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Article *in* Energy Engineering · August 2012

DOI: 10.1080/01998595.2012.10531822

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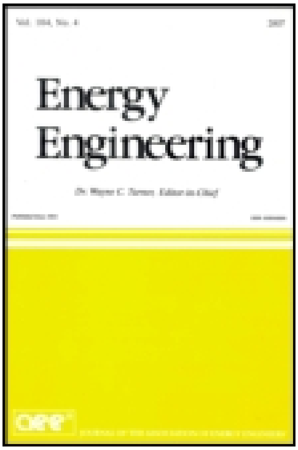

Energy Engineering
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/uene20

Establishing Baseline Electrical Energy Consumption in Wood Processing Sawmills for Lean Energy Initiatives: A Model Based on Energy Analysis and Diagnostics

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Version of record first published: 23 Jul 2012

To cite this article: Bhaskaran Gopalakrishnan, Yogesh Mardikar, Deepak Gupta, Seyed Mohammad Jalali & Subodh Chaudhari (2012): Establishing Baseline Electrical Energy Consumption in Wood Processing Sawmills for Lean Energy Initiatives: A Model Based on Energy Analysis and Diagnostics, Energy Engineering, 109:5, 40-80

To link to this article: http://dx.doi.org/10.1080/01998595.2012.10531822

A Peer Reviewed Publication

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ABSTRACT

This research focuses on the benchmarking of electrical energy use at sawmills. *Lean energy* (a programmatic concept similar to lean manufacturing) is facilitated by this research, which furthers the understanding of energy intensity at sawmills, leading to reductions in operating costs and increases in profitability. A user-friendly interactive model, Baseline Electrical Energy Consumption in Wood Processing Sawmills (BEECWPS), was developed to enable the user to create an energy profile based on sawmill process dynamics and to provide information about product, process, and system parameters. These parameters were gathered by visiting six sawmill facilities in West Virginia. A detailed methodology was developed to collect the field data and determine an energy intensity. The proposed model has the capability of developing the energy benchmark for a facility under consideration, upon successful submission of required data, and will aid lean energy initiatives within the organization. Manufacturing engineers can use BEECWPS to effectively identify the effect of product, process, and system parameters on energy consumption and intensity to revise production system strategies.

INTRODUCTION

Sawmills transform wooden logs into lumber by applying a variety of manufacturing operations. In most of the states in the US, there are numerous sawmill facilities that have contributed significantly to the economy. In an effort to survive the effects of market trend dynamics, the wood processing industrial sector has some of the same major concerns as other industrial sectors, such as high operating costs, low profit margins, and the struggle for capturing market share around the globe. To some extent, the lack of knowledge about increasing energy efficiency at sawmills has led to excessive operating costs and the consequent erosion of market share in a globally competitive market.

In this research, visits to six sawmill facilities with varying production capacities were made. A day-long activity for each sawmill began with discussions with plant engineers about the facility's annual energy usage and operating characteristics of the manufacturing equipment. The energy bills were studied using the rate schedule for variations in usage over the year. After listing the types of products being made at the facility, a brief outline of the manufacturing process was developed. Information was gathered about the types of wood species processed at the facility, annual production, overall yield, and process waste. Further discussions focused on the major energy-consuming equipment used at the facility, and the plant manager then gave a detailed tour. A detailed equipment list was generated on the plant layout provided earlier, and necessary digital images and videos were then taken to document the specific details of the process. Major energy-consuming equipment was identified, based on its rated capacity.

The second half of the day was used for data collection activities. Data collection questionnaires prepared prior to the visits were used to note the details of the process and the equipment. Measuring tape, an infrared temperature gun, a stroboscope (tachometer), and several other tools were used to gather relevant information. While studying a particular process, electrical data on the electrical motors were logged using data loggers. Data collected from the loggers were stored on a personal computer and discussed with the plant engineers.

Data on annual energy consumption and annual production for the six wood facilities visited are shown in Table 1. It can be seen that the ratio of the annual electrical energy consumption in kilowatt hours (kWh) per year to the annual production in thousand board feet, Mbf (M=1000) ranges between 124 kWh/Mbf and 586 kWh/Mbf. Energy costs in a typical sawmill facility can range 1-10% of the total operating costs. Sawmills producing very similar products differ in their specific energy consumption. Continuous cost-cutting efforts must include energy costs. It therefore becomes important for sawmill facility managers to know the energy savings potential of their facility. Some facilities were highly energy efficient (*lean*) and others were not. An opportunity to develop an energy baseline to identify energy assessment potential and realize energy savings by taking appropriate energy efficiency measures (EEMs) was present.

All of the six facilities in Table 1 process logs to air-dried lumber except facilities 1 and 6, which produce kiln-dried lumber. Facility 1 has over 20 kilns using low-pressure steam produced from boiler to dry the lumber. Also, this facility used a significant number of fans in the kilns. Facility 6 has a kiln with a few fan motors. Facility 3 makes veneer from the lumber produced from its sawmill and thus has a significant number of additional electric motors, justifying the highest energy use. Facility 3 also performs chemical treatment to the cants (blocks of wood with a rectangular or square cross section) from sawmill in hot water tanks, which are heated by electric heaters. Altogether, this adds to the energy usage by this facility. Facilities 2, 4, and 5 do not have kilns.

Table 2 lists the total motor capacities for different equipment used in six different sawmills. Based on the manufacturing process for a particular facility, there are some motors used in addition to those used in the basic equipment. In order to understand the baseline energy consumption and opportunities for reducing energy in sawmills, one must know the fundamental aspects relating to process and equipment used as outlined in the following section.

The aim of this research was to develop an interactive model to determine the baseline energy required for the operation of sawmills. (See Figure 1.)

The research also focused on determination of the actual energy consumption for each sawmill. This was facilitated by the use of equipment such as current and power transducers, and data loggers. Actual energy usage can also be determined from the energy bills. After comparing the actual energy usage with the theoretical energy requirement, the models developed in this research were able to establish a lowest practical value for the baseline energy for each sawmill. The difference between the actual and baseline energy requirement for a sawmill reveals the potential for energy efficiency measures.

LITERATURE REVIEW

Several energy efficiency initiatives such as the Best Practices program and Save Energy Now (SEN) program have been developed

Table 1: Annual energy and production data for six sawmill facilities

	Facility 1	Facility 2	Facility 3	Facility 4	Facility 5	Facility 6
Total Annual Electricity Usage (kWh)	7,168,168	724,992	4,327,670	927,168	900,000	2,185,920
Total Annual Production (Mbf)	21,218	5,858	7,382	7,280	5,500	13,000
kWh / Mbf	338	124	586	127	164	168
Kilns Used	Yes	No	Yes	No	No	Yes

Av. 250

Table 2: Total capacities of equipment used in sawmills

Facility	Debarker	Head Saw	Head Saw Carriage	Re-saw	Edger	Trimmer	Planer	Chipper	Air Compressor	Other Motors	Total (hp)
1	100	400	200	300	100	50	150	330	300	1,340	**3,270**
2	50	200	100	60	50	15	-	150	60	237	**922**
3	25	75	-	-	-	-	-	290	100	520	**1,010**
4	50	250	-	200	50	56	-	200	60	118	**984**
5	120	200	-	40	75	90	-	200	115	280	**1,120**
6	25	200	150	-	300	110	-	200	75	320	**1,380**
Total (hp)	**370**	**1,325**	**450**	**600**	**575**	**321**	**150**	**1,370**	**710**	**2,815**	**8,686**

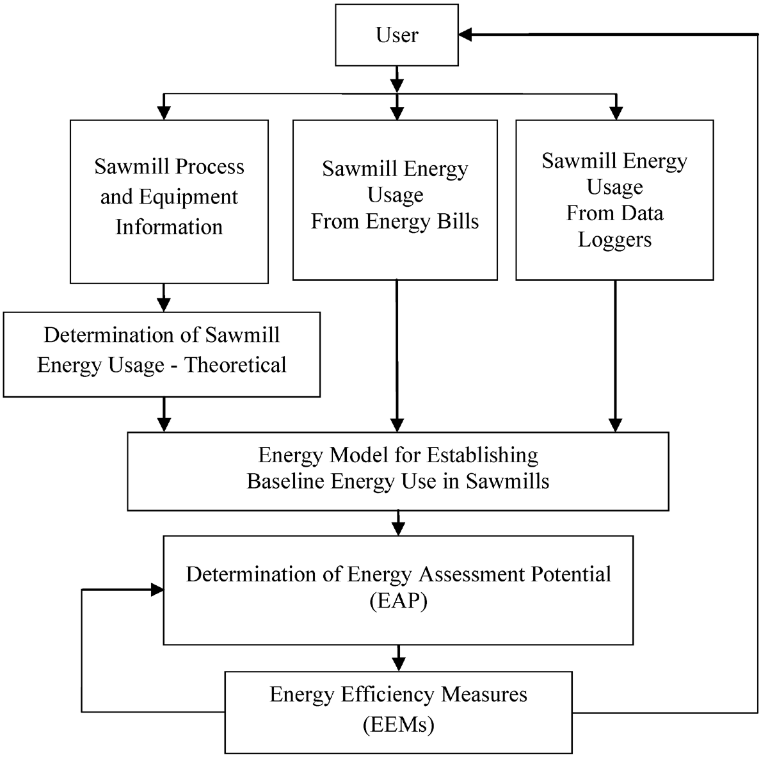


Figure 1: System diagram

by the U.S. Department of Energy (US DOE) [3]. Murata, et al. [4] performed a study on a band saw at a sawmill facility to study the effect of changes in sawing conditions on the speed of the saw wheels and the power consumption. From the results of the study, it was observed that the speed of the wheels dropped drastically at the start of sawing, then settled at the setpoint speed after a small duration (2-3 seconds). The power consumption increased instantaneously at the start of the sawing process and dropped gradually as the sawing progressed.

Northwest Energy Efficiency Alliance reported a case study on motor load profiling to enable it to make decisions about the maintenance of the electrical motors at Crown Pacific Lumber [5]. The study revealed that the motors were oversized in most cases and were designed per the production requirements of that old mill. The facility was able to replace its old, oversized, inefficient motors with new, energy efficient motors; the payback on investment was less than two years.

Wengert and Meyer [6] report on the importance of understanding the electric utility billing system and its components to help reduce costs. Some of the important recommendations provided in the research are proper sizing of electrical motors, use of direct drives instead of belts and gears wherever possible, cogeneration of power at the facility, use of efficient lighting systems, regular maintenance of the burners in the boiler, and use of radiant heaters instead of convection heaters.

Garner [7], in his article on energy conservation in the pulp, paper, and wood products industry , discusses energy profiling. The article lists tools for achieving effective energy conservation and management, such as energy auditing, energy measurement and monitoring, and development of an energy balance at the system level.

Development of energy load profiles for sawmills in the Amazon region was the preliminary objective of a study [8]. Development of the equipment load profiles facilitated the estimation of power and energy requirements by sawmills in the region and assisted in identifying opportunities for on-site power generation using the wood waste. The main observations made during the visit were that the motors were old and operating at a much lower efficiency than premium efficiency motors and that improper motor loading was apparent.

The usefulness of data logging equipment such as power meters to measure the power consumed by various machines at sawmills was the focus of a study by Adams [9]. It was observed that most sawmill equipment used three-wire and three-phase circuits, which can be monitored using a wattmeter. It is stated that power monitoring studies have had little or no importance in the past, due to low energy costs, but that continuous increases in energy costs have now made such studies inevitable and beneficial to energy users.

Kulatunga [10] emphasizes the importance of using energy analysis and diagnostics equipment, as well as the necessity to use state-of-the-art equipment, such as power meters to check the power quality; data loggers to determine the energy use trend; light intensity meters to check the light levels; thermal imaging, along with the use of infrared temperature guns to identify insulation opportunities; and combustion analyzers to measure the boiler or furnace efficiency, among others.

Daly and Flye [11] note the importance of effective and accurate data collection methods and subsequent data analysis. They discuss state loggers (to monitor the operation time of the electrical motors and air compressors), light on/off loggers, power usage loggers, and air quality monitoring loggers. These authors believe that "tracking power consumption and usage was essential in evaluating a system's overall performance, and energy and efficiency demands of an equipment can be monitored and recorded through the use of data loggers."

Mozzo [12] discusses the importance of correctly setting the baseline for energy projects conducted in the performance contracting business. As he mentions, it is important to first set a baseline of the existing energy usage level for a particular system under study. It is expected from such energy analysis and subsequent implementation that the equipment or system efficiency level will increase, resulting in a reduction of energy usage. The difference in these two levels of energy usage (i.e., before and after the details of the project are implemented) will be the energy savings to be realized and will depend on the accuracy of the baseline. Further, four types of methodologies are presented to effectively set a baseline: stipulation, standardization, specifications from the manufacturer, and actual measurements.

Gopalakrishnan, et al. [13] present an energy utilization profile for nine wood manufacturing facilities. Based on the manufacturing processes and the throughput, production parameters for the individual facilities are evaluated with respect to total energy usage and specific energy consumption. The possibility of actual implementation of energy efficiency measures (EEMs) is then determined, and a total of six prominent ones are discussed. The authors also discuss the importance of development and implementation of EEMs to help reduce energy costs in wood industries. The potential for their implementation relies largely on the progression of the energy efficiency report to the *investment grade level*. The investment grade energy efficiency report is developed after significant interaction with plant personnel, vendors, energy service companies (ESCOs), and other entities that provide the necessary information for accurately evaluating the energy and cost savings potential of the EEMs with respect to changing product, process, and system parameters over time.

Pawlik, et al. [14] discuss the necessity of an energy audit and the need to know the energy usage for the major energy consuming equipment in a particular facility. They state that it is equally important to know the proportion of the current energy usage by any particular equipment with respect to total energy requirement for that facility.

Carole, et al. present a summary of energy profiles in the chemical industry [15]. Six major energy-intensive chemical products, which accounted for more than 50% of the total industry's process energy, are considered in the analysis. In addition to data on process flows and energy usage for different processes, the article also provides a comparison of the theoretical minimum energy usage with the actual energy consumption.

A case study of a middle school in North Carolina presents real-time experience in energy savings through efficient lighting system design using daylights [16]. The analysis team reports the use of energy simulation software to estimate the reductions in energy use for various efficient lighting system designs. For the final design, the software estimated a reduction of 64% in the energy usage, whereas the real-time data monitoring revealed that 85% of the lighting energy usage can be reduced on sunny days, and around 60% on cloudy days, thus giving an average of 67.5%.

Ramírez, et al. [17] developed a methodology to determine the tendency for energy efficiency in the Dutch food industry. They conclude by mentioning that "energy policies are developed with predictions, which are based on modeling that incorporates real-time indicators, such as the specific energy consumption or energy intensity."

CONCEPT OF LEAN ENERGY

Leanness can be defined as making necessary changes to minimize waste. Waste uses resources but does not add value to the product [19]. It takes many forms and can be found at any time and in any place. There are the wastes of complexity, labor, overproduction, space, energy, defects, materials, time, and transport [20]. Japanese industry began the long process of developing and refining manufacturing processes to minimize waste in all aspects of operations [21]. Waste minimization can be achieved by the elimination of those activities that do not add value to the product being made. Initially, waste can be easily identified in all processes, and early changes can reap huge savings. As the processes continually improve, waste reduction will be more incremental as the company strives to achieve a waste-free process. Continuous improvement is at the core of lean thinking [22].

Continuous improvements in the areas of quality improvement, scheduling of resources, and productivity enhancement play a vital role in lean manufacturing. The non-allowable waste in the manufacturing environment is mostly visible, such as waste due to the piling of inventory, improper manpower and machine scheduling, process waste, and many other commonly observed practices in the industrial environment. However, opportunities for lean energy are for the most part not as obvious as in lean manufacturing, although analysis of data may reveal hidden non-essential energy consumption (NEEC).

A company should have a lean energy policy in effect. Lean energy can be achieved by uncovering aspects that contribute to the nonessential energy component. Benchmarking, therefore, plays an important role in unveiling the possibility of any NEEC. It is likely that operations are already energy efficient, without any NEEC. However, it is necessary to first measure energy use before finding ways to control it.

Lean energy is a programmatic process implemented within an organization. This type of programmatic process can be triggered by the concepts outlined in this research. This article discusses the variation between the theoretical minimum energy that should be consumed by the motor, based on operating conditions, versus the current energy consumption. If this type of approach is practiced by an organization, it is likely to make every effort in checking every motor as to the motor's status on how far away it is operating from the theoretical energy consumption value. If the gap is small, then the motor is somewhat lean in terms of its energy usage, and vice versa. If the motor is not lean in terms of the energy usage, then effort can be invested to focus on making it as lean as possible.

This process is similar to a human being making a programmatic effort to lose weight and become lean, which should all begin with finding one's own body weight and comparing it to the ideal weight that the particular human being should have. Then the programmatic effort for a healthy lifestyle can begin—but the initial determination and benchmarking is very much a part of the overall programmatic effort to become lean.

Assume there are eight different sawmill facilities as examples for discussion purposes. Figure 2 shows the operating energy levels for eight such arbitrary sawmill facilities. Terms relevant to Figure 2 are defined below.

- *Theoretical Minimum Energy* is the minimum energy that will be used by the system to perform the desired operation. This energy level represents the energy usage for a given sawmill facility under operation without considering system inefficiencies.

- *Actual Energy* is the energy consumed by the equipment based on real-time power measurements. This energy level represents the actual energy usage for a given sawmill facility with all the system inefficiencies in effect. The actual energy consumed by the eight facilities is indicated by their position (1-8) on Figure 2.
- *Baseline Energy* is the lowest practical value above the theoretical energy level to which the actual energy usage can be reduced. This energy level represents the energy usage for a given sawmill facility after eliminating some of the possible system inefficiencies by implementing energy efficiency measures.

In reference to Figure 2, it seems probable that facilities 1 and 5 might already be close to lean in terms of energy levels, falling close to the energy baseline. Facility 3 is at the borderline, maintaining its position of being energy efficient, whereas Facilities 2, 4, 6, 7, and 8 have a higher NEEC component that can be reduced by implementation of energy efficiency measures.

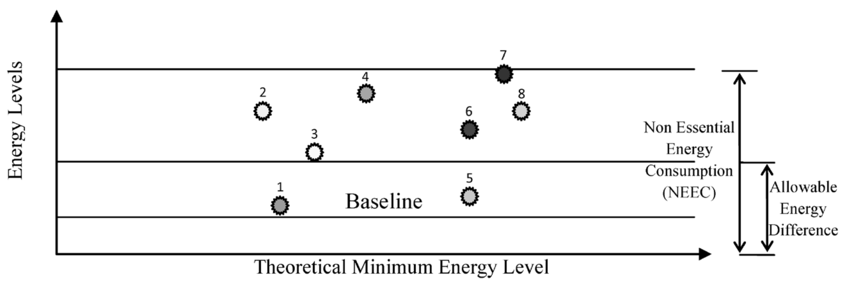


Figure 2: Energy benchmarking in sawmills

Hence, benchmarking or baselining energy for sawmill operations, along with the determination of actual energy utilization by real-time data collection, is essential to determining the likelihood of any NEEC in the system. Baseline energy level is the lowest practical value for energy consumption above the theoretical energy level required to achieve the production targets. The NEEC in the system is the difference between the current energy levels and the theoretical energy required to perform a particular operation. The NEEC component is composed of sub-layers, some of which are unavoidable and simply impossible for the system to eliminate. (See facilities 1 and 5 in Table 2.) By the application of a lean energy policy, the avoidable part of the NEEC can be minimized and brought down close to the baseline energy level into the allowable energy range. Such is the case in facilities 2, 3, 4, 6, 7, and 8 of Table 2.

SAWMILL PROCESSES

Sawmill operations such as debarking, sawing, edging, trimming, chipping, and drying require energy-consuming equipment and machinery, while operations such as the grading of logs and lumber, and quality inspection require operator skills and knowledge about the process and the product. Figure 3 shows the typical process flow in sawmills.

ENERGY USE IN SAWMILLS

As of 1998, sawmills in the US used around 0.167 quadrillion Btu of energy. A total of 0.492 quadrillion Btu of energy was used by the lumber and wood products industry [1]. Total energy usage for different sectors in the forest products industry was 3 quadrillion Btu, as shown in Figure 4.

Figure 5 shows the breakdown of sawmill operating costs. Raw materials account for 60% of the total operating costs, whereas labor and overhead costs are 15% each; the energy costs are 10% of the total sawmills operating costs [2].

ENERGY CONSUMPTION IN A TYPICAL SAWMILL

Typical sources of energy utilized in sawmills are electricity, natural gas, wood waste, and fuel oil. Electricity is required to operate motors in equipment such as the debarker, head saw, re-saw, edger, trimmer, chipper, planer, fans, and pumps, as well as in material handling equipment such as conveyors and belts. Normally, natural gas and/or wood waste is used in the boiler (steam generator) to generate low-pressure steam. This steam is used to dry the lumber in a kiln. Product layout of a sawmill, along with the total equipment capacities is shown in Figure 6.

Sawmill operations necessitate the use of heavy electrical motors and natural gas equipment such as boilers. Electric motors are used to

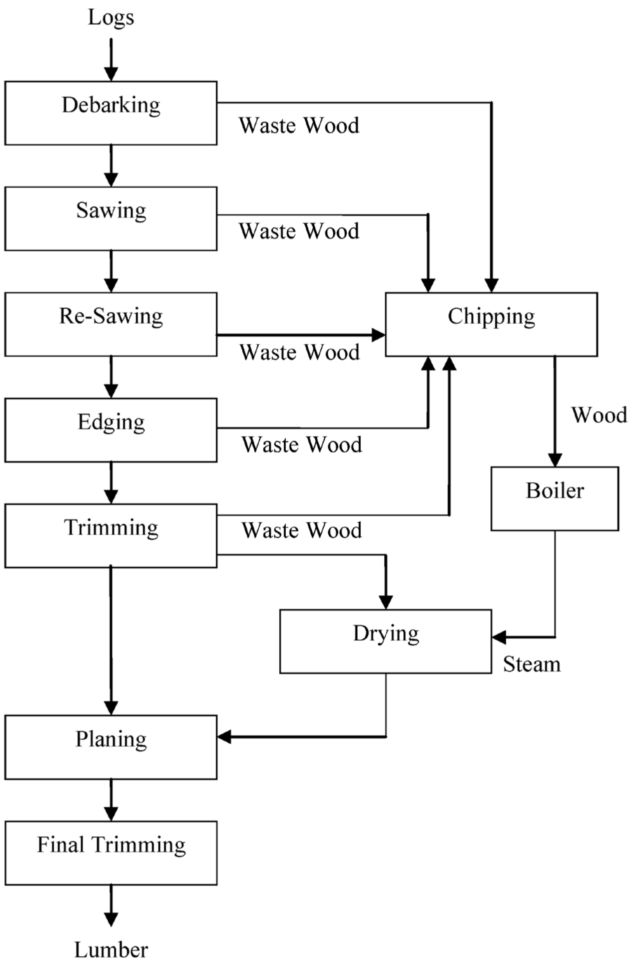


Figure 3: Process flow diagram for sawmill operation

run most of the equipment in sawmills. Large motors serve as a source of mechanical energy and provide power to the cutting tools. The smaller motors feed the raw material to the cutting tools. In general, the motor capacities range between 1/4 horsepower (hp) to 400 hp. Large electric motors use multiple belt drives to transmit power from the motor shaft to the cutting tool shaft. The small motors typically use chain drives to transmit power to the conveyor. Most of the motors in a sawmill use three-phase power.

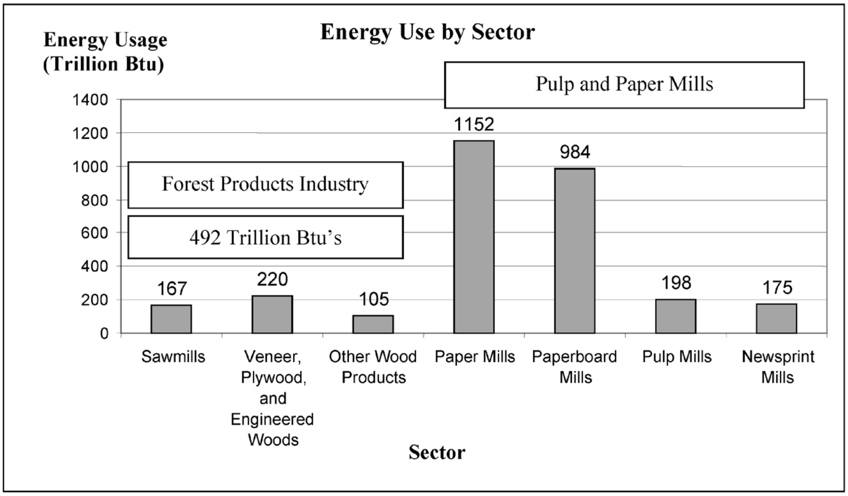


Figure 4: Energy use distribution for the forest products industry [1]

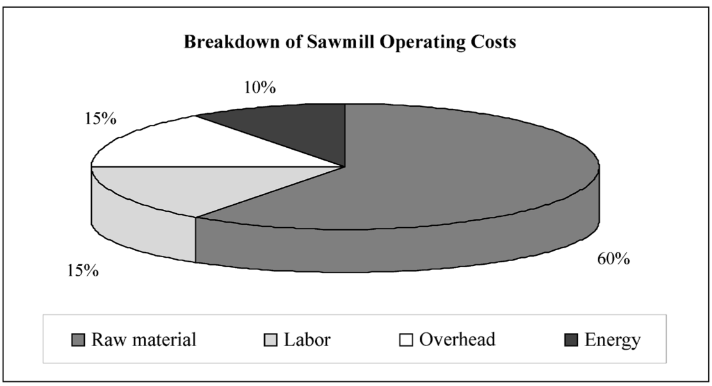


Figure 5: Breakdown of sawmill operating costs [2]

SAWMILL ENERGY FLOW DIAGRAM

Figure 7 depicts the energy flow diagram for the manufacturing operation at sawmill Facility 1, with the total equipment capacities. For example, in the drying process, low-pressure steam from the boiler and electric energy for kiln fans are supplied as an input. Hot exhaust and condensate leave the system as exhaust energy. Natural gas/fuel oil/wood waste is used as an input energy to the boiler that produces the low-pressure steam.

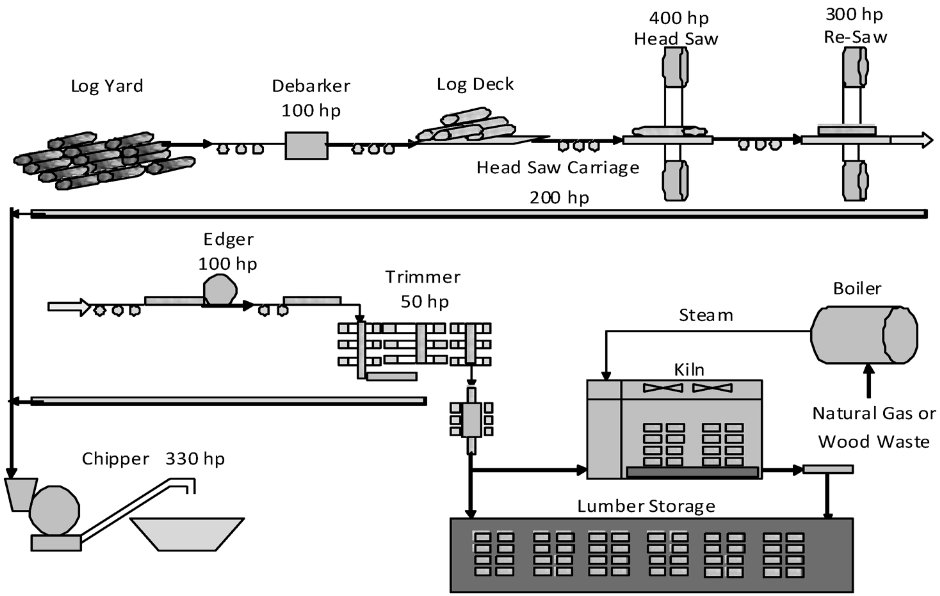


Figure 6: Product layout for a typical kiln-dried lumber facility

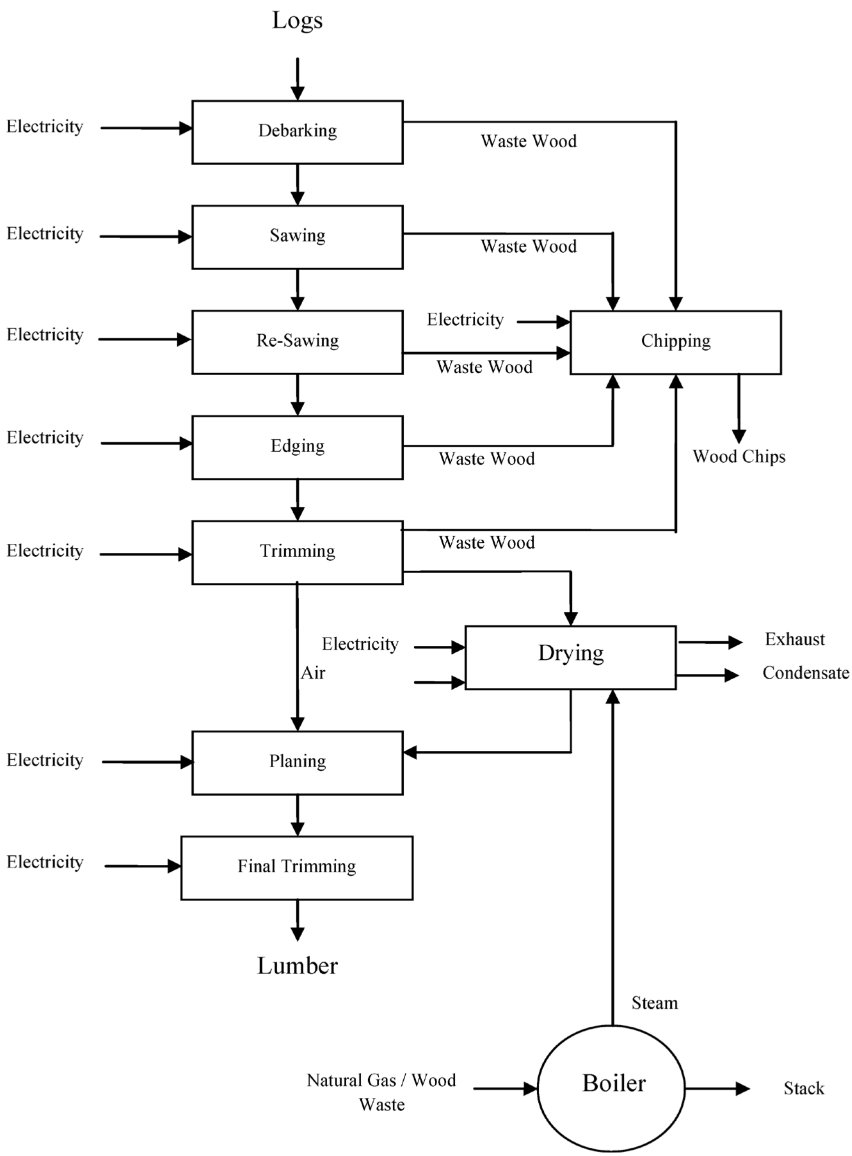


Figure 7: Sawmill energy flow diagram

ENERGY SAVINGS POTENTIAL

Being the largest end users of energy in a typical sawmill, the electrical motors become obvious candidates for energy analysis and determination of possible energy savings potential. An important distinction between a motor operation at sawmill versus at other manufacturing facilities is the rigorous working environment at sawmills under which the equipment operates. The equipment—and thus the electrical motors—undergo significant lifetime wear. Under such working conditions, the equipment may turn out to be, for the most part, less energy efficient. The energy usage for sawmills can vary significantly. (See Figure 2.)

As mentioned earlier, energy savings potential is determined based on the difference between the existing level (baseline) and the lowest level of energy consumption required to achieve production targets. Regular maintenance and energy efficiency activities in some facilities are likely to render energy use close to the baseline energy level. In this context, there may not be much potential for any further reduction in energy use at some sawmills. On the other hand, there may be significant energy savings potential for facilities having inefficient energy operations. Therefore, *it is important to develop an energy baseline by quantifying the theoretical energy that will be required by various manufacturing activities so as to achieve production targets*.

It is impractical to expect systems to operate at theoretical energy levels. Therefore, appropriate allowances must be considered for the establishment of the baseline. Consider, for example, two identical facilities, A and B, with annual energy usage of 75,000 kWh and 55,000 kWh, respectively. Also, assume that the energy baseline developed for such an operation is 50,000 kWh. This means that the energy consumption by Facility A is 50% higher than the baseline, and that of Facility B is 10% higher than baseline. Hence, considering appropriate allowances, Facility A seems to have significant NEEC and can therefore be termed a *non-lean* facility in terms of energy consumption.

Conversely, Facility B can be considered to be a lean facility. Detailed energy assessment of both these facilities is likely to reveal EEMs; typical areas to be addressed for Facility A could be motors operating at low loads (hence at low efficiencies), inadequate equipment maintenance, improper power transmission methods, significant system losses, and improper power quality. Implementation of some recommendations may help reduce energy consumption for Facility A to approximately 20% above the baseline. Facility B, being already lean, would have fewer EEMs available, and it may only be possible to reduce its energy consumption to around 5-8% above baseline. The results from the research reported here can help to determine the energy assessment potential for a sawmill, leading to the determination of the energy efficiency potential.

ESTABLISHMENT OF THE ENERGY BASELINE

Variability in a manufacturing process can be introduced due to many factors, such as raw materials, machinery used, and the human component. Understanding of process variability plays a vital role in establishing baseline energy consumption in wood processing sawmills. As an example to demonstrate variability, consider a typical log-sawing process using the head saw. A simple flow diagram for a log-sawing operation on the head saw is shown in Figure 8.

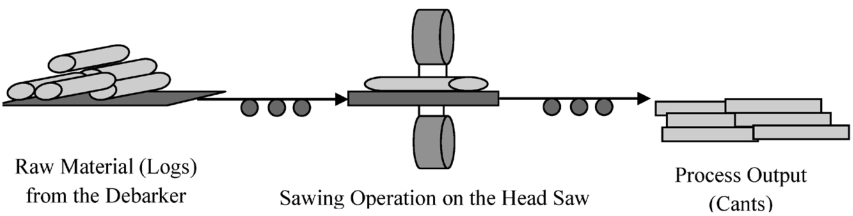


Figure 8: Typical log sawing operation

Some of the variability factors associated with energy consumption by the head saw operation are listed below.

1. Raw Materials:
   - Log dimensions
   - Wood species (hardwood/softwood)
   - Wood type within the species (hardness)
   - Moisture content in the logs
   - Fiber (grain) orientation while cutting
   - Temperature of the log
   - Knots, decays, and bird pecks
   - Other unknown elements

2. Sawing Operation on the Head Saw:

A. *Head Saw Equipment*

- Work piece dimensions: cant dimensions to be cut from the logs
- Type of saw (circular or band)
- Operating parameters of the saw (feed, speed, depth of cut, and saw kerf)
- Saw blade properties (number of teeth, width, length / diameter, and pitch)
- Mechanical properties of the saw blade
- Saw drive (motor operating characteristics: energy efficient / premium efficiency motor; mode of power transmission; and motor maintenance)
- Head saw system preventive maintenance
- Head saw system downtime
- Other unknown elements

B. *Head Saw Operator*

- Operator's skills
- Operator's understanding and knowledge about the process
- Other unknown human factors

All of the above factors contribute to variability in the energy consumption for the sawing operation. Some of the factors will be prominent, while others may prove to be less important. Also, it may not be feasible to collect data on some factors due to their inconsistency. Similarly, other factors leading to variability can be identified for the entire sawmill operation. Data were collected on these factors by observations, measurements, and discussions with plant personnel to arrive at a reasonable value for the overall system variability. Knowledge about system variability and accounting for variations in process energy consumption promotes the use of appropriate allowances. Implementation of energy efficiency measures, such as the use of premium efficiency motors, installation of variable speed drives, replacement of standard V belts with cog belts, a regular motor maintenance program (limiting the motor vibration levels), and practicing thin kerf sawing help in determining possible reduction in energy levels for a sawmill facility and thus lead to the development of an energy baseline.

The factors included in the model for determining theoretical energy requirement are listed in Table 3. The theoretical energy requirement for any wood cutting manufacturing process is derived by using the principles of physics, motor operational characteristics, and properties of the wood being cut. The user can change the parameters on Table 3 in the proposed model and thus influence the theoretical energy usage for the sawmill operation. However, it is important to note that not all manufacturing process parameters can be changed—and for those that can be altered, one has to be sensitive to the feasible ranges for these parameters.

Table 3: Factors included in the model to determine theoretical energy

Factors
- Wood species (hardwood/softwood)
- Wood type within the species (hardness)
- Moisture content in the wood
- Fiber (grain) orientation while cutting
- Dimensions to be cut from the workpiece; workpiece dimensions
- Type of equipment (circular saw, band saw, disc chipper, rosser debarker)
- Operating parameters of the equipment (feed, speed, depth of cut, and saw kerf)
- Saw blade properties (number of teeth, width, length/diameter, and pitch)
- Mechanical properties of the saw blade, chipper disc, debarker
- Equipment downtime

Table 4 lists some of the factors that can be altered without impacting productivity, so as to save energy. (The list is in three subcategories: easy, difficult, and impossible.)

For discussion purposes, consider a facility having a single-motor-driven piece of equipment for cutting wood. Assume the actual power consumption for this motor is 150 kW. Let the value for the theoretical power requirement be 100 kW. Now, implementing the factors in category 1 of Table 4 (i.e., factors easy to change), the power consumption has been brought down to 125 kW. (See Figure 9.) Reducing the power consumption below this level will be more difficult than what could be achieved by the implementation of the factors in category 1 of Table 4. With regular maintenance of the motor and additional operator training, the power consumption may be reduced from the already reduced value of 125 kW to, say, 110 kW. The power consumption cannot be lowered

Table 4: Category of factors enabling the establishment of baseline energy

Factors easy to change—Guaranteed reduction in energy usage
- Drive motor operating characteristics:
  - Properly sized motors; energy efficient/premium efficiency motors; mode of power transmission; motor vibration analysis, motor loading—VSDs

Factors difficult to change—Reduction in energy usage difficult
- Other losses in the motor (electrical—I_2R, magnetic—core, mechanical—windage & friction)
- Operator's understanding and knowledge about the process—Operator skills

Factors impossible to change—Unavoidable energy loss
- Temperature of the wood
- Knots, decays, and bird pecks
- Other unknown elements—random effects
- Other unknown human factors
- Environment

beyond this level (110 kW). So, as depicted in Figure 9, it will be possible to reduce, for similar systems, power consumption from their existing levels (150 kW) to 125 kW, and, for a few, it would be possible to lower it to 110 kW. Therefore, the power consumption level corresponding to the 110 kW can be identified as the baseline, whereas the 25 kW (125 kW – 100 kW) can be identified as the allowable energy difference.

OBJECTIVES OF THE MODEL

Following are some of the major objectives in building the BEECWPS model.

- To enable the user to input data pertaining to the production and energy usage in sawmill operations to perform system energy analysis
- To estimate theoretical energy requirements for major energy intensive processes in sawmills
- To estimate actual energy consumption for the selected process from real-time data collection such as amperage, voltage, and power factor
- To establish an energy baseline by determining the non-essential energy consumption for the processes

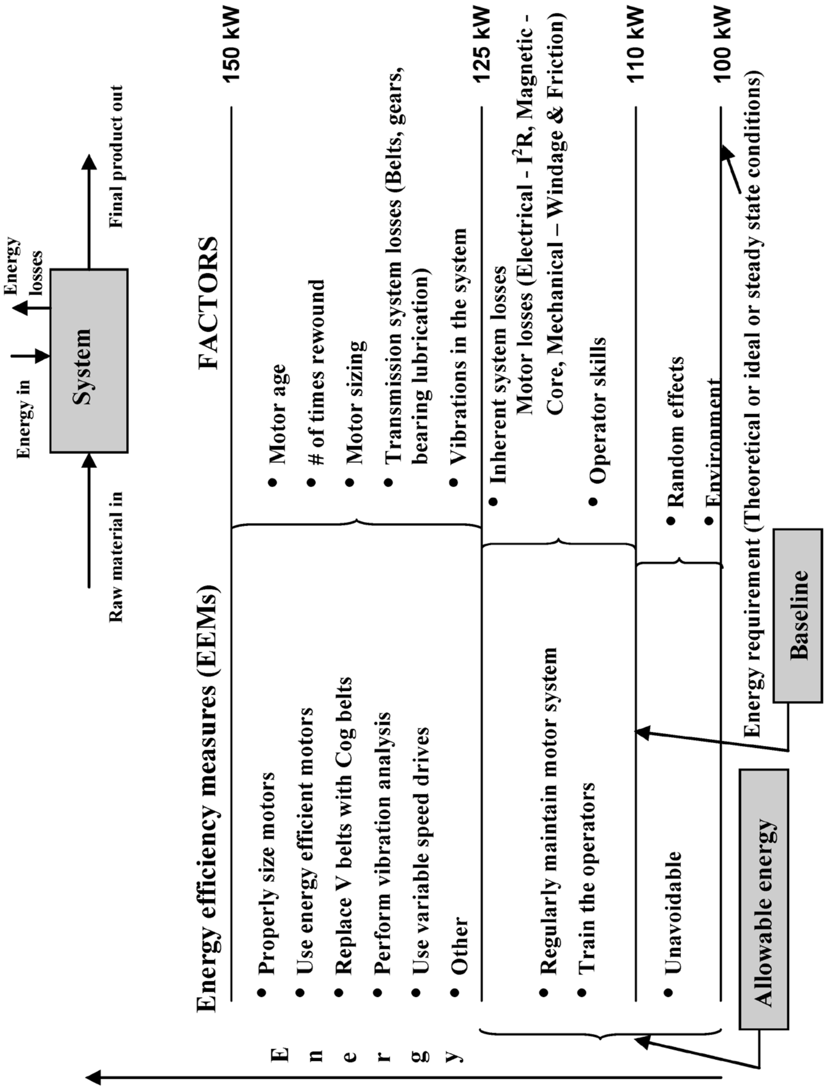


Figure 9: Example of the establishment of baseline energy

- To assist the user in studying the effect of process parameters on energy consumption by running the model for varying process parameters—sensitivity analysis
- To determine the specific energy consumption (SEC) for the existing and proposed scenario
- To provide economic analysis based on energy costs savings and implementation costs
- To provide graphical representation of the results obtained from the analysis
- To facilitate programmatic lean energy initiatives

MODEL ASSUMPTIONS

- The annual operating hours are determined after considering the breaks (e.g., lunch breaks) and scheduled annual maintenance shutdown. Other unpredicted shutdowns due to random causes will have to be provided separately in the model.
- Specific data gathered from discussions with the plant personnel (related to variability in the production parameters) is assumed to be the true representation of the actual annual production.
- Annual throughput is based on the actual board feet of lumber produced, not on the number of logs processed per year.
- Variation in the physical properties between the wood species is considered, but variation within the log of a particular wood species itself is not modeled.
- Only one type of end-product, wooden boards (green lumber, no artificial drying) is considered in the model; provisions to accommodate different board dimensions to be manufactured is provided in the model.

MODEL DEVELOPMENT

The design of the model was using VisualBasic® software on a platform of Microsoft EXCEL®. The system details of the model and software system are shown in Figure 10.

QUESTIONNAIRE PREPARATION

A detailed questionnaire was prepared for data collection purposes. Separate questionnaires were prepared for the following different processes.

- Debarking, using a rosser head debarker
- Sawing process, using a band saw or a circular saw
- Edging process, using a circular saw
- Trimming process, using a circular saw
- Planning process, using a circular peripheral milling cutter
- Chipping process, using a disc chipper
- Other miscellaneous operations using saws

Input
Production Parameters
Energy Costs
Energy Consuming Equipment
Process Flow
Measured data

Output
Equipment Energy Usage – Theoretical
a. Debarker
b. Head Saw
c. Re-saw
d. Edger
e. Trimmer
f. Planer
g. Chipper
Equipment Energy Usage – Actual
Process Flow – Power Requirement
Baseline Energy Establishment
Specific Energy Consumption
Economic Analysis
Sensitivity Analysis

Figure 10: Model architecture

Although the basic outline of the questionnaires for different processes is the same, they differ in information specific to the process. The questionnaire is divided into following five subsections.

- *Process parameters* help to collect data on the wood type, wood species, moisture content in the wood, dimension of the piece being cut, the final dimensions of the product made from this process, depth of cut, number of cuts made over unit time, number of cuts per wood piece based on original dimensions, feed speed of the piece being cut, speed of the saw blade, and speed of the wheels.
- *Saw blade and equipment specifications* help to collect information about the equipment manufacturer; the material of the wheel along with the dimensions and the distance between two wheels; and saw blade dimensions such as the length, width, pitch, number of teeth, gullet area, saw kerf, and type of drive.

- *Electric motor nameplate information*
- *Data logger measurement information*

The information can be collected for additional motors used in sawmills, such as air compressors and dust collectors. The questionnaire also has provisions to document data for these supporting motors.

EXAMPLE

As an example, theoretical cutting of power consumption for debarker is presented as follows. In this process, the log and the cutter head are both rotated. Typically, the direction of rotation of the cutter head and the log is opposite, as in up-milling. Debarking of logs using a rosser head debarker is an application of the peripheral milling operation.

The power required in the actual debarking of wood logs varies with the properties of the wood logs, such as the density, moisture content, cutting velocity, feed speed of the cutter head, and required depth of cut:

$$P_{Cutting} = \frac{(0.746\ kW/hp) \times (1/2) \times [D \times w \times F \times S\ c\ (1 + M/100) \times W_w] \times v^2}{144\ (inch^2/ft^2) \times g \times 33{,}000\ (lb\text{-}ft/min)/(hp)} \qquad (1)$$

Where,

$P_{Cutting}$ = Power required for debarking the log, (kW)
D = Depth of cut (thickness of bark to be removed in inches)
w = Width of cut (inches)
F = Feed speed (ft/minute)
S = Specific gravity of wood (a fraction based on wood type)
M = Moisture content in the log (%)
W_w = Weight of cubic foot of water in pounds (lb/ft^3)
v^2 = Peripheral velocity of cutter head (ft/sec)
± feed speed (ft/sec)
+ for same direction of rotation of the cutter head and the log
– for opposite direction of rotation of the cutter head and the log
g = gravitation constant (32.2 ft/sec/sec)

Therefore, the actual power (AP) and energy consumption (EC) by the drive motor, for the debarking operation using a rosser head debarker, is given by equations 2 and 3, respectively:

$$AP_{(Drive\ Motor)} = (\text{cutting power}) = \sqrt{3}*V*I*\cos(\Phi) \quad (2)$$

$$EC_{(Drive\ Motor)} = (\text{cutting power}) \times UF \times H$$
$$= (P_{Cutting}) \times UF \times H \quad (3)$$

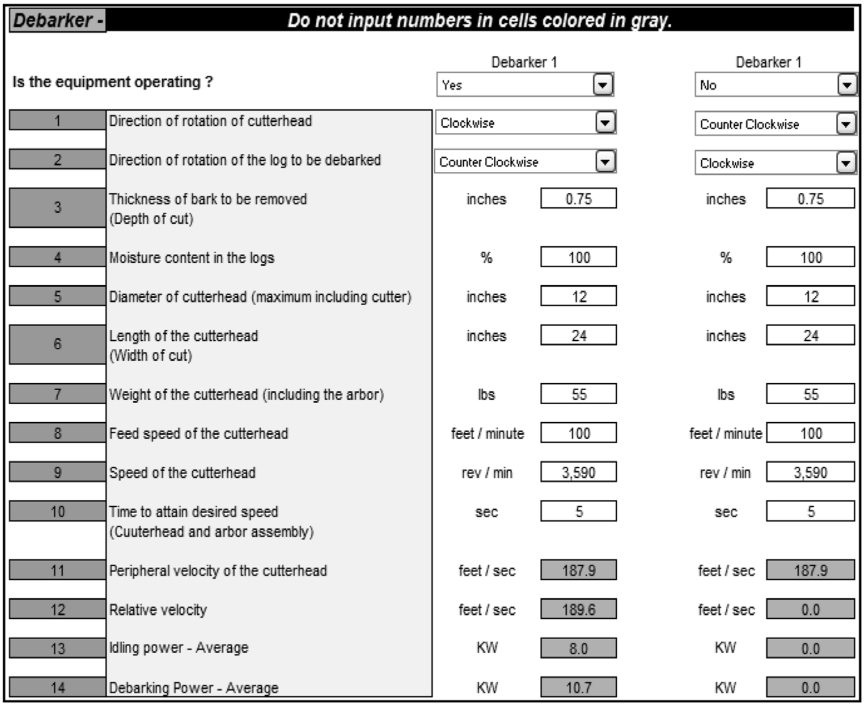
Where,

H = Annual motor operating time (hours/yr)
UF = Utilization factor (%)
V = Measured input voltage (volts)
I = Measured input current (amperes)
cos(Φ) = Measured power factor (no units)

Power factor is important in the study of energy consumption by sawmills. The efficiency of the motor is significant when considering efforts to reduce the gap between the theoretical and actual energy consumption. The actual input energy consumed by any motor has been calculated using the equation $\sqrt{3}*V*I*\cos(\Phi)$, where V is the voltage, I is the current, and cos(Φ) is the power factor. However, in the research reported in this article, input power was calculated based on the current recorded by data loggers; hence, no use of motor efficiency is needed in this calculation. If one were to use the output power as specified in the nameplate of the motor, then this value would have to be divided by the motor efficiency. Calculations similar to those in equation (1) are performed by the BEECWPS model in the debarker module to determine the power requirement for the remaining weeks when other types of wood species are also processed. (See Figure 11.)

DETERMINATION OF UTILIZATION FACTOR

The utilization factor is defined as the fraction of time during which equipment is operated, and load factor is defined as the fraction of available capacity used to provide the required output. For example, if equipment is used for only 6 hours during an 8-hour shift, the utilization factor is 6/8, or 75%. If the output power required to perform the operation is 10 hp, and a 25-hp motor is used to supply the power, the load factor would be 10/25, or 40%. An example data set is provided in Table 5; the calculations for utilization and load factors are shown below.



Debarker - Do not input numbers in cells colored in gray.

		Debarker 1		Debarker 1	
	Is the equipment operating ?	Yes		No	
1	Direction of rotation of cutterhead	Clockwise		Counter Clockwise	
2	Direction of rotation of the log to be debarked	Counter Clockwise		Clockwise	
3	Thickness of bark to be removed (Depth of cut)	inches	0.75	inches	0.75
4	Moisture content in the logs	%	100	%	100
5	Diameter of cutterhead (maximum including cutter)	inches	12	inches	12
6	Length of the cutterhead (Width of cut)	inches	24	inches	24
7	Weight of the cutterhead (including the arbor)	lbs	55	lbs	55
8	Feed speed of the cutterhead	feet / minute	100	feet / minute	100
9	Speed of the cutterhead	rev / min	3,590	rev / min	3,590
10	Time to attain desired speed (Cuuterhead and arbor assembly)	sec	5	sec	5
11	Peripheral velocity of the cutterhead	feet / sec	187.9	feet / sec	187.9
12	Relative velocity	feet / sec	189.6	feet / sec	0.0
13	Idling power - Average	KW	8.0	KW	0.0
14	Debarking Power - Average	KW	10.7	KW	0.0

Figure 11: Sub-module displaying the theoretical power required in the debarking operation

Calculation of Utilization Factor

No. of minutes (amps) are <= 0.073 (least ct)	32509
Total number of minutes recorded	43431
Utilization factor (UF)	0.252

The logger was set up to measure current for one month; it collected 43,431 data points, each stamped at 1-minute intervals; i.e., we have data for 43,431 minutes. (See Figure 12.) When the motor is not drawing any current, the logger records a value 0.073 amps (very close to 0). The count for which the value close to 0 is recorded is found from data as 32,509; i.e., the current draw was zero for 32,509 minutes. Current was greater than 0 for all remaining data points; i.e., the edger was in the routine duty cycle the remaining time. The average utilization factor for the recorded period can be found as:

UF = 1 – (Time for which current is zero) ÷ (Total time current was recorded)
= 1 – 32,509/43,431
= 0.252

MODEL EXECUTION SUMMARY

Six sawmill facilities were visited for research and analysis purposes [18]. Data collected from the facilities were used to determine the theoretical energy requirement and actual energy consumption for sawmill processes. The NEEC was determined, and important factors contributing to the NEEC and energy baseline were analyzed. Upon successful implementation of energy efficiency measures (which could have resulted from implementing measures in categories 1 and 2) at one of the facilities included in this research, it was found that the baseline energy requirement for the sawmill operation will be 563,717 kWh/yr, as compared to the actual energy consumption of 613,888 kWh/yr. On average, the actual energy consumption is approximately 8.9% higher than the baseline energy consumption. Out of this 8.9%, approximately 3.9% falls under category 1 EEMs, and 5% under category 2 EEMs. In other words, the facility can certainly reduce its existing energy consumption by 3.9%, but it will have to invest considerable time and money to achieve the additional 5% energy reduction. Reduction in energy usage beyond 8.9% would be difficult for this facility. Establishment of the baseline energy level has enabled the facility to reduce a portion of the NEEC by the identification of energy efficiency measures for each of the manufacturing processes contributing to the total NEEC.

Table 5: One-month current profile for a 200-hp edger at a surveyed sawmill facility

#	Time, GMT-04:00	Curr, Amps
1	3/25/2010 6:00	0.073
2	3/25/2010 6:01	0.073
3	3/25/2010 6:02	0.073
4	3/25/2010 6:03	0.073
5	3/25/2010 6:04	0.073
154	3/25/2010 8:33	57.788
155	3/25/2010 8:34	56.323
156	3/25/2010 8:35	104.224
157	3/25/2010 8:36	57.056
158	3/25/2010 8:37	58.667
159	3/25/2010 8:38	59.985
[illegible]	4/24/2010 9:4[illegible]	0.073
43427	4/24/2010 9:46	0.073
43428	4/24/2010 9:47	0.073
43429	4/24/2010 9:48	0.073
43430	4/24/2010 9:49	0.073
43431	4/24/2010 9:50	0.073

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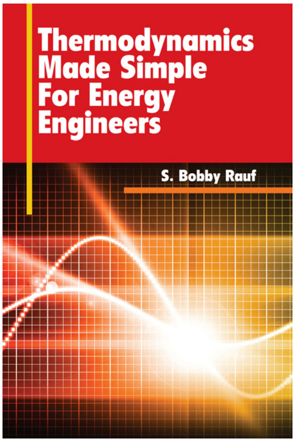

S. Bobby Rauf, P.E., C.E.M.

The purpose of this book is to provide an overview of important principles and concepts in the field of thermodynamics, written in a fashion that makes this abstract and complex subject easy to comprehend. Intended to serve the needs and interests of energy-involved engineers, the content, concepts and principles are presented in a way which also will allow many non-engineering professionals with some math background to follow the material and gain useful knowledge. For energy engineers who may have been away from direct engineering practice for a period of time, this book can serve as a quick and effective refresher. Thermodynamic topics including enthalpy, entropy, latent and sensible heat, heats of fusion, and heat of sublimation are clearly presented. Also covered are phases of substances, the law of conservation of energy, SFEE, the first and second laws of thermodynamics, ideal gas law, and respective mathematical statements. The author provides an examination of specific thermodynamic processes, as well as heat and power cycles such Rankine, Carnot and the differences between them. Case studies illustrate various thermodynamics principles, and each chapter concludes with a list of questions or problems for self-assessment, with answers provided at the end of the book.

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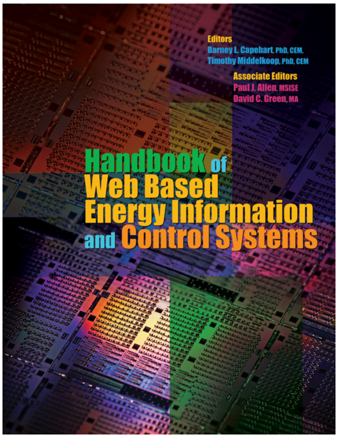

Edited by Barney L. Capehart, Ph.D., C.E.M. and Timothy Middelkoop, Ph.D., C.E.M.

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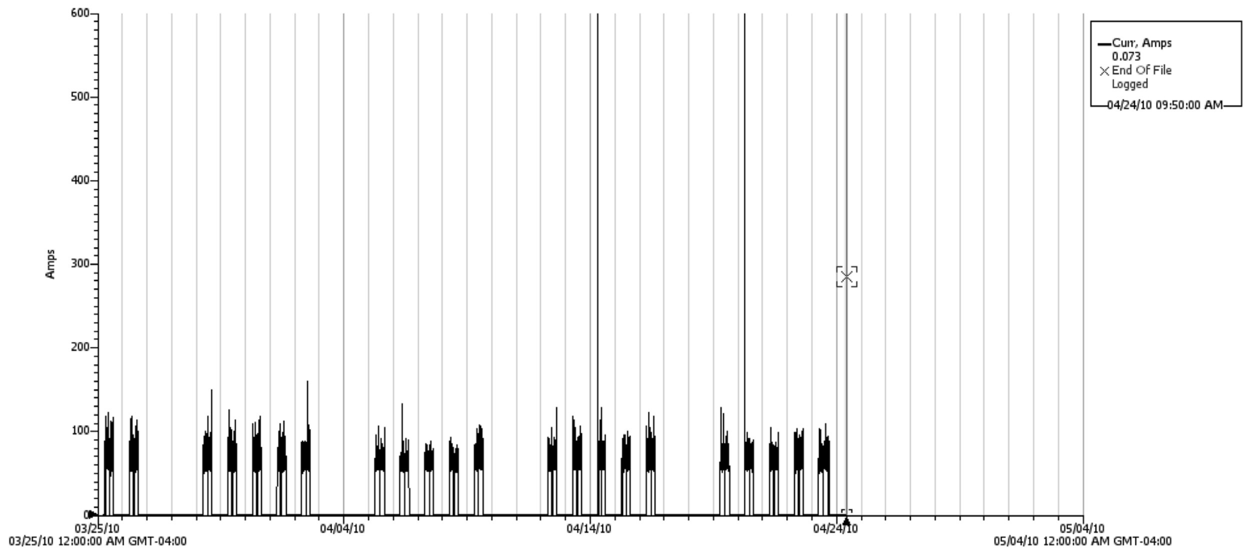


Figure 12: Graphical representation of the 200-hp edger current profile

SENSITIVITY ANALYSIS

In this module, a sensitivity analysis is performed, accounting for the variations in the annual power consumption, annual energy consumption, and specific energy consumption due to the type of wood species being processed at Facility 2.

Power Consumption Based on Wood Species

Facility 2, for example, processes mainly three types of species—maple, red oak, and white oak. Red oak and white oak account for approximately 60% (of which 80% is red oak and 20% is white oak); and maple accounts for 40%. After comparing the shear strength of each of these species, it can be seen that white oak is the hardest, red oak is in the medium range, and maple is the softest of the three species being processed at Facility 2. Table 6 lists the values for power consumed (kW) by equipment at Facility 2 for different wood species.

Figures 13, 14, and 15 show, for various wood species by the equipment at Facility 2, a comparison of the theoretical, baseline, and actual power consumption , respectively.

As expected, the value for power consumption increases with the strength of the wood species. The power consumption for white oak (fourth column from left in all three figures) is the highest, whereas the power consumption for maple (second column from left in all three figures) is the lowest. The first column in these figures is for the existing scenario at Facility 2, where a mix of all three species is processed around the year.

Energy Consumption Based on Wood Species

The energy consumed by any equipment is a function of the power consumption based on the operating load, the utilization factor (the percent of time for which the equipment operates), and the annual operating hours for the facility. Variations exist based on type of species processed, operating characteristics of the equipment, and system-level production parameters. For example, consider “Head Saw” equipment and “Other Support Equipment” for the actual power consumption in Figure 15 and the actual energy consumption in Figure 16; it can be seen that the power consumption for both of these categories of equipment is somewhat close, but the energy consumption does differ significantly. Table 7 summarizes the energy consumed by equipment for a variety of wood species being processed at Facility 2.

Table 6: Theoretical, baseline, and actual power consumption for a variety of wood species at Facility 2

		Power Consumption (kW)						
	Wood Species	**Debarker**	**Head Saw**	**Re-saw**	**Edger**	**Trimmer**	**Chipper**	**Other Motors**
Theoretical Power Consumption (KW)	**Mix of Species**	10.7	121.2	20.8	10.3	2.6	38.3	86.3
	All Maple	9.6	108.0	19.3	9.2	2.3	36.1	78.1
	All Red Oak	11.2	127.8	21.5	10.9	2.8	38.9	90.2
	All White Oak	11.7	134.5	22.3	11.5	2.9	42.7	95.5
Baseline Power Consumption (KW)	**Mix of Species**	31.7	127.1	23.9	18.4	6.6	55.4	113.2
	All Maple	28.4	113.3	22.2	16.4	5.8	52.2	102.4
	All Red Oak	33.2	134.0	24.7	19.5	7.1	56.3	118.3
	All White Oak	34.7	141.0	25.6	20.5	7.4	61.8	125.3
Actual Power Consumption (KW)	**Mix of Species**	35.0	139.8	26.7	20.9	7.1	64.1	124.3
	All Maple	31.4	124.6	24.8	18.7	6.3	60.4	112.5
	All Red Oak	36.6	147.4	27.6	22.1	7.6	65.1	129.9
	All White Oak	38.3	155.1	28.6	23.3	7.9	71.5	137.6

DISCUSSION

Simply consuming less energy per output does not contribute to being lean in energy terms. Spot checks of energy savings have to be backed up by a programmatic lean energy process, and one cannot do that until one has a way to determine and compare actual energy consumption and theoretical expected energy consumption of motors, the concept that is the focus of this research. The efficiency of the motor plays a large role in one not being able to closely approach the theoretical minimum energy consumption (not the calculation of the input power to the motor.) For a specific motor, if the gap between the theoretical energy consumption and actual is very large, then one has to consider improving the efficiency of the motor or replacing the motor with a motor of higher energy efficiency as one of the ways to reduce the gap. The gap analysis and benchmarking concepts outlined in this article are essential and important parts of a programmatic lean energy, ongoing continuous improvement effort by the organization.

Real-time data collected from one of the sawmill facility visits were used in the BEECWPS model. For one of the facilities, Facility 2, the theoretical energy requirement for only the major process equipment categories (not for the whole plant) was 266,294 kWh/yr, and actual energy usage was 384,914 kWh/yr (computed from the energy bills and power monitoring). Hence, the NEEC was determined to be 118,620 kWh/yr. Obviously, not all of this NEEC can be eliminated, because of the effectiveness of the EEM as well as the practical feasibility of EEMs based on product, process, and system parameters existing at the facility. The energy baseline was further developed for the entire equipment inventory at the facility and was determined to be 563,717 kWh/yr. The BEECWPS model was used to determine the expected total equipment energy usage at the facility to be 660,906 kWh/yr, which is lower than the actual energy consumption reported on the energy bills of 724,992 kWh/yr. Using the model, it was determined that the NEEC that can be reduced by the implementation of the EEMs can reduce the facility's total equipment energy usage (computed based on model) from 660,906 kWh/yr to 563,717 kWh/yr, a reduction of 97,189 kWh/yr (approximately 17%). This also implies a reduction of $7,144 (for an energy rate of $0.07350/kWh) from their annual energy costs of $53,289. The expected value of the SEC under current conditions was also determined by the BEECWPS model and was found to be 112.8 kWh/Mbf, as opposed to an

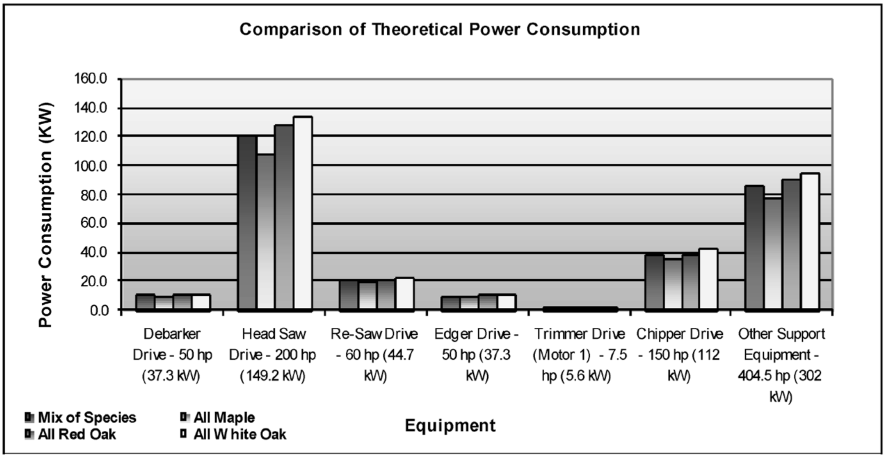


Figure 13: Comparison of theoretical power consumption for Facility 2

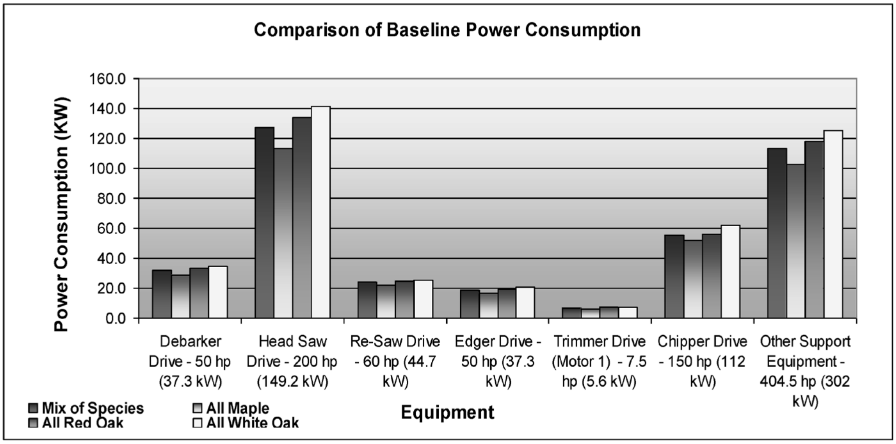


Figure 14: Comparison of baseline power consumption for Facility 2

actual value of 124 kWh/Mbf. If the facility succeeds in lowering current expected energy usage from 660,906 kWh/yr to 563,717 kWh/yr, the resulting SEC will be 96.2 kWh/Mbf.

It is important to note that from the six facilities visited, a facility with the lowest value for the SEC was selected for modeling and analysis. The research was started with the hypothesis that if there were opportunities to reduce the energy usage at the leanest facility, then there would be an opportunity to unveil a larger non-essential energy

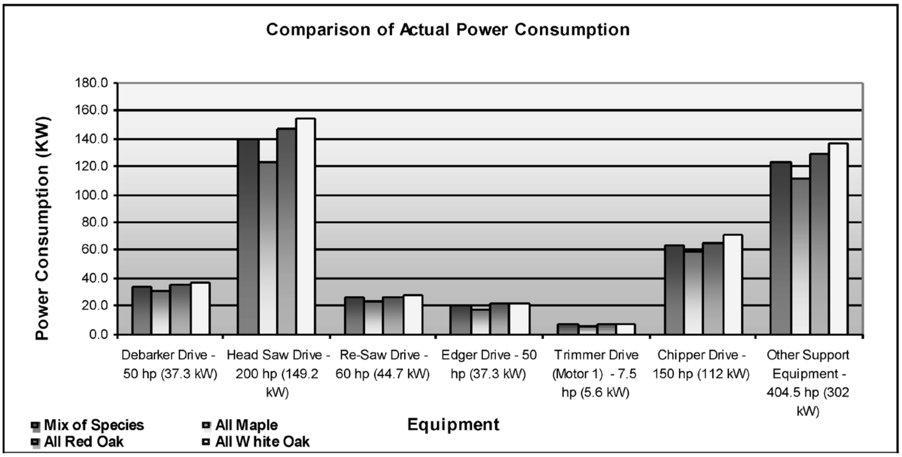


Figure 15: Comparison of actual power consumption for Facility 2

consumption component at the remaining facilities with higher SECs.

The BEECWPS model was used to perform sensitivity analysis and evaluate the effect of production parameters (such as wood species being processed, log diameters, board dimensions, and feed speed) on power consumption, energy consumption baseline, actual energy usage, and specific energy consumption in one of the sawmill facilities. The analysis resulted in the following:

- For the given mix of wood species, with the existing mix being 60% oak (of which 80% is red oak and 20% is white oak) and 40% maple, the SEC was determined to be 112.8 kWh/Mbf. If the facility decides to process only red oak, the SEC will increase to 117.7 kWh/Mbf; if only white oak, the SEC will increase to 124.7 kWh/Mbf; and if only maple, the SEC will reduce to 102.1 kWh/Mbf.

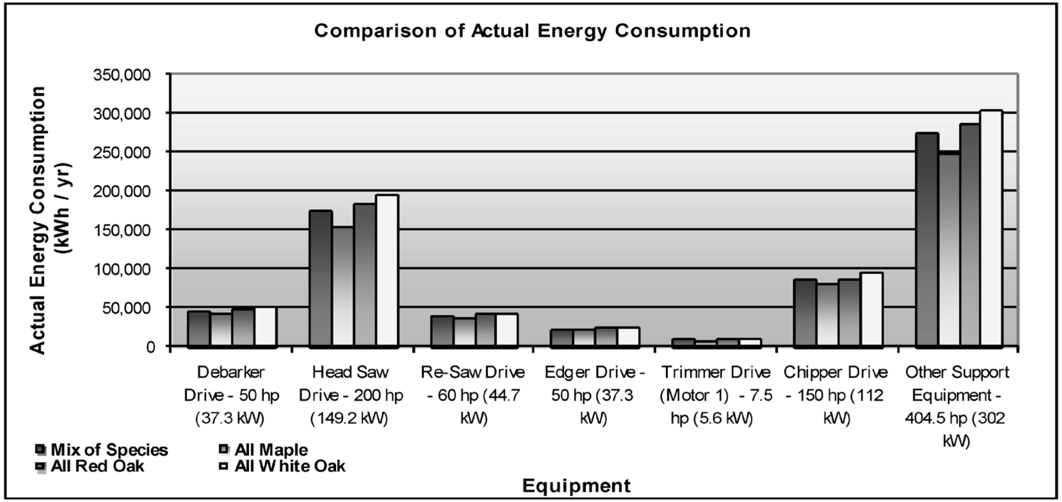
- It was found that if the log diameter is increased for the given mix of wood species in the model, the energy usage for the head sawing and the re-sawing operations increases, but the overall yield from larger-diameter logs increases and results in a lower SEC value. The SEC in this case was determined based on theoretical energy computations and was 134 kWh/Mbf for log diameter of 10 inches and 44 kWh/Mbf for log diameter of 14 inches.

- It was observed that if the desired board thickness is increased, there will be an increase in instantaneous power consumption (kW)

Table 7: Actual energy consumption based on wood species for Facility 2

Wood Species	Actual Energy Consumption (kWh / yr)						
	Debarker	Head Saw	Re-saw	Edger	Trimmer	Chipper	Other Motors
Mix of Species	47,359	175,652	41,289	24,240	9,607	86,734	275,320
All Maple	42,490	156,521	38,311	21,651	8,499	81,752	249,160
All Red Oak	49,572	185,217	42,678	25,652	10,346	88,092	287,762
All White Oak	51,785	194,927	44,266	27,064	10,716	96,775	304,671

Figure 16: Comparison of the actual energy consumption based on wood species for Facility 2



for the head sawing, edging, and trimming operations, as well as a reduction in power consumption for the re-sawing operation. Overall, the energy usage (kWh) for the head sawing, re-sawing, edging, and trimming operations will decrease, as less time is required to process same quantity of lumber. The energy usage for the remaining operations, such as debarking and chipping processes, will remain unchanged. The SEC based on computations for the theoretical energy consumption for a desired board thickness of one inch was determined to be 68.6 kWh/Mbf, and 61 kWh/Mbf for a thickness of 1.375 inch.

- Variation in the feed and speed affects energy usage for the head sawing operation. The SEC (kWh/Mbf) will decrease with the increase in the feed and speed at the head saw. Hence, the way in which the operator responds to irregularities in the log as observed while sawing on the head saw has an effect on the SEC. The sensitivity analysis can be extended for other important processes and production parameters at the equipment and the system levels. Although the diameter of the incoming log at sawmills has a significant impact on the process energy consumption, process yield, and SEC, sawmill owners may not have control over it. However, sawmill owners can manage the type of wood species processed at the facility, depending on their product demand and market share. From the sensitivity analysis performed for the example facility, it can be concluded that wood species is the most important factor driving the SEC.

The model was validated using data collected from another sawmill facility visited during the research. Manual calculations were also performed, and the results were found to be same as that from the proposed model.

CONCLUSION

Sawmill facilities are highly energy-intensive, with electrical energy representing a significant share of their total energy usage and operating costs. Electrical motors are extensively used in sawmill equipment. To minimize energy costs, one must understand the relationship between energy usage and production parameters. Expertise in the production process, along with continuous energy conservation practices, can play a significant role in reducing the energy usage at sawmills, thus reducing the operating costs while maintaining the product quality and market share. Therefore, developing a benchmarking tool for sawmills' energy consumption and understanding the specific energy consumption are critical. In this article, a model based on energy analysis and diagnostics, and designed to help reduce energy consumption, has been presented. After comparing the actual energy usage with the theoretical energy requirement, the model establishes a lowest practical value for the baseline energy for that sawmill. The difference between the actual and the baseline energy requirement for a particular sawmill will reveal the potential for energy efficiency measures and provide ingredients for a lean energy programmatic process in an organization. The article has espoused the concept of lean energy to imply that manufacturing processes and systems should use the least amount of energy practical, in terms of effective production strategies, as a part of the overall, continuous, improvement-oriented, lean energy process. Lower energy intensity implies lesser energy per unit of the product produced—a concept that relies on intensive energy efficiency methodologies. In terms of saw mills, there are a variety of energy efficiency measures that apply to the electrical and natural gas systems. These measures, when implemented, offer the facilitation of a *lean* approach in terms of energy usage. Reduction of energy is part of being lean and, in turn, leads to a reduction in operating costs and an increase in profitability. A discussion of the development of a subsequent programmatic effort for lean energy, based on the concepts presented here, can be explored as future research after significant efforts in observation of performance characteristics and implementation in an actual manufacturing setting.

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