OVERCOMING BARRIERS TO BIOMASS COGENERATION IN US WOOD PRODUCTS INDUSTRY

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Abstract. Cogeneration, also known as combined heat and power, is the simultaneous generation of electric and thermal energy from the same fuel source. Some proven benefits of cogeneration are much higher efficiencies than conventional power generation and its ability to facilitate distributed energy and lower energy costs. Also, when cogeneration is fueled with wood biomass, there are additional environmental benefits such as using a renewable energy source and lower greenhouse gas emissions. However, only a small number of wood product manufacturers (North American Industry Classification System codes 321 and 337) have adopted this technology. In this study, drivers, perceptions, and barriers for cogeneration were investigated to gain understanding of the reasons for the low adoption of this technology among wood product manufacturers. Interviews of experts and companies were conducted to identify and understand major topics of cogeneration adoption within the industry. Subsequently, a nonprobability, target survey of nonadopters was carried out to identify operational characteristics, perceptions about benefits of cogeneration, and barriers to its implementation. Findings show that economies of scale and coincidence between thermal and electric loads are some of the major factors for cogeneration feasibility. Main barriers identified were the initial investment and complexity, companies' return-on-investment requirements, utility tariff policies, and inadequate policies and incentives. Another major finding was a lack of awareness and knowledge about cogeneration, which presents organizations that support the forest products industry with an opportunity to provide education and outreach. However, because of the small sample size (52 responses), generalization of these results to the population of interest is not feasible.

Keywords: Forest products industry, cogeneration, combined heat and power.

INTRODUCTION

The US wood products industry has faced many difficulties and significant downsizing during the last decade. Competition from imports and the decline in the housing industry, among other developments, have caused thousands of plant closures throughout the country (Woodall et al 2011). Adding to this challenging environment has been the steady increase in energy prices. For example, the price of electricity for industrial users has increased at an average annual rate of 3.2% from 2003 to 2013 (EIA 2014). A comparison of purchased energy as a percentage of value of shipments from 1999 to 2009 in the wood products industry showed increases between 18% and 82% (Fig 1). In a survey conducted in 2010 to identify the impact of rising energy prices on the hardwood industry (Espinoza et al 2011), 62% of respondents reported that their

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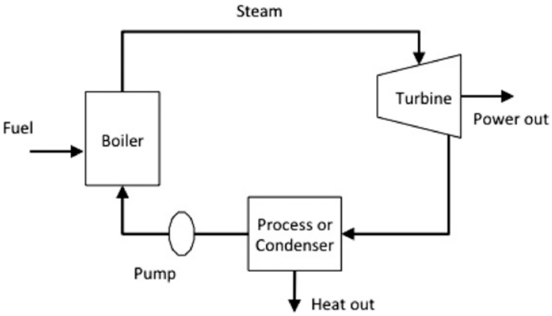


Figure 1. Steam turbine power cycle (EPA 2007).

energy expenditures had increased during the previous 5 yr and that the magnitude of the increase was on average 19%. This is very significant for an industry with historically low profit margins (AHEC 2006). The increased energy costs clearly threaten profitability and indicate a need to decrease energy expenditures.

Another important development during this time has been the increase in concerns about energy independence, climate change, and environmental sustainability. There has been a global push to increase the share of energy generated from renewable sources, because these types of fuels produce relatively low levels of greenhouse gas emissions. For example, the European Union has a goal of 20% of energy inputs coming from renewable sources by 2020 (European Comission 2011). In the United States, 29 states now have renewable energy portfolio standards and 9 have renewable energy goals (DSIRE 2014; NYSERDA 2015), and the federal government aims to have 20% of the electric energy consumed by its agencies sourced from renewable sources by 2020 (The White House 2013). These goals invariably consider a mix of renewable energy sources such as solar, wind, hydropower, geothermal, and biomass. Among the latter, woody biomass has been gaining attention for its environmental advantages compared with fossil fuels: it is abundant, is renewable, has low carbon emissions, metals, and sulfur, and produces minimal amounts of ash compared with coal (Bergman and Zerbe 2004; Bowyer et al 2011; Jackson et al 2010). Given that about 40% of the electric energy in the United States is generated from coal (EIA 2014) and coal is responsible for 24.5% of all carbon dioxide emissions and also for a great part of sulfur dioxide and nitrogen oxide emissions to the atmosphere (C2ES 2014), significant benefits could be gained from increasing the use of wood biomass for both thermal and electric energy generation. In addition, wood biomass has cost advantages compared with other energy sources; for example, the average price of electricity in 2013 was \$18.9 per GJ, whereas the price of wood waste and biomass-based energy for industrial use averaged \$2.46 per GJ in 2012 (EIA 2014). The forest products industry has historically sourced a considerable part of its energy from wood biomass, making the sector a leader in biomass utilization for energy generation, with 53% of its energy inputs from biomass (EIA 2014).

Cogeneration can be defined as the simultaneous generation of thermal and electrical energy from the same energy source (EPA 2014a). Cogeneration plants typically have efficiencies that double those of simple power plants, because they use rejected heat to produce thermal energy (Fig 1). Facilities that generate significant amounts of biomass as a byproduct, pay high prices for purchased electricity, and have a steady need for steam are good candidates for cogeneration (EPA 2014b). Also, under the right conditions, cogeneration can be an opportunity for the facility to earn revenue from supplying energy to the local utility. The US pulp and paper industry generated about two-thirds of their energy needs from biomass in 2005, and close to 100% of the electricity generated on-site was cogenerated (Kowalczyk 2012). Within the US wood products industry (North American Industry Classification System [NAICS] codes 321 [wood products] and 337 [furniture and related products]; US Census Bureau 2015), cogeneration has the potential to cover a considerable part of its energy needs from wood residues. The only estimate of cogeneration potential in wood products and furniture industries calculated a 2 GW of additional cogeneration capacity (OnSitEnergy Corporation 2000). However, relatively few companies in the industry have adopted cogeneration technology. According to data from the combined heat and power (CHP) database, wood products and furniture companies represent only 8% of the cogeneration capacity in the forest products industry and only 1% of the total cogeneration capacity in the country (ICF International 2013). A survey of primary and secondary hardwood companies found that only 3.4% of respondents had adopted some kind of cogeneration technology (Espinoza et al 2011). Similarly, the Energy Consumption by Manufacturers Survey of 2010 reported that only 0.5% of wood products establishments operated some cogeneration technology (EIA 2014). Possible reasons for this lack of widespread adoption are high initial investment, not enough steam pressure generated on-site, complexity of operation, more profitable outlets for biomass, environmental regulations, low fossil fuel cost (ie natural gas), and costs outweighing benefits (Lamb 2008). A number of studies have been conducted in the past looking at the feasibility of wood-fueled cogeneration. A 2010 study explored the feasibility of developing woody biomass cogeneration in the sawmills of western Montana (NorthWestern Energy 2010). The study concluded that no obstacles existed in terms of biomass supply, technology, interconnection, and environmental permitting but found that the size of the investment was a major challenge. Feasibility of wood-based cogeneration was also investigated in an integrated forest products company in Oregon (The Beck Group 2011). The analysis concluded that given the projected revenues and expenses, the project was not financially feasible at the time of the analysis, with the major flaw being the high cost of the fuel. A much older study analyzing the economic feasibility of cogeneration at sawmills in West Virginia (Brock 1987) found that cogeneration was only feasible for large sawmills (with more than 23,597 m^3 of annual production) and only under certain conditions (tax credits and avoided costs of $0.035 per kWh). Lastly, another study in West Virginia analyzed the economic suitability of implementing cogeneration in a wood products industrial park (Vasenda and Hassler 1993) and concluded that the project was unfeasible, mainly because of the high capital cost of the plant and the small size of the operation (2.5 MW). Adequate policies and new developments in cogeneration technology may help overcome some barriers to its adoption. Also, there is a lack of current information about the benefits and drawbacks of cogeneration applied to the wood products industry. Research is needed to develop a sound, detailed scientific analysis to help understand the potential benefits of cogeneration operations for the wood products industry and the major factors for technical and economic feasibility. Outcomes will facilitate decision making by companies interested in the technology.

RESEARCH OBJECTIVES

As environmental concerns intensify and energy prices rise, the US wood products industry faces a strong motivation to improve energy efficiency and decrease energy consumption. In addition, the market environment also urges the industry to focus on cost reduction to sustain its profitability and compete with cheaper imports. One alternative is the adoption of energy-saving technology. Cogeneration from woody biomass represents a significant opportunity for most primary and secondary mills to decrease their expenditures in thermal and electric energy through the use of byproducts, thus becoming more competitive.

The goal of this study was to evaluate wood-biomass-based cogeneration technology for US wood product manufacturers and to identify barriers to its adoption. The specific objectives were to 1) investigate the status of biomass-based cogeneration in the wood products industry, 2) identify perceived and actual barriers to adoption of cogeneration, and 3) investigate economical and technical conditions under which cogeneration could become a viable option for wood product manufacturers.

METHODS

To accomplish the study's objectives, a combination of literature review, expert and industry interviews, and a target survey of wood product manufacturers was used. A detailed explanation of methods is given in the following sections.

Interviews

After an extensive literature review, interviews with cogeneration experts and industry representatives were conducted to identify and learn about the critical topics of cogeneration as they apply to the wood products industry. Particular attention was placed on the conditions under which it becomes a viable option for energy generation in the wood products industry and the major barriers to its adoption. A list of potential interviewees was compiled by consulting several sources such as relevant publications and suggestions by experts. Technology experts, industry adopters, and nonadopters were included in this list. Initial contacts were made to ask for participation and schedule interviews. Table 1 lists the types of organizations and roles of the interviewees. Specific topics included in the interviews were 1) conditions and drivers for cogeneration, 2) barriers to cogeneration, 3) role of policies, and 4) the interviewee's outlook for cogeneration. The interviews were recorded, transcribed by a professional service, and then coded for analysis. Established qualitative research methods for thematic content analysis (Berg 2001) were used to analyze and identify major themes from the transcripts. Specifically, the transcripts were analyzed in four steps: a first round to identify potential errors or inconsistencies; a second, very detailed reading to identify major themes in the transcripts (open coding, an initial organization of the data); a third step to code the data in categories and subcategories; and lastly, the interpretation of results (connecting categories and themes to develop a story). Organization and analysis of the responses were carried out using Excel spreadsheet software (Microsoft, Redmond, WA).

Table 1. Interviewees' organizations and roles.

Organization	Role
University	Bioenergy policy expert
Wastewater treatment plant	Superintendent
Engineering firm specialized on bioenergy systems	Principal
Wood product manufacturer—nonadopter	Facility engineering manager
Wood product manufacturer—nonadopter	Research and development
Wood product manufacturer—nonadopter	Director
University campus—adopter	Facilities manager
Wood product manufacturer—adopter	Environmental manager
Pulp and paper manufacturer—adopter	Director of energy services
Wood product manufacturer—adopter	Operations manager

Target Survey of Nonadopters

With the major input of the expert and industry interviews, a targeted web-based survey of US wood product manufacturers was conducted. Nonadopters were the main focus of this survey. Web surveys are increasingly popular and are a very cost-effective way of collecting information (Rea 2005). Carefully designed web surveys can achieve response rates comparable with the more traditional method of mailed surveys (Kaplowitz et al 2004). The targeted sampling approach used was a nonprobability strategy in which the researchers do not have certainty of if all potential respondents have the same chance of selection (Rea 2005), thus generalizations from the results cannot be made to the entire population of interest. The reasons for selecting this sampling strategy as opposed to random sampling were mostly related to time and resource limitations and availability of lists of current and valid e-mail addresses. However, efforts were made to have a sample as representative of the target population as possible, as explained in the following section.

Sample development. A convenience sample of companies in the population of interest (NAICS codes 321 [wood products] and 337 [furniture and related products]) was developed using the Wood2Energy database (Wood2Energy 2014) and other sources. This database is maintained by University of Tennessee's Center for Renewable Carbon and contains 23,685 records (as of September 2014) of "major forest product industries that produce residues, users of residues for energy (boilers, ethanol producers, etc.) and related industries" in the United States and Canada (Wood2Energy 2014). This database contains several fields, which can be used to sort companies. For this study, the following criteria were used: 1) US-based companies, 2) wood-based manufacturers and sawmills, 3) nonadopters of cogeneration, and 4) companies listing an e-mail address. A list of about 3000 companies resulted after this first selection. However, it was noticed that some states were overrepresented in the initial sample (because the database contained a disproportionate number of companies in some states); thus, figures from the 2012 census were used (US Census Bureau 2013) to calculate the geographic distribution of companies (by state) and then calculate the number of companies from each state that needed to be dropped (randomly) from the initial list to have a more accurate representation of the actual distribution. This resulted in a list of 1426 companies. Because e-mail addresses change frequently, one last step was taken to refine the distribution list; several sources were used to verify if the e-mail addresses were current and if companies were still in business. These sources included companies' web sites, industry associations' directories, directories maintained by state governments, and web-based business directories. Random calling was also used to find working e-mail addresses, and it was found that some companies, especially the very small ones, do not use an e-mail address for communications. After all this process, a final distribution list of 946 companies was obtained and used for the industry survey.

Questionnaire development. The Tailored Design Method was followed (Dillman 2009) to develop and conduct the survey. The survey instrument was developed in three steps: 1) a list of topics and an initial draft were created based on interviews conducted during the first stage of the research, 2) the questionnaire was subjected to review by industry and experts, and 3) a survey pretest was conducted among a small sample drawn from the distribution list. The initial step was to develop a "wish list" of information to collect from companies, according to the research objectives and the information obtained from the interviews with experts and industry representatives (previous section). This list was then turned into survey questions, following the advice from survey research literature (Alreck and Settle 2004; Dillman 2009). A web-enabled questionnaire was created using Qualtrics survey software (Qualtrics 2014) and sent to four experts, two from industry and two from the academic world, for review. Changes were made to the questionnaire according to reviewers' suggestions. The third and last step in the questionnaire development was a survey pretest, which was conducted by sending an invitation to participate to 103 companies, which were randomly selected from the initial distribution list. Six fully completed questionnaires were received (37 e-mails were undeliverable). Changes were made based on response patterns and feedback received. A final version of the questionnaire was then ready for its final distribution. The major sections included in the final questionnaire were 1) general company characteristics, 2) operations characteristics, 3) familiarity and status regarding cogeneration, and 4) perceived benefits and barriers for cogeneration. Table 2 summarizes the questionnaire sections, individual questions, and type of responses.

LIMITATIONS

As with any research, there were limitations and potential sources of error that needed to be considered when making inferences and generalizations from the results. These limitations are explained in the following sections.

Interviews

- Because of the small sample size (10 interviews), generalization of results was not feasible. The interviews were conducted to learn about the most important topics and inform the next stage of the research: the industry survey.

Table 2. Summary of questionnaire items.

Topic	Question	Type of response/scale
Company characteristics	Use of wood as major raw material	Yes/No
	Type of operation (14 choices and "other")	Multiple choice
Operation characteristics	Lumber drying operation	Yes/No with follow up
	Total kiln capacity (only if "yes" was selected)	Numerical entry and units
	Wood-fired boiler	Yes/No with follow up
	Wood-fired boiler capacity (only if "yes" was selected)	Numerical entry and units
	Price of purchase electricity	Numerical entry
	Wood residues generated (six types and "other")	Numerical entry and green or dry
	Cogeneration facility	Yes/No
Familiarity and status	Familiarity with cogeneration (four choices)	Multiple choice
	Status of company in regards to cogeneration (five choices)	Multiple choice
Perceived benefits and barriers	Benefits from cogeneration (five statements plus "other")	4-point agreement Likert scale[a]
	Reasons preventing cogeneration adoption (10 statements)	4-point agreement Likert scale[a]
	Other reasons preventing cogeneration	Open ended
	Required payback period for cogeneration (five choices)	Multiple choice
	Conditions to consider cogeneration	Open ended

[a] Likert scale included "Strongly agree," "Agree," "Disagree," and "Strongly disagree;" plus a "Don't know" option.

- Some participants, such as technology experts and industry adopters, may tend to have a positive bias for wood-based cogeneration.
- Some professionals, such as equipment providers and utility representatives, who may have relevant knowledge and insights, are not represented in the sample.
- Telephone interviews need to be kept short, thus decreasing the possibility of having in-depth discussions.

Industry Survey

- Results cannot be generalized to the population because a nonprobability sampling strategy was adopted. The distribution list was developed based on e-mail availability. The number of respondent firms represents a small fraction of the industry. However, the authors considered that the sample provides a good cross section of the industry and that the needs experienced by the respondent firms are probably experienced by the rest of the companies in the US wood products industry.
- The most important limitation for the survey sample development is to have a list of working e-mail addresses for the companies included in the survey, allowing the invitation to participate in the web survey to be sent. In contrast to telephone numbers, it is not general practice for companies to list their e-mail addresses in business directories or company web sites. Also, frequently, these addresses change and are no longer valid. Lastly, e-mail addresses listed in companies' web sites are normally generic addresses (info or sales) with the purpose of receiving sales inquiries and will not necessarily be routed to the appropriate person.
- Limitations inherent to any survey apply to this study (Dillman 2000; Alreck and Settle 2004). In any case, the reader should be aware that answers received represent the knowledge and opinions of one representative from each company and may not reflect those of other employees.

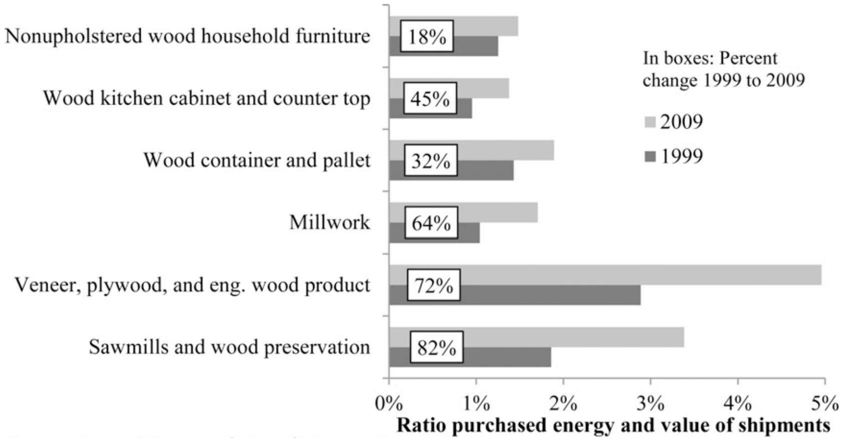
RESULTS AND DISCUSSION

Expert and Industry Interviews

Experts and industry representatives listed in Table 1 were interviewed during spring and summer of 2014. The interviews were recorded (with interviewees' consent), transcribed by a professional service, and then coded for analysis. The major findings from the analysis are presented in this section and divided into three groups: drivers, factors, and barriers to cogeneration.

Drivers for cogeneration.

- Energy costs: The most common response, when asked about the motivations and drivers



Source: Annual Survey of Manufacturers. Census Bureau.

Figure 2. Ratio of purchased energy and value of shipments in wood products industry (Espinoza and Bond 2010).

for cogeneration, was the increasing cost of energy. This is evidenced by the following facts: Electric energy price for industrial users increased at an average annual rate of 3.2% from 2003 to 2013 (EIA 2014), and the share of energy expenditures on companies' budgets has increased considerably in the wood products industry (Fig 2). The Environmental Protection Agency (EPA) estimates that operations paying more than 7 cents per kWh (¢/kWh) for power are good candidates for cogeneration (EPA 2014b). According to the Energy Information Administration, in 2010, wood products and furniture manufacturers paid an average of 7.5 and 9.5 ¢/kWh, respectively (EIA 2014). One survey among Appalachian hardwood sawmills reported an average energy consumption and electric energy bill combined of 8.7 ¢/kWh (Wenshu et al 2012).

- Growing energy needs: All companies interviewed for this study mentioned "growing energy needs," especially thermal energy, as a major driver for considering cogeneration. One respondent indicated that their company found that considerable savings (approximately $1 million/year) could be achieved by drying lumber in-house instead of purchasing dry lumber from external suppliers. This also allowed them to have better control on drying quality. A softwood lumber manufacturer mentioned that market trends toward kiln-dried lumber encouraged them to expand their drying operations significantly.
- Wood residue use: A need for more profitable outlets for wood residues was also mentioned by interviewees as a major driver for cogeneration. A millwork manufacturer indicated that cogeneration was selected rather than other alternatives for residue use such as animal bedding and domestic fuel.
- Environmental driver: Of all the drivers mentioned during the interviews, environmental considerations were not regarded as a major driver, especially for manufacturers. Also, sometimes, environmental considerations appeared to discourage cogeneration adoption. As one manufacturer indicated, purchasing electricity from a utility that in turn obtains a considerable part of its energy from wind allowed the company to meet its environmental goals without resorting to cogeneration. However, the environmental component was a critical driver for the wastewater treatment plant and university campus representatives interviewed for this study.

Factors for cogeneration.

- Scale of operation: This was a common theme in the interviews. Responses suggest that economies of scale make cogeneration more or less feasible for wood product manufacturers. This is important, because it has been suggested that cogeneration is feasible at any size, from microcogeneration (less than 0.1 MW) to megascale cogeneration (greater than 100 MW) (Bullock 2011). An engineering firm specializing in bioenergy systems indicated that small operations find it difficult to generate enough wood residues and that steam becomes too expensive for very large operations (maintenance and operation costs). Biomass power plants in the United States range from 5 to 110 MW (Mayhead and Shelly 2011). Companies interviewed for this study that were operating cogeneration facilities had electric generation capacity between 5 and 20 MW. According to the Wood2Energy database, wood-based cogeneration facilities in the wood products sector (including furniture manufacturers) have an average generation capacity of 9.3 MW (Wood2Energy 2014). The CHP database, maintained by ICF International (2013), indicates an average installed capacity of 9.2 MW for wood products and furniture companies.

- Match between electric and thermal loads: According to our interviewees, along with economies of scale, a good coincidence between electric and thermal load was mentioned as one of the most important factors for economic feasibility of cogeneration. The importance of strategy for system design was also mentioned. There is no general optimum, and the design strategy should be based on capital cost, operating profiles, energy prices, expectations for growth, and financial objectives. For example, a cogeneration system is designed to meet certain steam load profiles, and tradeoffs are associated with each decision. Some alternatives are designed to meet the peak steam load, meet the maximum annual wattage, or design for base load (Bullock 2010). Another set of operating strategies includes utility load conservation (maximize cogeneration's share of total load), load building (maximize purchased energy), base loading (meet year-round load requirement), and peak load shaving (minimize peak load required from utility) (Clarke et al 2012).
- Low seasonal variability in thermal loads: Cogeneration operations need constant thermal loads throughout the year to be economically feasible. One guideline indicated that at least 5000 h of operation per year is needed to justify cogeneration (EPA 2014b). In general, processes with heating and cooling needs can be good candidates for cogeneration. One secondary manufacturer with a relatively small drying operation indicated that their thermal load during summer was between 5.6 and 6.3 GJ and during winter was about 22.1-25.3 GJ, thus making the thermal load too variable to justify cogeneration.
- Location (relative to utilities and fuel): Because of the low energy density of wood biomass, location relative to fuel is especially important for bioenergy operations. Ideally, a facility will generate enough wood residues to feed its boiler, but this is not always the case. One of the adopters interviewed for this study sources two-thirds of the wood residues needed for its cogeneration facility from mills within a 129-145 km radius. Location relative to utilities is also an important factor. A softwood manufacturer mentioned that its central location helped them obtain a good price for the electric energy generated and sold back to the grid; in fact, this facility sells 100% of the energy generated and purchases its power from a local coop. However, location can also act as a barrier; as one sawmill indicated, their proximity to windmills prevented them from obtaining a good price for the electricity generated, thus making cogeneration less attractive.
- Age of thermal equipment: Companies that need considerable upgrading of their thermal equipment (boiler, steam lines) for the implementation of cogeneration may find it financially challenging to engage in such investment. This was one of the major disincentives to the adoption of cogeneration for one of the sawmill representatives interviewed for this study. Conversely, companies with thermal equipment that is in need of upgrading (eg because of age or business expansion) are more likely candidates for cogeneration implementation.

- Spark spread: Spark spread is the difference ($/kWh) between the price of delivered electric energy and the cost of generating power with a cogeneration system (EPA 2014a). This metric is an important consideration for the economic feasibility of a cogeneration project and the design strategy to be used. One manufacturer interviewed for this study estimated its cost to produce power through cogeneration at about 11-13 ¢/kWh and received 3-4 ¢/kWh from the utility for energy sold back to the grid. Because of this, the company minimizes the amount of energy that it sells to the grid (about 10-15% of the total generated).

Barriers to cogeneration.

- Initial investment: Economies of scale are important for the initial investment required for a cogeneration plant. According to experts and the literature, smaller operations (up to 5 MW) can cost about $3.5 million per MW of installed capacity, whereas large ones (40 MW or larger) can cost $2.0 million per MW; operations in the midrange (about 20 MW) require an investment of about $1.7-$2.5 million per MW of installed capacity (Mayhead and Shelly 2011; Scahill 2004). For some operations, an important component of the initial investment is the acquisition of emissions control equipment, which for some projects can represent 25% of the total investment. Also, if thermal equipment needs upgrading, to handle a newly installed cogeneration unit (eg piping for high pressure steam), it can add considerably to the capital requirements.
- Company hurdle rate and required payback period: Although experts mentioned that, in general, cogeneration projects have relatively short payback periods, companies sometimes require even shorter payback periods (less than 5 yr) to consider implementing a project. Manufacturing facilities typically are on tight budgets and managers are encouraged to keep short-term costs down. One survey of energy managers found that they look for projects with payback periods of 3 yr or less (Chittum and Kaufman 2011). Cogeneration projects can be attractive investments but do not always meet core business return of investment goals.
- Complexity of operation and maintenance: All adopters interviewed coincided that there is a need to hire personnel with specific qualifications to run and maintain the cogeneration facility, which typically requires careful monitoring. For example, a softwood lumber manufacturer interviewed for this study needed to hire 10 full-time new employees to run the cogeneration plant. The representative from the engineering firm mentioned that personnel with the proper qualifications to run a cogeneration plant are in high demand and thus difficult to recruit and retain.
- Adequate markets for wood residues: Although looking for better use of wood residues was a major driver for considering cogeneration, having more profitable outlets for them can also be a barrier. One secondary manufacturer, which considered cogeneration in the past but decided not to adopt it, sells its high-quality residues for $40-$50 per dry ton and buys residues from nearby sawmills for $20-$30 per ton for its wood-fired boilers.
- Tariff policies by utilities and inadequate power purchase agreement: Because most cogeneration projects are designed to meet thermal loads, there is usually a discrepancy between a manufacturing facility's load and the cogeneration output. Thus, companies need to negotiate power purchasing agreements with utilities. All interviewees agreed that this factor can make or break the economic feasibility of a cogeneration project and frequently acts as a disincentive to cogeneration. Depending on location, utilities may charge fees and rates that hurt the economics of a cogeneration investment, such as exit fees (a utility-imposed fee to a manufacturer for sourcing power needs from cogeneration facilities; Kowalczyk 2012), load retention rates (special rates negotiated with utility to prevent a manufacturer from implementing cogeneration; Brown and Sedano 2003), utility standby rates (levied by utilities when a cogeneration facility shuts down, for emergency or maintenance reasons, and relies on power from the grid; ACEEE 2013), or

life of contract demand ratchets required by some utilities.

- Emission regulations and permitting issues: Adopters interviewed for this study mentioned that for small operations, emission regulations are usually not a big hurdle, but as the size of the operation increases, emission requirements become more stringent. One manufacturer mentioned that the type of regulation to apply in each case is based on "potential" emissions and not actual emissions. This can be a major factor in sizing decisions, as going beyond a certain level of potential emissions (eg 100 tons) places an operation in a different bracket with more stringent and costly requirements. Large operations may need to meet New Source Review requirements (EPA 2014c), which require installation of Best Available Control Technology and the emission standards are based on fuel input, which does not take into account the higher efficiency of cogeneration facilities (Kowalczyk 2012). In general, air quality regulations do not recognize the environmental advantages of biomass-based cogeneration (Elliott et al 2003).
- Inadequate policies and incentives: The EPA lists 349 policies related to cogeneration in its Cogeneration Policies and Incentives database (EPA 2013). However, energy efficiency gains are not sufficiently recognized (eg net decrease in emissions, improved environmental performance, and decreased grid congestion). Some of our interviewees noted that the incentives from Public Utility Regulatory Policies Act of 1978 (PURPA), which in large part facilitated important increases in cogeneration capacity, were rolled back with the passage of the Energy Policy Act of 2005, mostly affecting utilities' power buying obligations. Regional differences are important. In general, poor spark spreads are typically found in the Southeast and Midwest. The Northeast, MidAtlantic, and Gulf Coast regions are seen as more favorable to cogeneration, and the West is, in general, perceived as neutral to negative in regard to cogeneration, with the exception of California, Oregon, and Washington (Chittum and Kaufman 2011). The American Council for an Energy-Efficient Economy (ACEEE) ranks states according to the degree to which their regulatory and policy environment encourages cogeneration implementation. The latest rankings (2013) are summarized in Table 3.
- Lack of education awareness: Lastly, several interviewees mentioned that there is a lack of awareness and education about cogeneration technologies. However, according to some of the interviewees, an opportunity appears to exist for reaching wood product manufacturers with education and technical assistance about cogeneration technologies. Several organizations and government agencies have implemented education and technical assistance efforts, such as the CHP Partnership by EPA (EPA 2014d) and the CHP Technical Assistance Partnerships (TAPS) by the Department of Energy's Office of Energy Efficiency and

Table 3. State scorecard for cogeneration.[a]

Score range[b]	States
4.0-5.0	Massachusetts, Connecticut
3.0-3.9	Ohio, Oregon, California
2.0 or 2.9	Arizona, New Jersey, New York, Washington, Illinois, Maine, Maryland, Michigan, North Carolina, Rhode Island, Texas, Vermont, Wisconsin
Less than 2.0	Colorado, Delaware, Indiana, Iowa, New Hampshire, New Mexico, Pennsylvania, Utah, District of Columbia, Florida, Kansas, Minnesota, Nevada, South Dakota, Tennessee, West Virginia, Alabama, Alaska, Arkansas, Georgia, Hawaii, Louisiana, Missouri, Montana, North Dakota, South Carolina, Virginia, Idaho, Kentucky, Mississippi, Nebraska, Oklahoma, Wyoming

[a] Downs et al (2013).

[b] Scale goes from 0 to 5.0. High scores are given to states for which regulations and policies encourage deployment of cogeneration technology. Factors considered in the rankings were interconnection rules, inclusion in the states' renewable energy standard, financial incentives, favorable net metering, and output-based regulations.

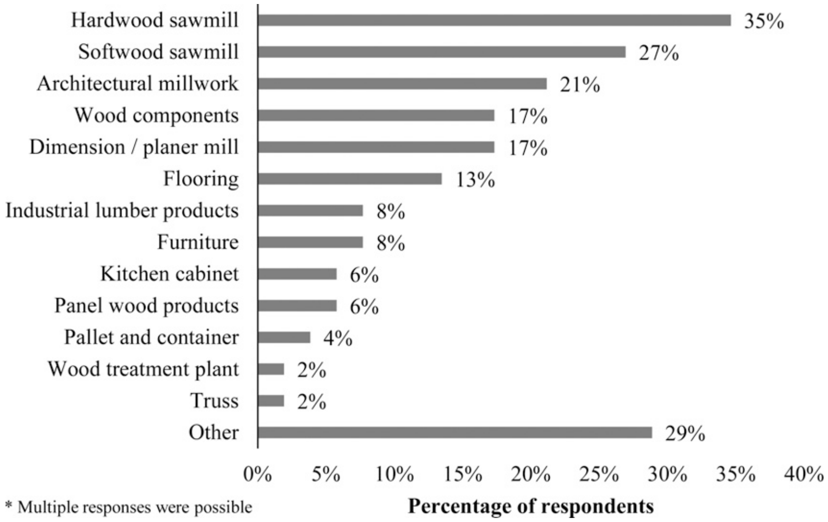


Figure 3. Respondent's main products ($N = 52$).

Renewable Energy (USDOE 2014). Also, there are several at the state government level and with industry associations, such as the Texas Combined Heat and Power Initiative (TXCHPI 2014).

Survey of Wood Product Manufacturers

The survey was conducted in the summer of 2014, with one initial distribution and two reminders, lasting 4 wk in total. The initial distribution list contained 946 companies. However, a great number of e-mail addresses failed to be delivered (262). Also, 28 companies that responded but completed less than 30% of the questionnaire were eliminated from the analysis. Accounting for all this and four other companies that declined to participate, the adjusted response rate was of 8%, or 52 usable responses. Given the sampling method used and the low response rate, it is important to state that the conclusions listed here apply only to the facilities that responded to the survey.

Company demographics. The first item in the questionnaire asked respondents to indicate if they use wood (in any form) as a major raw material to manufacture their products. Those answering "no" (two companies) were directed out of the questionnaire, because they were not part of our population of interest. The respondents belonged to a diverse set of subsectors (Fig 3), with a majority in the sawmill business, architectural millwork, wood components, dimension mills, and flooring. Many respondents reported other products, namely glulam, butcher blocks, industrial work benches, wood pellets, hardwood face veneer, cants, tool handles, stairs, unique residential style pieces, and cooperage stock.

Companies responding to this survey were concentrated in the eastern United States, with some in the western United States. Figure 4 illustrates the respondents' locations. One company located in Alaska is not shown in the map.

The geographical distribution (by US region) of companies in the distribution list and the respondents' location was compared using statistical tools (Table 4). A Pearson χ^2 test showed no significant difference between the regional distribution of respondents and companies in the distribution list (p value of 0.011). Comparisons among the industry distributions of respondents cannot be made statistically (the source database does not use the same subsector categories used in the survey). However, there was a disproportionate number of sawmills (hardwood and softwood) among respondents compared with other

Figure 4. Location of survey respondents (not all companies provided location, and one company in Alaska is not shown). Source: Google Maps.

subsectors (35% and 27% of respondents, respectively; Fig 3).

Operation characteristics. The survey questionnaire also included questions related to the respondents' operation characteristics, including if companies operated lumber dryers and wood-fired boilers (and their respective capacities) and the amount of wood residues generated on a monthly basis. Table 5 summarizes responses to these questions. Overall, three quarters of respondents reported year-long steam needs, and 56% indicated that they operate wood-fired boilers.

To assess how the survey sample compares with the actual population, comparisons need to be made between the operation characteristics reported by respondents (Table 5) and the values published. The different operation characteristics of respondents are subsequently compared with values in the literature.

- Kiln capacity: Average kiln capacity of respondents (1546 m^3) was greater than the national average of 698 m^3 reported in the nation-wide survey of 1509 companies conducted by Rice et al (1994) and the averages reported by Bergman and Bowe, who indicated an average kiln capacity of 1000 m^3 for hardwoods mills (Bergman and Bowe 2012) and 1420 m^3 for softwood mills (Bergman and Bowe 2010).

Table 4. Regional distribution of companies in the sample.[a]

US region	Distribution list (%)	Respondents (%)
Midwest	24.2	29.4
Northeast	24.2	33.3
Pacific	0.1	2.0
South	44.4	25.5
West	7.0	9.8

[a] Pearson $\chi^2 = 15.8$; p value $= 0.011$.

Table 5. Respondents' operation characteristics ($N = 52$).

Lumber drying	
Respondents with lumber dryers	39 (75.0%)
Average drying capacity (m^3)	1546
Wood-fired boilers	
Respondents with wood-fired boilers	29 (55.8%)
Wood-fired boiler average capacity (MW per hour)	9.30
Purchased electricity	
Average price electricity (¢ per kWh)	9.1
Wood residue generation (tons per month)[a]	
Sawmill average residue production	3807
Secondary manufacturer average residue production	1416

[a] Dry and green tons were not segregated to calculate the averages.

- Boiler capacity: According to a report on industrial boilers carried out for the Oak Ridge National Laboratory, the average wood-fired boiler capacity was 7.44 MW/h for boilers installed at lumber manufacturers during the period 1992-2002 (Energy and Environmental Analysis Inc 2005). This was below the average reported by respondents (9.30 MW/h).
- Price of electricity: The price paid for electricity reported by respondents (average of 9.1 cents per kWh) was higher than the average price data published in the Energy Information Administration's 2010 Annual Survey of Manufacturers for wood products and furniture manufacturers (7.7 cents per kWh in 2010; EIA 2014).

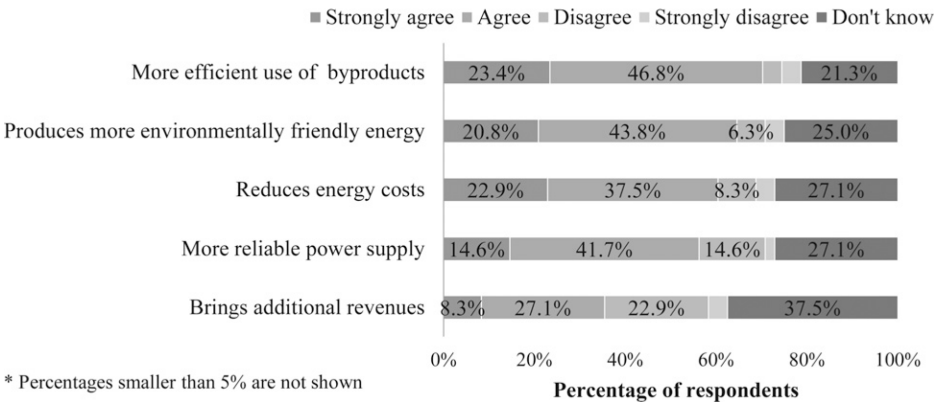
Familiarity with cogeneration and company status regarding cogeneration. Companies were asked about their familiarity with cogeneration technologies, as well as the status of the company regarding cogeneration. Answers are summarized in Table 6. Overall, 63.4% of respondents reported being somewhat or very familiar with cogeneration, whereas 30.7% indicated being not very familiar or not at all familiar with cogeneration. Familiarity results were also consistent with responses to the next question, in which companies were asked to report their status in regard to cogeneration (responses are summarized in the bottom half of Table 6). Of all respondents to this question, 36.5% indicated that they do not have enough information to consider cogeneration. This suggests that there is opportunity for education and outreach efforts in the industry and confirms some of the interviewees' responses in the first phase of the study. More than half of respondents (53.8%) indicated no interest in implementing cogeneration.

Table 6. Familiarity with cogeneration and company status regarding cogeneration ($N = 52$).

Familiarity with cogeneration	Percentage of respondents
Not at all familiar with cogeneration	11.5
Not very familiar with cogeneration	19.2
Somewhat familiar with cogeneration	51.9
Very familiar with cogeneration	11.5
Unanswered	5.8
Status regarding cogeneration	—
We do not have enough information to consider cogeneration	36.5
We are not interested in cogeneration	28.8
We have considered adopting cogeneration but decided it is not for us	25.0
We operated cogeneration in the past but discontinued its use	1.9
We have plans to implement cogeneration in the near future	1.9
Unanswered	5.8

Perceived benefits of cogeneration. As with any other technology, adoption of cogeneration not only depends on the objective evaluation of suitability but also on the perceptions about the technology benefits that the potential adopter may have. To evaluate this, companies were asked to rate their agreement with a number of statements. The scale used included the following options: "Strongly disagree," "Disagree," "Agree," "Strongly agree," and "Don't know." Overall, 70.2% of respondents either strongly agreed or agreed (23.4% and 46.8%, respectively, Figure 5) that cogeneration makes efficient use of wood residues; while this percentage was 64.6% for good environmental performance, and 60.4% for cogeneration having potential for energy cost reduction. Agreement was not as widespread with cogeneration's ability to provide a more reliable source of power (56.3%), and there was low level of agreement with the statement regarding cogeneration as revenue generator (35.4%). However, a considerable number of respondents selected "don't know," which again highlights the need for education among wood product manufacturers.

Barriers for cogeneration adoption. As mentioned previously, perceived barriers to cogeneration can be as important as actual barriers. Respondents were asked to rate their agreement with a number of statements about barriers to cogeneration adoption. Responses are shown in Fig 6. Unfortunately, this is the question that received the lowest response rate, and response was not uniform across different statements, going from 8 to 30. For this reason, in Fig 6, the percentages are calculated based on the number of respondents for each category and are aggregated for agreement ("strongly agree" plus



* Percentages smaller than 5% are not shown

Figure 5. Perceived benefits from cogeneration ($N = 48$).

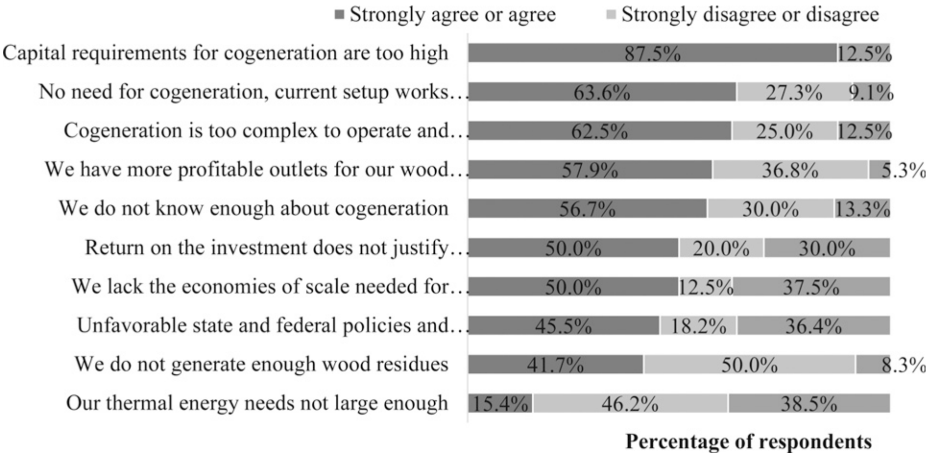


Figure 6. Barriers to cogeneration adoption (N = variable).

"agree") and disagreement ("disagree" and "strongly disagree"). Capital requirements were by far the most important barrier for cogeneration implementation, with 87.5% of respondents indicating agreement with the statement, which is consistent with the interview results (previous section). Half the respondents (50%) disagreed with the statement that fuel availability (wood residues) is a limitation for cogeneration. Similarly, only 15% agreed that thermal needs are not large enough to justify cogeneration. A considerable number of respondents selected the "don't know" option (ranging from 5.3% to 38.5%). Half the respondents (50%) agreed that they do not possess the economies of scale to justify cogeneration, whereas 38% of the respondents to that question selected the "don't know" option. A similar scenario was observed with the statements about return on investment and policies and regulations, with 30% and 36.4% of respondents reporting no knowledge of the topic. These companies would clearly benefit from having better information about cogeneration feasibility and relevant policies and regulations.

A follow-up open-ended question asked companies to provide any other reasons that prevent them from considering cogeneration. Ten companies provided answers, five of which were related to inadequate boiler capacity (eg low-pressure boilers) or low-steam needs. The rest

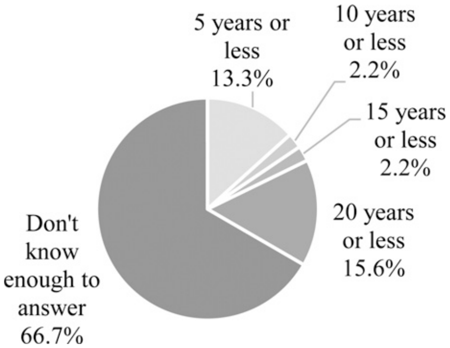


Figure 7. Required payback for a cogeneration investment ($N = 45$).

of the responses were related to high initial investment and residue requirements.

Conditions for cogeneration. In the last section of the questionnaire, companies were asked about what they thought would be an adequate payback period to make cogeneration an attractive investment. Answers are summarized in Fig 7. Two-thirds of companies indicated not having enough information about it to answer this question. Among those who specified a payback time, answers were at the two extremes: 15.6% of companies requiring 20 yr or shorter payback and 13.3% of respondents requiring 5 yr or shorter payback.

One last open-ended question allowed respondents to mention the conditions that should be met before they consider cogeneration for their operations. In total, 34 participants responded to this question, and answers were categorized in six groups. Results are reported in Table 7. Examples of responses are also shown.

SUMMARY AND CONCLUSIONS

Research was conducted to understand the drivers, factors, and barriers to cogeneration adoption in the wood products industry (NAICS codes 321 and 337). A three-step process that included literature review, interviews with experts and industry, and a targeted survey of industry was used as a research approach. Given the sampling method used and the low response rate, the conclusions listed here apply only to the facilities that responded to the survey. A summary of the major findings from this study follows:

- From interviews with experts, it was found that the major drivers (in order of importance) for cogeneration implementation in wood products firms are reduction of energy costs, growing energy needs by companies, desire to more effectively use wood residues, and improvement of the company's environmental performance. The most important factors that our interviewees considered when thinking about a cogeneration investment were scale of the operation, good match between electric and thermal loads, having low seasonal variability in thermal loads, location relative to fuel and utilities, age of thermal equipment, and difference between price of delivered energy and cost of cogeneration-based energy (spark spread). The most important barriers mentioned were large investment required, companies' return of investment requirements, complexity of operating and maintaining a cogeneration unit, more profitable markets for wood residues, tariff policies by utilities, emission regulations and permitting issues, inadequate policies and

Table 7. Conditions for respondents to consider cogeneration implementation.

	Frequency of responses	Sample response
Economic feasibility	10	"Cost of electrical energy must increase to have an acceptable ROI"
Technology feasibility	7	"Complete analysis on wood waste, payback period, price obtained for KWh, capital investment costs for new boiler, steam lines, etc."
Energy cost/price	7	"The avoided electrical costs must at least offset the revenue from selling residue products"
Scale of operation	4	"Acquiring more land, erecting more dry kilns"
Policies and incentives	3	"It would be heavily subsidized and large tax incentives made available"
Regulation/permitting	2	"Boiler MACT has convinced us to halt all expansion plans that use scrap wood fuel as an energy source"

incentives, and lack of awareness about cogeneration among industries.

- Companies with a wide range of products and geographical locations completed the industry survey. However, most respondents were primary manufacturers (sawmills), architectural millwork manufacturers, wood components producers, and dimension lumber and planer mills. Companies in 30 states answered the survey, of which most indicated they were located in the eastern United States.
- On average, many of the companies responding to the survey appeared to have some of the characteristics that make an operation a candidate for cogeneration: 75% had year-long steam needs, and 56% operated wood-fired boilers. The latter paid on average 9.1 ¢/kWh for delivered electricity, and they reported sizable amounts of wood residue generation (4.14×10^7 kg/yr for sawmills and 1.54×10^7 kg/yr for secondary manufacturers).
- Most survey respondents indicated being somewhat or very familiar with cogeneration (63.4%), whereas 30.7% were not very or not at all familiar with cogeneration. Most companies reported not being interested in cogeneration (53.8%) with about half of these respondents indicating that they have considered it but decided not to adopt the technology. More than one-third (36.5%) of respondents said they lack the information necessary to consider cogeneration.
- Regarding perceived benefits from cogeneration, there was a high level of agreement with statements regarding the technology's efficient use of wood residues, environmental performance, and potential for cost reduction. Only 35.4% agreed that cogeneration could provide revenue from selling energy back to the grid.
- According to the survey, the most important barriers perceived were the capital requirements and then the complexity of operation and maintenance. Having more profitable outlets for wood residues appeared to be another important barrier. Respondents did not appear to think that fuel availability and lack of thermal loads were significant barriers for the implementation of cogeneration for their operations. However, many respondents indicated not knowing enough to rate the barriers listed.

Technical barriers to cogeneration usually originate from the limitations of a particular operation (fuel, location, purchase agreements, etc.) and not from cogeneration technology, because this is a well-understood technology. It is also important to differentiate between perceived barriers (eg uncertainty about maintenance or fuel) and actual barriers (eg required capital and emissions control requirements), which this study tried to address. Repeatedly, answers appeared to indicate a lack of knowledge and awareness about cogeneration. This is surprising considering the attention given to this topic lately. This represents an opportunity to provide education and outreach. The authors consider that further research is needed on feasibility of wood biomass cogeneration, including case studies of successful (and not successful) implementations that could inform companies interested in cogeneration. Given the efforts by federal and state governments to provide technical assistance to industries to increase awareness and adoption of cogeneration, results from this study suggest much more work is needed to reach potential candidates for cogeneration implementation.

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