for the thermal energy demand of each scenario, shown as wood chip boilers, pellet boilers, or district heating.

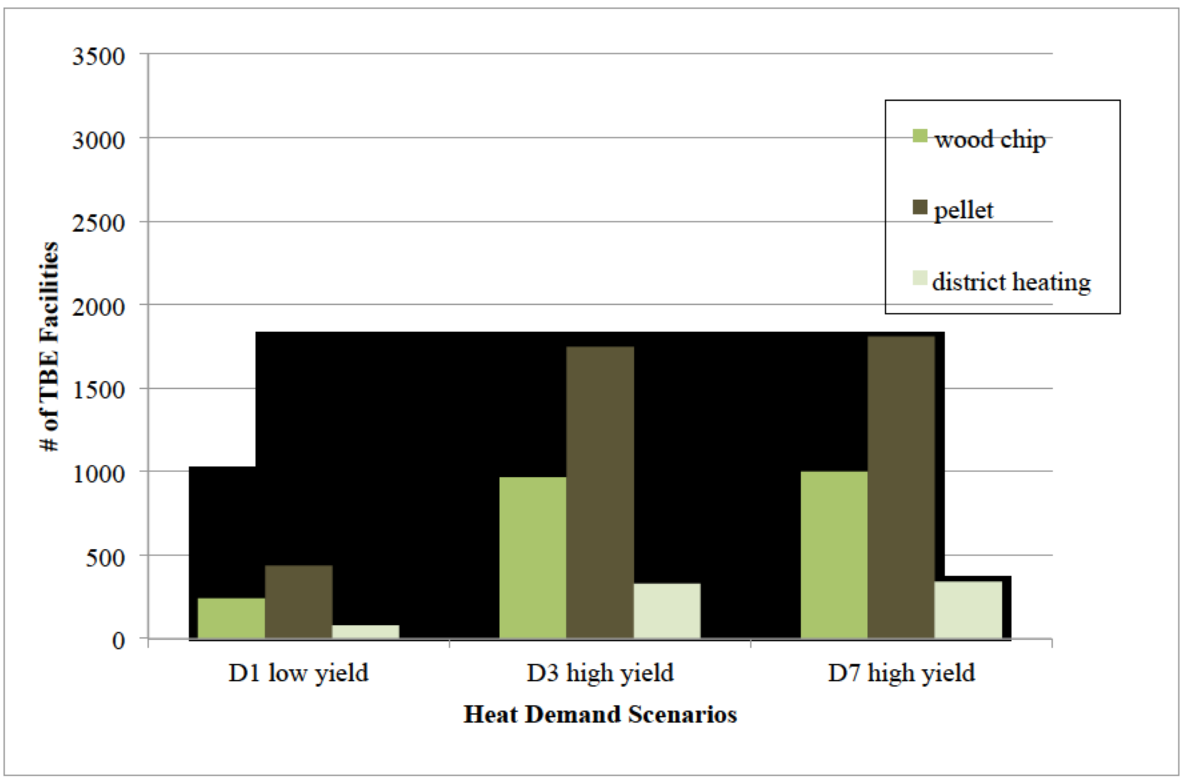
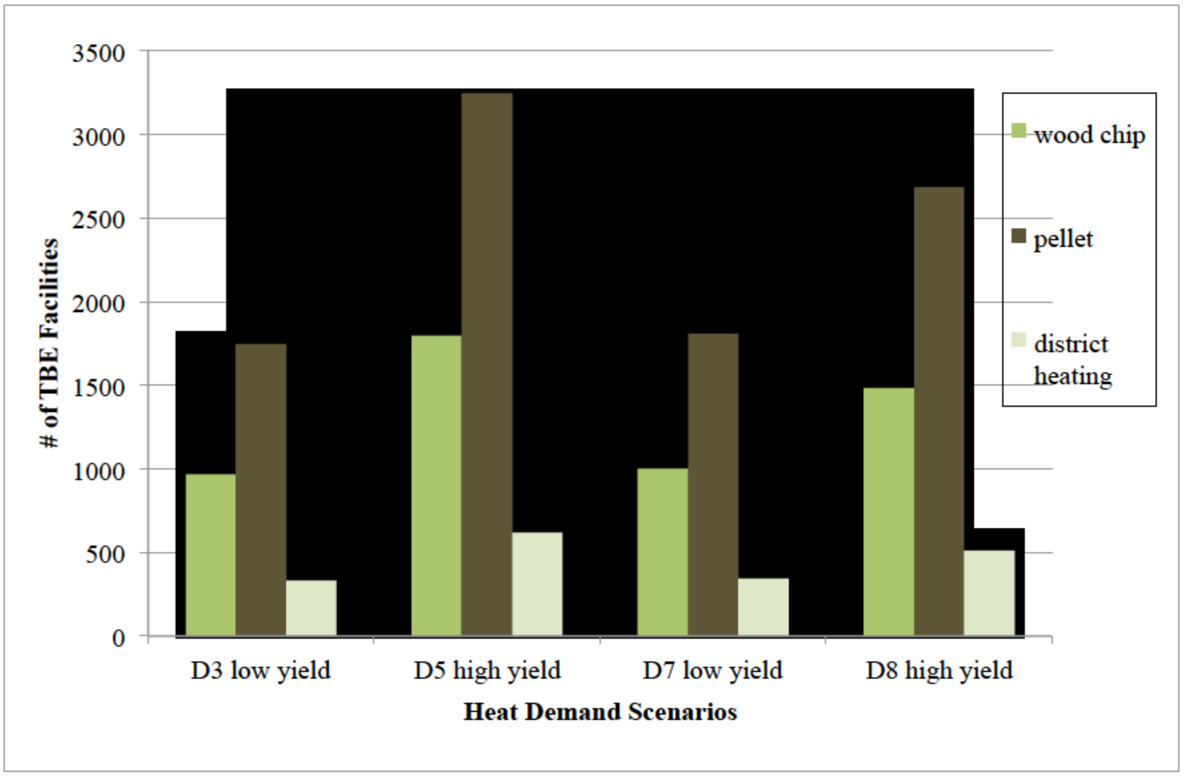


Figure 9: Heat demand scenarios that would stimulate fuel reduction treatments relevant to restoration targets for the Malheur National Forest (close to 30,000 acres per year) if currently exported pellets *are* redirected to meet new demand, with low (5 GT/ac) or high (GT/ac) biomass yield. Number of individual thermal bioenergy facilities that would be required to account for the thermal energy demand of each scenario, shown as wood chip boilers, pellet boilers, or district heating.



5 Summary and Conclusions

Our case study of thermal and cogeneration bioenergy in eastern Oregon seeks to understand what factors have enabled existing developments, and how they relate to regional dry forest restoration objectives. We identify five primary factors that influence both TBE and CHP systems: available supply, social acceptance, financing, forest sector considerations, and scale. The two types of bioenergy have both shared and distinct attributes within each factor, which differentiate project implications. We find that their relationship to restoration objectives is not straightforward, and is best understood as arising from factor interactions around social acceptance, a scale mismatch, and financial feasibility:

1. Thermal bioenergy systems appear to be more financially, socially, and environmentally feasible because of their attributes related to financing, scale, and social acceptance factors. In contrast, biomass cogeneration systems face substantial challenges within the financing factor, due primarily to inexpensive alternative electricity sources and the limited application of available policy instruments. They may additionally experience social acceptance resistance because of scale.
2. A scale mismatch suggests existing thermal bioenergy is unable to be a meaningful mechanism for fuel reduction treatments at a landscape scale. The relatively larger volume demand of cogeneration facilities suggests such systems would be more easily able to facilitate biomass removals that are immediately meaningful for regional restoration.
3. Our scaling up exercise suggests that the potential does exist to aggregate small-scale thermal bioenergy systems to generate a landscape-scale demand, although implementation would likely involve challenges.

For many in eastern Oregon, bioenergy has represented a "great hope" for much-needed dry forest restoration that could offset costs while providing tangible benefits to local communities. Our research suggests that all bioenergy is not created equal, and that tradeoffs exist beyond restoration objectives. CHP financial limitations may be addressed through policy measures that encourage higher electricity prices, which might also overcome social acceptance concerns if scale limitations are explicitly incorporated (e.g., California's Senate Bill 1122). While TBE is limited in its application to landscape-scale restoration, its relative financial feasibility and benefit to local economies suggests such systems be valued and promoted alongside other bioenergy ambitions. Policy mechanisms may be needed to help finance capital costs where heat demand is small, or low interest loans are unavailable. In addition, as a more widely acceptable form of bioenergy, TBE may be an important step to increasing public awareness and education about the range of bioenergy applications, thus enabling future developments at larger scales.

This research focuses on a cluster of bioenergy systems that has been recognized as a model for Oregon (Dovetail Partners 2013), in a region spearheading new restoration strategies (USDA FS n.d.). As such, our findings are particularly relevant to eastern Oregon, and likely offer insights for other areas similarly characterized by dry mixed conifer forests, prevalent public land ownership, and resource-dependent rural communities. The five factors of adoption we identify may also be applicable to other forms of bioenergy, although their attributes and factor interactions will likely change to reflect site-specific conditions. While we sought to include a broad range of perspectives, more individuals representing the forest products industry and the Blue Mountain Forest Partners collaborative were interviewed, potentially weighing our results more heavily towards these perspectives. Finally, our case suggests that more research is needed to better understand what scale of bioenergy is considered appropriate and acceptable within perspectives of active restoration. Future research should also seek to untangle the tradeoffs between a development strategy of building many small-scale facilities compared to a few large-scale facilities, in terms of restoration impacts, social acceptance, financial feasibility, local economies, and other considerations.

Bibliography

Agee, J.K. 1993. *Fire Ecology of Pacific Northwest Forests*. Washington DC: Island Press.

Aguilar, F. and H.E. Garrett. 2009. Perspectives of woody biomass for energy: Survey of state foresters, state energy biomass contacts, and national council of forestry association executives. *Journal of Forestry* 107(6): 297-306.

Aguilar, F. X., N. Song, and S. Shifley. 2011. Review of consumption trends and public policies promoting woody biomass as an energy feedstock in the US. *Biomass and Bioenergy* 35 (8): 3708–3718.

The American Recovery and Reinvestment Act (ARRA). 2014. Last updated January 30. http://www.recovery.gov/arra/Pages/default.aspx

Becker, D.R., D. Abbas, K.E. Halvorsen, P.J. Jakes, S.M. McCaffrey, and C. Moseley. 2009a. *Conventional Wisdoms of Woody Biomass Utilization*. Available at www.forestry.umn.edu/publications/staffpapers/index.html or biomass.forestguild.org/.

Becker, D.R., D. Larson, E.C. Lowell. 2009b. Financial considerations of policy options to enhance biomass utilization for reducing wildfire hazards. *Forest Policy and Economics* 11: 628-635.

Becker, D.R., C. Moseley, and C. Lee. 2011. A supply chain analysis framework for assessing state-level forest biomass utilization policies in the United States. *Biomass and Bioenergy* 35 (4): 1429–1439.

Becker, D.R., D. Eryilmaz, J.J. Klapperich, and M.A. Kilgore. 2013. Social availability of residual woody biomass from nonindustrial private woodland owners in Minnesota and Wisconsin. *Biomass and Bioenergy* 56: 82-91.

Berg, B.L. and H. Lune. 2012. *Qualitative Research Methods for the Social Sciences, 8th ed.* New Jersey: Pearson Education, Inc.

Biomass Energy Resource Center (BERC). 2014. "Schools." Last accessed 2/6/14. http://www.biomasscenter.org/resource-library/case-studies/schools.

Biomass Project List: Oregon Woody Biomass Projects and Status (Biomass Project List). 2011. Presented at an Oregon Board of Forestry meeting, Lakeview, Oregon, September 7-8. Available at http://www.oregon.gov/odf/pages/board/bof_090711_meeting.aspx.

Biomass Thermal Energy Council (BTEC). 2012. "BTEC News." Last modified June 25. http://www.biomassthermal.org/news/Jun25.asp.

Blue Mountains Forest Partners (BMFP). N.d. "Home." Last accessed 2/2/14. https://sites.google.com/site/bluemountainsforestpartners/home.

Blue Mountain Forest Partners (BMFP). 2010. *BMFP Proposal for Restoration Treatment Levels on the Malheur National Forest*. 12 p.

Blue Mountains Forests Revised Land and Resource Management Plan: Proposed Action (BMF Revised Plan). 2010. US For. Serv. Pacific Northwest Region. 122 p.

Bridgwater, T. 2006. Review: Biomass for energy. *Journal of the Science of Food and Agriculture* 86: 1755-1768.

Brown, E. and M. Mann. 2008. *Initial Market Assessment for Small-Scale Biomass-Based CHP*. NREL/TP-640-42046. National Renewable Energy Laboratory. 19 p.

Brown, R.T., J.K. Agee, and J.F. Franklin. 2004. Forest restoration and fire: Principles in the context of place. *Conservation Biology* 18(4): 903-912.

Brown, S.J. and M. Webb. 2010. Restoring forest health: Collaboration and responsibility.

Oregon State Bar.

Buchholz, T. and T. Volk. 2008. Is project scale the key to sustainable modern bioenergy systems? Paper presented at the Berlin Conference on the Human Dimensions of Global Environmental Change, Berlin, February 22-23.

Burton, J. and K. Hubacek. 2007. Is small beautiful? A multicriteria assessment of small-scale energy technology applications in local governments. *Energy Policy* 35 (12): 6402–6412.

Cameron, J.B., A. Kumar, P.C. Flynn. 2007. The impact of feedstock cost on technology selection and optimum size. *Biomass and Bioenergy* 31: 137-144.

Campbell, J.L. M.E. Harmon, and S.R. Mitchell. 2012. Can fuel-reduction treatments really increase forest carbon storage in the western US by reducing future fire emissions? *Frontiers in Ecology and Environment* 10(2): 83-90.

Charnley, S., E.M. Donoghue, C. Moseley. 2008. Forest management policy and community well-being in the Pacific Northwest. *Journal of Forestry* (December): 440-447.

Cherubini, F. and A.H. Strømman. 2011. Life cycle assessment of bioenergy systems: State of the art and future challenges. *Bioresource Technology* 102: 437-451.

Cook, J. and J. Beyea. 2000. Bioenergy in the United States: Progress and possibilities. *Biomass and Bioenergy* 18: 441-455.

Creswell, J.W. 2007. *Qualitative Inquiry and Research Design: Choosing Among Five Approaches*. Thousand Oaks: Sage Publications.

Database of State Incentives for Renewables and Efficiency (DSIRE). 2012. "California Incentives/Policies for Renewables and Efficiency." Last reviewed October 10. http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=CA167F&re=0&ee=0

Davis, E.J., N. Christoffersen, K. Couch, and C. Moseley. 2012. *Forest Restoration and Biomass Utilization for Multiple Benefits: A Case Study from Wallowa County, Oregon*. Ecosystem Workforce Program Working Paper Number 29. 8 p.

Difs, K., E. Wetterlund, L. Trygg, and M. Söderström. 2010. Biomass gasification opportunities in a district heating system. *Biomass and Bioenergy* 34: 637-651.

Domac, J., K. Richards, S. Risovic. 2005. Socio-economic drivers in implementing bioenergy projects. *Biomass and Bioenergy* 28: 95-266.

Dong, L., H. Liu, S. Riffat. 2009. Development of small-scale and micro-scale biomass-fuelled CHP systems – A literature review. *Applied Thermal Engineering* 29: 2119-2126.

Dornburg, V. and A.P.C. Faaij. 2001. Efficiency and economy of wood-fired biomass energy systems in relation to scale regarding heat and power generation using combustion and gasification technologies. *Biomass and Bioenergy* 21(2):91–108.

Dovetail Partners, Inc. 2009. *Community-Based Bioenergy and District Heating: Benefits, Challenges, Opportunities and Recommendations for Woody Biomass.* 18 p.

Dovetail Partners, Inc. 2013. *Biomass Energy in Grant County: Case Studies.* Grant 2012-002: Next Steps in Scaling-up Woody Biomass Energy: Learning and Priorities. U.S. Endowment for Forestry and Communities, Inc. 49 p.

Dwivedi, P. R. Bailis, and T.G. Bush. 2011. Quantifying GWI of wood pellet production in the southern United States and its subsequent utilization for electricity production in the Netherlands/Florida. *Bioenerg. Res.* 4: 180-192.

Ecological Restoration Institute (ERI). 2013. *The efficacy of hazardous fuel treatments: A rapid assessment of the economic and ecologic consequences of alternative hazardous fuel treatments: A summary document for policy makers*. Northern Arizona University. 28 p.

Egger, C., C. Öhlinger, B. Auinger, B. Brandstätter, N. Richler, and G. Dell. N.d. "Biomass heating in Upper Austria: Green energy, green jobs." 40 p. Available at http://www.oec.at/en/publications/

Emhofer, W. 2012. "Biomass Combustion Technology." Paper presented at the International Training Seminar: Biomass Heating Market Development and Technologies, Linz, Austria, September 10-13.

Eugene Water Electric Board (EWEB). 2013. *Oregon Renewable Portfolio Standard 2012 Compliance Report and 2013-2030 Implementation Plan*. Available at: http://www.oregon.gov/energy/RENEW/RPS/Pages/RPS_Compliance.aspx. 8 p.

Evans, A.M. and A.J. Finkral. 2009. From renewable energy to fire risk reduction: a Synthesis of biomass harvesting and utilization case studies in US Forests. *GCB Bioenergy* 1: 211–219.

Federal Energy Regulatory Commission (FERC). 2012. *State of the Markets Report*. 72 p.

Forest Biomass Working Group. 2012. *Growing Oregon's Biomass Industry: Oregon's Forest Biomass Strategy.* Available at http://oregon.gov/energy/RENEW/Biomass/Pages/forest_biomass_working_group.aspx 24 p.

Franklin, J.F. and K.N. Johnson. 2012. A restoration framework for federal forests in the Pacific Northwest. *Journal of Forestry* 110(8): 429-439.

Gold, S. and S. Seuring. 2011. Supply chain and logistics issues of bio-energy production. *Journal of Cleaner Production* 19: 32-42.

Gunn, J.S., D.J. Ganz, W.S. Keeton. 2011. Biogenic vs. geologic carbon emissions and forest biomass energy production. *GCB Bioenergy* 4(3): 239-242.

Haden, A. 2013. "Grant County Biomass Thermal Energy Cluster." Presentation at the annual Harvesting Clean Energy Conference, Corvallis, Oregon, January 27-29.

Hagmann, R.K., J.F. Franklin, K.N. Johnson. In press. Historical structure and composition of ponderosa pine and mixed-conifer forests in south-central Oregon. *Forest Ecology and Management.*

Han, H.S., H.W. Lee, and L.R. Johnson. 2004. Economic feasibility of an integrated harvesting system for small-diameter trees in southwest Idaho. *Forest Products Journal* 54(2): 21-27.

Hessburg, P.F., J.K. Agee, and J.F. Franklin. 2005. Dry forests and wildland fires of the inland Northwest USA: Contrasting the landscape ecology of the pre-settlement and modern eras. *Forest Ecology and Management*, 211: 117-139.

Hibbard, M., S. Lurie, and T.H. Morrison. 2012. *Healthy Economies, Healthy Environments: Multifunctionality and the New Natural Resource Economy*. Rural Futures Lab Foundation Paper No. 5. 29 p.

Hudiburg, T.W., B.E. Law, C. Wirth, and S. Luyssaert. 2011. Regional carbon dioxide implications of forest bioenergy production. *Nature Climate Change* 1: 419-423.

Hurteau, M.D. and M.L. Brooks. 2011. Short- and long-term effects of fire on carbon in US dry temperate forest systems. *BioScience* 61(2): 139-146.

Itron. 2004. *Biomass Market Assessment*. Prepared for Oregon Energy Trust. 103 p.

Jenkins, B.M. 1997. A comment on the optimal sizing of a biomass utilization facility under constant and variable cost scaling. *Biomass and Bioenergy* 13(1/2): 1-9.

Johansson, L.S., C. Tullin, B. Leckner, P. Sjövall. 2003. Particle emissions from biomass combustion in small combustors. *Biomass and Bioenergy* 25: 435-446.

Johansson, A., P. Kisch, and M. Mirata. 2005. Distributed economies – a new engine for innovation. *Journal of Cleaner Production* 13(10–11): 971–979.

Jones, G., D. Loeffler, D. Calkin, W. Chung. 2010. Forest treatment residues for thermal energy compared with disposal by onsite burning: Emissions and energy return. *Biomass and Bioenergy* 34: 737-746.

Katers, J.F., A.J. Snippen, and M.E. Puettmann. 2012. Life-cycle inventory of wood pellet manufacturing and utilization in Wisconsin. *Forest Products Journal* 62(4): 289-295.

Kauffman, M., C. Davis, and P. Chang. 2012. *2011/12 Oregon Biomass Heat Case Studies.* 23 p.

Kelly, E.C. and J.C. Bliss. 2009. Healthy forests, healthy communities: An emerging paradigm for natural resource-dependent communities? *Society and Natural Resources* 22: 519-537.

Krumenauer, M. 2013. "Oregon's Biomass Experience: An Integrated Approach to Forest Biomass." Presentation at the Oregon State University Starker Lectures, Corvallis, Oregon, May 16.

Kuehl, G.J. 2010. Oregon's big gamble: BETC and the economics of renewable energy and conservation. *Oregon Law Review* 89(701): 701-724.

Kumar, A., J.B. Cameron, P.C. Flynn. 2003. Biomass power cost and optimum plant size in western Canada. *Biomass and Bioenergy* 24: 445-464.

Lippke, Oneil, Harrison, Skog, Gustavsson, and Sathre. 2011. Life cycle impacts of forest management and wood utilization on carbon mitigation: Knowns and unknowns. *Carbon Management* 2(3): 303-333.

Madlener, R. 2007. Innovation diffusion, public policy, and local initiative: The case of wood-fuelled district heating systems in Austria. *Energy Policy* 35: 1992-2008.

Malheur Nation Forest (MNF). 2011. *Southern Blues Restoration Coalition*. 48pp.

Mangoyana, R.B. and T.F. Smith. 2011. Decentralised bioenergy systems: A review of opportunities and threats. *Energy Policy* 39: 1286-1295.

Manomet Center for Conservation Sciences (Manomet). 2010. *Biomass Sustainability and Carbon Policy Study.* Prepared for the Commonwealth of Massachusetts Department of Energy Resources. 182 p.

Martinson, E.J. and P.N. Omi. 2013. Fuel treatments and fire severity: A meta-analysis. US For. Serv. Res. Pap. RMRS-RP-103WWW, Rocky Moutnain Res. Stn., Fort Collins, CO. 35 p.

Mason, C.L., B.R. Lippke, K.W. Zobrist, T.D. Bloxton, K.R. Ceder, J.M. Comnick, J.B. McCarter, and H.K. Rogers. 2006. Investments in fuel removals to avoid forest fires result in substantial benefits. *Journal of Forestry* 104 (1): 27–31.

McCormick, K. 2005. Sustainable Bioenergy Systems: Experiences from Sweden. Proceedings of the Asia Pacific Roundtable on Sustainable Consumption and Production, Melbourne, Australia, 10-12 October.

McCormick, K. 2010. Communicating bioenergy: A growing challenge. *Biofuels, Bioproducts and Biorefining* 4: 494-502.

McKechnie, J., S. Colombo, J. Chen, W. Mabee, and H.L. MacLean. 2011. Forest bioenergy or forest carbon? Assessing trade-offs in greenhouse gas mitigation with wood-based fuels. *Environmental Science & Technology* 45: 789-795.

McKendry, P. 2001. Energy production from biomass (part 2): Conversion technologies.

Bioresource Technology 83: 47-54.

McKinstry. 2012. *Enterprise School District Biomass Boiler Installation Measurement and Verification Report: Year 4*. 11 p.

McNeil Technologies, Inc. 2003. *Biomass Resource Assessment and Utilization Options for Three Counties in Eastern Oregon*. Prepared for the Oregon Department of Energy. 177 p.

Merschel, A.G., T.A. Spies, and E.K. Heyerdahl. In press. Mixed-conifer forests of central Oregon: Effects of logging and fire exclusion vary with environment. *Ecological Applications*.

Miller, J.D., H.D. Safford, M. Crimmins, and A.E. Thode. 2009. Quantitative evidence for increasing forest fire severity in the Sierra Nevada and Southern Cascade Mountains, California and Nevada, USA. *Ecosystems* 12: 16-32.

Mirata, M., H. Nilsson, and J. Kuisma. 2005. Production systems aligned with distributed economies: Examples from energy and biomass sectors. *Journal of Cleaner Production* 13 (10–11): 981–991.

Mitchell, S.R., M.E. Harmon, and K.E.B. O'Connell. 2009. Forest fuel reduction alters fire severity and long-term carbon storage in three Pacific Northwest ecosystems. *Ecological Applications* 19(3): 643–655.

Moseley, C. and E.J. Davis. 2010. *Stewardship Contracting for Landscape-Scale Projects.* Ecosystem Workforce Program Working Paper Number 25. 24 p.

National Forest Health Restoration: An Economic Assessment of Forest Restoration on Oregon's Eastside National Forests (NFHR). 2012. Prepared for Governor John Kitzhaber and Oregon's Legislative Leaders. 84 p.

National Institute for Food and Agriculture Newsroom. 2011. "Newsroom." Last modified October 11. http://www.csrees.usda.gov/newsroom/news/2011news/09281_biofuel_production.html

Nicholls, D. L, R.A. Monserud, and D.P. Dykstra. 2008. Biomass utilization for bioenergy in the Western United States. *Forest Products Journal* 58(1/2): 6-16.

Nicholls, D. L, R. Monserud, and D. Dykstra. 2009. International bioenergy synthesis-lessons learned and opportunities for the Western United States. *Forest Ecology and Management* 257(8): 1647–1655.

Nielsen-Pincus, M. and C. Moseley. 2009. *Social Issues of Woody Biomass Utilization: A Review of the Literature*. Ecosystem Workforce Program Working Paper Number 20. 15p.

Nielsen-Pincus, M. and C. Mosely. 2013. The economic and employment impacts of forest and watershed restoration. *Restoration Ecology* 21(2): 207-214.

Oak Ridge National Laboratory (ORNL). 2009. *Biomass Energy Data Book, 2nd ed*. ORNL/TM-2009/098. Prepared for the United States Department of Energy. 246 p.

Oregon Forest Resources Institute (OFRI). 2006. *Biomass Energy and Biofuels from Oregon's Forests*. 410 p.

NVivo. N.d. "About Queries." Last accessed 3/14/14. http://help-nv9-en.qsrinternational.com/nv9_help.htm#concepts/about_queries.htm.

Oregon Blue Book. 2014. "Incorporated Cities: Arranged by County." http://bluebook.state.or.us/local/cities/bycounty.htm.

Oregon Department of Energy (ODOE). N.d.-a. "Oregon's Bioenergy Resource Map." Last accessed 3/18/14. http://www.oregon.gov/energy/RENEW/Biomass/Pages/Bioenergy_map.aspx.

Oregon Department of Energy (ODOE). N.d.-b. "RPS Compliance." Last accessed 3/05/14. http://www.oregon.gov/energy/RENEW/RPS/Pages/RPS_Compliance.aspx.

Oregon Department of Energy (ODOE). N.d.-c "Where does Oregon's Electricity come from?" Last Accessed 3/20/14. http://www.oregon.gov/energy/pages/oregons_electric_power_mix.aspx.

Oregon Department of Energy (ODOE). N.d.-d. "Wood Energy Cluster Development Resources." Last accessed 03/20/14. http://www.oregon.gov/energy/RENEW/Biomass/Pages/Wood-Energy-Cluster-Development-Resources.aspx.

Oregon Department of Energy (ODOE). 2013. *State of Oregon, Oregon Department of Energy: 2013-2015 Biennial Energy Plan*. 69 p.

Pacific Northwest Utilities Conference Committee (PNUCC). 2010. *Northwest Regional Forecast of Power Loads and Resources*. 33 p.

Payne, T. 2013. "Getting it Out of the Forest." Panel at the annual Harvesting Clean Energy Conference, Corvallis, Oregon, January 27-29.

Phillipi, L. 2013. "The Future of Our Forests: Energy's Role in Forest Management." Panel at the annual Harvesting Clean Energy Conference, Corvallis, Oregon, January 27-29.

Powell, D.C. 2011. Active management of dry forests in the Blue Mountains: Silvicultural considerations. US For. Serv. White Paper F14-SO-WP-Silv-4. 128 p.

Power, T.M. and R. Barrett. 2001. *Post-Cowboy Economics: Pay and Prosperity in the New American West*. Washington DC: Island Press.

Power, T.M. 2005. Public timber supply, market adjustments, and local economies: Economic assumptions of the Northwest Forest Plan. *Conservation Biology* 20(2): 341-350.

Rainville, R., R. White, and J. Barbour. 2008. Assessment of timber availability from forest restoration within the Blue Mountains of Oregon. US For. Serv. Gen. Tech. Rep. PNW-GTR-752, Pacific Northwest Res. Stn., Portland, OR. 65 p.

Reeb, J. 2009. *Home Heating Fuels: Should I switch to firewood or wood pellets?* EC 1628-E. Oregon State University Extension Service. 6 p.

Remington, C., C. Davis, and M. Krumenauer. 2012. *Oregon's Thermal Energy Baseline.* Sustainable Northwest. 26 p.

Resource Innovations. N.d. *Wood Heat Solutions: A Community Guide to Biomass Thermal Projects.* 31 p.

Restaino, J.C. and D.L. Peterson. 2013. Wildfire and fuel treatment effects on forest carbon dynamics in the western United States. *Forest Ecology and Management* 303: 46-60.

Rezaie, B. and M.A. Rosen. 2012. District heating and cooling: Review of technology and potential enhancements. *Applied Energy* 93: 2-10.

Robbins, P., H. Gosnell, and S.J. Gilbertz. 2009. Writing the new west: A critical review. *Rural Sociology* 74(3): 356-382.

Rural Voices for Conservation Coalition and Coalition for Eastern Forests and Communities (RVCC and CEFC). 2011. "Sustainable Biomass Energy: The Need for a Comprehensive Energy Policy that Includes Thermal Energy." 4 p.

Salomón, M., T. Savola, A. Martin, C. Fogelholm, and T. Fransson. 2011. Small-scale biomass biomass CHP plants in Sweden and Finland. *Renewable and Sustainable Energy Reviews*

15: 4451-4465.

Schmidt, J., S. Leduc, E. Dotzauer, G. Kindermann, E. Schmid. 2010. Cost-effective CO_2 emission reduction through heat, power and biofuel production from woody biomass: A spatially explicit comparison of conversion technologies. *Applied Energy* 87: 2128-2141.

Schultz, C.A., T. Jedd, and R.D. Beam. 2012. The collaborative forest landscape restoration program: A history and overview of the first projects. *Journal of Forestry* 110(7): 381-391.

Sessions, J., K. Tuers, K. Boston, R. Zamora, and R. Anderson. 2013. Pricing forest biomass for power generation. *Western Journal of Applied Forestry* 28(2): 51-56.

Shindler, B. 2009. "Public Acceptance of Wildland Fire Conditions and Fuel Reduction Practices: Challenges for Federal Forest Managers." In *People, Fire, and Forests: A Synthesis of Wildfire Social Science,* edited by T.C. Daniel, M. Carroll, C. Moseley, and C. Raish, 37-54. Corvallis: Oregon State University Press.

Sikkema, R., M. Steiner, M. Junginger, W. Hiegl, M.T. Hansen, and A. Faaij. 2010. The European wood pellet markets: Current status and prospects for 2020. *Biofuels, Bioproducts and Biorefining* 5 (3): 250–278.

Sippula, O., J. Hokkinen, H. Puustinen, P. Yli-Pirilä, J. Jokiniemi. 2009. Comparison of particle emissions from small heavy fuel oil and wood-fired boilers. *Atmospheric Environment* 43: 4855-4864.

Slee, B. 2009. Re-imagining forests as multifunctional and sustainable resources for a low carbon rural economy: The potential for forest-based rural development. Paper presented at Developing Rural Policies to Meet the Needs of a Changing World OECD Conference, Quebec, October 13-15.

Smith, D., J. Sessions, K. Tuers, D. Way, and J. Traver. 2012. Characteristics of forest-derived woody biomass collected and processed in Oregon. *Forest Products Journal* 62 (7/8): 520-527.

Solomon, B.D., J.R. Barnes, K.E. Halvorsen. 2007. Grain and cellulosic ethanol: History, economics, and energy policy. *Biomass and Bioenergy*. 31: 416-425.

Spelter, H. and D. Toth. 2009. North America's wood pellet sector. US For. Serv. Res. Pap. FPL-RP-656, Forest Products Laboratory. Madison, WI. 21 p.

Stephens, S.L., J.J. Moghaddas, C. Edminster, C.E. Fiedler, S. Haase, M. Harrington, J.E. Keeley, E.E. Knapp, J.D. McIver, K. Metlen, C.N. Skinner, and A. Youngblood. 2009. Fire treatment effects on vegetation structure, fuels, and potential fire severity in western U.S. forests. *Ecological Applications*. 19(2): 305-320.

Stephens, S.L., R.E. Boerner, J.J. Moghaddas, E.E.Y. Moghaddas, B.M. Collins, C.B. Dow, C. Edminster, C.E. Fiedler, D.L. Fry, B.R. Hartsough, J.E. Keeley, E.E. Knapp, J.D. McIver, C.N. Skinner, and A. Youngblood. 2012. Fuel treatment impacts on estimated wildfire carbon loss from forests in Montana, Oregon, California, and Arizona. *Ecosphere* 3(5)38: 1-17.

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

Strauss, A.L. 1987. *Qualitative Analysis for Social Sciences*. Cambridge: Cambridge University Press.

Sustainable Northwest (SNW). 2013. "The Solution Grows on Trees." Last modified November

11. http://www.sustainablenorthwest.org/blog/posts/the-solution-grows-on-trees.

United States Census Bureau. 2014. "State and County Quickfacts." Last modified January 6. http://quickfacts.census.gov/qfd/states/41/41023.html.

United States Census Bureau. 2006-2010. "American Community Survey 5-Year Estimates, DP-03 Selected Economic Characteristics." Available at http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_10_SF4_DP03&prodType=table.

United States Department of Agriculture Economic Research Service (USDA ERS). 2014. "Atlas of Rural and Small-Town America." Last modified February 7. http://www.ers.usda.gov/data-products/atlas-of-rural-and-small-town-america/about-the-atlas.aspx#.UyuQqHddVyo.

United States Department of Agriculture Forest Service (USDA FS). N.d. "Eastside Restoration." Last Accessed 3/20/14. http://www.fs.usda.gov/detail/r6/landmanagement/resourcemanagement/?cid=stelprdb5423597.

United States Department of Agriculture Forest Service (USDA FS). 2012. *Increasing the Pace of Restoration and Job Creation on Our National Forests*. 9 p.

United States Department of Education. 2005. "Qualified Zone Academy Bonds." Last modified February 17. http://www2.ed.gov/programs/qualifiedzone/generalqzab.html.

United States Energy Information Administration (US EIA). 2014. "Short-Term Energy Outlook." Last modified March 11. Available at http://www.eia.gov/forecasts/steo/realprices/.

United States Environmental Protection Agency (EPA). 2013. "Air Trends." Last modified September 3. http://www.epa.gov/airtrends/.

United States Environmental Protection Agency (US EPA). N.d. *Small Entity Compliance Guide for Area Source Boilers*. National Emission Standards for Hazardous Air Pollutants for Area Sources: Industrial, Commercial, and Institutional Boilers. 40 CFR Part 63, Subpart JJJJJJ. Available at: http://www.epa.gov/ttn/atw/boiler/boilerpg.html. 36 p.

Upreti, B.R. 2004. Conflict over biomass energy development in the United Kingdom: Some observations and lessons from England and Wales. *Energy Policy* 32: 785-800.

Vallios, I., T. Tsoutsos, G. Papadakis. 2008. Design of biomass district heating systems. *Biomass and Bioenergy* 33: 659-678.

Villeneuve, J., J.H. Palacios, P. Savoie, S. Godbout. 2012. A critical review of emission standards and regulations regarding biomass combustion in small scale units (<3 MW). *Bioresource Technology* 111: 1-11.

Weber, B. and Y. Chen. 2012. Federal forest policy and community prosperity in the Pacific Northwest. *Choices: The Magazine of Food, Farm and Resource Issues* 27(1).

Westerling, A.L., H.G. Hidalgo, D.R. Cayan, T.W. Swetnam. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. *Science* 313: 940-943.

Wilson, P.L., and J.W. Funck, and R.B. Avery. 2010. Fuelwood characteristics of northwestern conifers and hardwoods (updated). US For. Serv. Gen. Tech. Rep. PNW-GTR-810, Pacific Northwest Res. Stn., Portland, OR. 50 p.

Winkler, R., D.R. Field, A.E. Luloff, R.S. Krannich, and T. Williams. 2007. Social landscapes of the Inter-Mountain West: A comparison of 'Old West' and 'New West' communities. *Rural Sociology* 72(3): 478-501.

Wynsma, B., R. Aubuchon, D. Len, M. Daugherty, and E. Gee. 2007. Woody biomass utilization deskguide. US For. Serv. National Technology and Development Program. 84 p.

Yin, R.K. 2003. *Case Study Research: Design and Methods, 3rd ed*. Thousand Oaks: Sage Publications.

Zhang, Y., J. McKechnie, D. Cormier, R. Lyng, W. Mabee, A. Ogino, and H.L. MacLean. 2010. Life cycle emissions and cost of producing electricity from coal, natural gas, and wood pellets in Ontario, Canada. *Environmental Science & Technology* 44: 538-544.

APPENDICES

Appendix A: Detailed interviewee descriptions.

Interviewee Identification	Organization Category	Sex	Description
01	Forest Products Industry	M	Owner of a forest products manufacturing company based in Oregon. Company produces densified wood pellets and bricks, smoking fuels, and animal shavings and bedding.
02	Forest Products Industry, Blue Mountain Forest Partners	M	Timber manager for a sawmill and pellet plant located in Grant County. The company produces lumber, densified wood pellets and bricks, and animal shavings and bedding.
03	Project Champion, Non-Profit	M	A project champion for the first biomass boiler installed in an Oregon school. Also Executive Director of a non-profit in Wallowa County focused on rural economic development and land stewardship.
05	Bioenergy Developer	M	President of a bioenergy development company based out of Portland Oregon. Interviewee was involved in the pellet plant construction located in Grant County, and is also responsible for the four TBE installations in Grant County.
07	County Government, Blue Mountain Forest Partners	M	Grant County Commissioner and business owner.
10	US Forest Service, Blue Mountain Forest Partners	M	US Forest Service staff member for the Malheur National Forest.
11	Project Champion	M	CEO of a hospital in Harney County and project champion of the first TBE installation in Oregon.
12	Forest Products Industry	M	Manager of a whole log processing facility in Wallowa County, producing post/pole, firewood, densified wood products, heat and electricity.
13	Forest Products Industry	M	President of a forest contracting business. Involved in a former business venture to construct a CHP facility in Wallowa County.
14	Conservation Advocate, Non-Profit, Blue Mountain Forest Partners	F	Director of a non-profit conservation organization that works in the Blue Mountains and Eastern Oregon Cascades to “protect, defend, and restore” natural ecosystems.
16	Oregon Department of Forestry	M	Stewardship Forester with Oregon Department of Forestry based out of La Grande Oregon.
17	Project Champion	F	School board member and project champion for a TBE installation in a Grant County K-12 public school.
18	Community Member, Blue Mountain Forest Partners	M	Grant County community and local collaborative member, involved with assessing Malheur National Forest restoration needs and bioenergy potential in the county.
20	County Government, Blue Mountain Forest Partners	F	Grant County Economic Development Coordinator.
22	Forest Products Industry, Blue Mountain Forest Partners	F	Self-employed forestry consultant in Grant County.
23	US Forest Service, Blue Mountain Forest Partners	F	US Forest Service staff for the Malheur National Forest.

Appendix A (Continued)

24	Conservation Advocate, Non-Profit, Blue Mountain Forest Partners	M	Conservation advocate with an Oregon non-profit conservation group that aims to “protect and restore wildlands, wildlife and waters”.
27	County Government, Blue Mountain Forest Partners	M	Former Grant County Judge.
32	Oregon Department of Forestry	M	Biomass Resources Specialist with Oregon Department of Forestry, based out of Springfield Oregon.
33	Project Champion	M	Superintendent of a Grant County School District, project champion of a TBE installation in a Jr./Sr. high school.

Appendix B: Final node framework, using the computer software program NVivo.

Nodes were inductively assigned to all transcribed sources (interviews and researcher notes), and were also deductively informed by literature regarding distributed economies, new natural resource economies, and scale. Below the nodes are displayed as a hierarchy; most nodes describe a particular aspect of the node one level above. The number of sources that each node was assigned to, in addition to the number of times each node was assigned, are included. Higher-level nodes aggregate the sources and references of lower-level nodes.

Name	Sources	References
BE Development	53	2546
BE-Business	34	386
Alternative options	26	145
Financing	25	121
Savings	17	53
BE-Govt	35	192
BE-policy	22	76
Subsidies	23	76
BE-Public opinion	28	130
Education	9	22
Climate change	29	150
Air quality	13	34
Carbon	15	25
Renewable	18	49
Dev Model	32	405
Centralized	4	7
Decentralized	12	40
Integrated	23	133
Scale	28	217
Large	12	29
Small	19	60
Implementation	22	148
Challenges	20	94
Obstacles	3	6
Driver	20	53
Infrastructure	30	433
Knowledge	22	157
Champions	9	27
Models	21	92
Europe	9	38
New England	6	10
Workforce	13	32
Physical	27	271
BE-FPI	20	131
Tech	18	55
Transportation	16	49
Types of BE	48	702
Cogen	25	93
Electricity	17	69
Heat	34	254
Liquid fuels	7	18
Manufacturing	22	119

Appendix B (Continued)

Community development	46	573
Buy local	22	103
Isolation	8	15
Local assets	19	65
Economic activity	44	377
Community investment	8	19
Natural resource	42	302
Consumption	9	17
Productionist	34	204
Protection	17	44
Non-natural resource	11	15
Social wellbeing	24	88
Demographics	11	24
Relationships	9	19
Forest health	53	1824
Ecology	40	394
Disturbance	32	158
Disease	9	14
For-climate	7	9
Wildfire	32	130
Dry forest	7	20
Nutrient cycling	6	12
Science	24	57
Structure	26	127
Density	19	51
Large stucture	11	34
Old growth	8	25
Government	43	729
For-policy	24	67
Planning	13	31
USFS	43	615
Collaboratives	34	213
Coll-relationships	10	14
Common ground	10	21
Stewardship	14	28
USFS-Funding	12	47
Public opinion	21	87
Distrust	4	10
Restoration	46	613
Active management	42	487
Economics	23	133
Utilize	18	61

Appendix B (Continued)

FPI-Infra	30	151
Southwest	6	7
Timber sales	18	54
For-Protection	21	57
Litigation	13	26
Rest-scale	19	63
Scale mismatch	10	22
GC case study	34	185
MLC	30	135
PW	13	25
Geo scale	40	550
International	17	36
Local	27	200
National	32	152
Regional	29	162
Market	44	745
Demand	34	298
Dem-product	17	63
Dem-raw material	26	157
Dem-nonsaw	22	112
Dem-saw	6	14
Energy	23	73
Supply	41	446
Raw material	39	387
Non-sawlog	30	138
Sawlog	27	100
Supp-product	14	59
Quality	6	24
Miscellaneous	24	69
Authority	16	28
Paradigm	6	25
Quote	34	234
Risk	32	213
Flexibility	13	19
Stability	20	45
Sustainability	18	66
3-Legs	2	4
Urgency	7	13

Appendix C: Explanation of coding analysis process.

The NVivo computer software (Version 9) permits users to construct and run queries using text searches, word frequency, coding, matrix coding, compound, coding comparison, or group formats (NVivo n.d.). Queries can search both text and assigned nodes. For example, matrix coding searches for the co-occurrence of designated nodes. Researchers can use Boolean logic to construct meaningful queries, such as searching for every instance where "A and B, and not C" occur. Below we offer examples of early queries and their results to illustrate how this process led to an evolution and refinement of important case themes over time.

Our first queries identified evidence coded as "driver" or "challenge" with regard to developing a bioenergy industry. Retrieved text was analyzed for co-occurring nodes, as well as primary themes and sub-themes. **Tables A.1** and **A.2** reflect the preliminary results from these initial queries. Next, we constructed new queries with the objective to 'cast a wider net' to capture data that reflects these themes, but may not have been coded as "driver" or "challenge". One result of these queries and our evolving understanding of the case is represented in **Table A.3**. Notice that "themes" and "sub-themes" have been reframed as "attributes" and "motivations". This process of building on queries and refining themes was repeated multiple times. The attributes and motivations in **Table A.3** evolved into the nine attributes identified in **Table A.4**. These were ultimately condensed into five primary factors and supporting attributes that influence bioenergy developments, shown in **Table A.5**. The five factors were ranked according to the number of times each factor was referenced, calculated by summing the number of references assigned to each attribute (including data from interviews and participant observation). We also counted the number of interviewees (out of twenty) who referenced each factor. We considered the final five factors to reflect the key themes carried throughout this process in the most meaningful and concise manner.

Appendix C (Continued)

Table A.1: List of initial themes and sub-themes identified from queried data coded as a bioenergy "driver," using NVivo query tools and manual analysis.

Driver Themes	Sub-Themes
Business	• Market demand • Savings • Policy and incentives • Sustainable supply • Public opinion • Risk
Infrastructure	• Models • Technology • Champions
Forest Focus	• Disturbance and active management • Market pull • Waste utilization • USFS directive • Healthy forests, health communities • Collaborative input
Community	• Community investment • Social wellbeing • Buy local • Economic activity • Productionist • Diversify
Climate	• Climate change • Air quality
Models	• European local resilience • European politics • New England

Appendix C (Continued)

Table A.2: List of initial themes and sub-themes identified from queried data coded as a bioenergy "challenge," using NVivo query tools and manual analysis.

Challenge Themes	Sub-Themes
Business	• Market demand • Financing • Policy and incentives • Sustainable supply • Public opinion • Risk assessment
Infrastructure	• Models • Knowledge • Physical • Scale
Forest Focus	• Market pull • USFS • Economic activity
Climate	• Climate change

Table A.3: Example of one iteration of evolving themes and sub-themes refined through expanded queries and manual analysis. This example shows themes reframed as bioenergy development attributes and motivations, with associated sub-categories.

Attributes	Sub-Categories
Business	• Market demand • Financing • Policy and incentives • Sustainable supply • Public opinion • Risk of supply
Infrastructure	• Existing models • Available technology • Competent developers • Champions • Physical infrastructure
Motivations	**Sub-Categories**
Business	• Personal savings/economy • Risk assessment
Forest	• Disturbance and active management • Market pull • Waste utilization
Community	• Healthy forests/communities • Economic activity • Local resilience • Social wellbeing

Appendix C (Continued)

Table A.4: Example of a later iteration of themes, framed as attributes.

Attributes
1. Alternative Options
2. Financing
3. Scale
4. Development Model
5. Policy and Incentives
6. Available Supply
7. Public Opinion
8. Forest Products Industry Infrastructure
9. Social Infrastructure

Table A.5: Final iteration of bioenergy development themes, framed as primary factors with attributes.

Factors	Attributes
1. Available Supply	• Magnitude • Accessibility
2. Social Acceptance	• Education and Awareness • Climate • Scale of Utilization
3. Financing	• Capital and Operating Costs • Funding Mechanisms
4. Forest Sector	• Integration and Capacity • Local Economies
5. Scale	• Biomass Energy Facility

Appendix D: Select characteristics of six thermal bioenergy facilities in Oregon outside of the case data.

Project Name	Feed-stock	Capacity MMBtu/hr (kW)	Approx. Demand (tons/yr)	Capital Costs ($)	Approx. Savings ($/yr)[†]	Funding Sources
Estacada[a,b]	Pellet	4.0 (1172)	185	1,007,363	13,000	• ODOE ARRA ($450,000) • Utility ratepayer charges • QZAB ($600,000) • BETC ($64,239)
Three Rivers Illinois Valley HS[b]	Pellet	1.03 (302)	185	418,040	30,000 (both Three Rivers schools)	• ODOE ARRA ($283,700) • BETC ($29,900) • QZAB ($134,340)
Three Rivers Evergreen[b]	Pellet	0.75 (220)	106	377,775	30,000 (both Three Rivers schools)	• ODOE ARRA ($220,122) • BETC ($8,100) • QZAB ($157,000)
Sisters School District[b]	Pellet	1.27 (372)	250	350,000	35,000 – 65,000	• BETC ($148,000) • Unique reserve funds
Days Creek[a]	Pellet	2.0 (586)	ND	480,000	10,000	• ODOE ARRA ($276,000) • BETC • QZAB
Oak Ridge School District[b]	Pellet	0.896 (264)	110	475,444	20,000	• ODOE ARRA ($265,898) • BETC ($40,271) QZAB ($330,000)

ND: No data.
[†]Savings represent prior heating costs less heating costs with biomass. Does not include deductions for loan payments.
[a]ODOE (n.d.-d)
[b]Kauffman *et al*. (n.d.)
Acronyms: ARRA is American Recovery and Reinvestment Act; BETC is Business Energy Tax Credit; ODOE is Oregon Department of Energy; QZAB is Qualified Zone Academy Bond; USDA is United States Department of Agriculture.

Appendix E: Thermal bioenergy data used to determine average capacity and annual fuel use for scaling up exercise.

State	Project Name	Installed	Feedstock	Capacity		Annual Fuel Use (tons or GT)†
				kW	MMBtu/hr	
VT	Barre Town Elementary and Middle School[a]	1996	wood chip	1300	4.5	688
ID	Council Schools[a]	2005	wood chip	440	1.5	400
MT	Darby Schools[a]	2003	wood chip	900	3	850
ME	Leavitt Area High School[a]	1999	wood chip	1300	4.5	ND
VT	Mount Abraham Union High School[a]	2006	wood chip	1800	6	900
OR	Enterprise School District[b]		wood chip	733	2.5	600
OR	Estacada[c,d]	2011	pellet	1172	4.0	185
OR	Three Rivers Illinois Valley HS[d]	2011	pellet	302	1.03	185
OR	Three Rivers Evergreen[d]	2011	pellet	220	0.75	106
OR	Sisters School District[d]	2011	pellet	372	1.27	250
OR	Days Creek[c]	2011	pellet	586	2.0	ND
OR	Oak Ridge[d]	2011	pellet	264	0.896	110
OR	Harney County Hospital[b]	2008	pellet	147	0.5	45
OR	Grant County Airport[b]	2010	pellet	220	0.75	50
OR	Blue Mountain Hospital[b]	2011	pellet	528	1.8	380
OR	Grant Union[b]	2012	pellet	586	2	180
OR	Prairie City[b]	2012	pellet	762	2.6	240
Average Pellet				469	1.60	173.10
Average Wood Chip				1079	3.67	687.6

†Annual fuel use for wood chip TBE assumed to be in green tons, and tons for pellet TBE.
ND: No data.
[a]BERC (2014)
[b]Case data
[c]ODOE (n.d.-d)
[d]Kauffman *et al*. (n.d.)