Pulp, Paper, and Paperboard Mills

Industry Brief

Industry Snapshot

Paper and paperboard mills are included in NAICS industry 3221, which is composed of establishments primarily engaged in manufacturing pulp, paper, or paperboard. This industry is one of two in the paper manufacturing industry (NAICS 322), which also includes converted paper product manufacturing (NAICS 3222).

Table 1 lists the three sub-industries that fall under the pulp, paper, and paperboard mills industry (NAICS 3221). This *Industry Brief* concentrates on these three industries, which are the most energy-intensive sub-sector in the US paper manufacturing industry.

Pulp is made by separating the cellulose fibers from the other impurities in wood or other materials. Pulp mills do not make paper or paperboard; they sell the pulp to paper or paperboard mills. Paper and paperboard mills make paper and paperboard, respectively, from pulp that they either manufacture on-site or purchase. The delineation between paper and paperboard is somewhat indistinct, but paperboard is generally thicker and more rigid than paper.

Figure 1 shows the top five pulp, paper, and paperboard mill states in the US in 2007. Pulp mills are concentrated in the southeast, while paper and paperboard mills are located in western and the eastern states.

Table 2 shows the top ten ranking of states with pulp, paper, and paperboard mills by value of 2007 shipments, number of employees, and number of establishments. The data represent the combination of all pulp, paper, and paperboard mills in each state. Wisconsin ranked first in all three categories, but by a particularly large

Table 1
NAICS Codes, Industry Descriptions, and Products Produced by NAICS Industry 3221

NAICS Code	Description	Products
32211	*Pulp mills*	*Deinked recovered paper, groundwood pulp, pulp manufacturing (chemical, mechanical, or semi-mechanical processes)*
32212	*Paper mills*	*Asphalt paper, bond paper, construction paper, cotton fiber paper, facial tissues, kraft paper, newsprint, office paper, paper towels, tissue paper, toilet paper*
32213	*Paperboard mills*	*Binder board, Bristol board, cardboard, chipboard, container board, boxboard, leatherboard, milk carton board, kraft liner, paperboard*

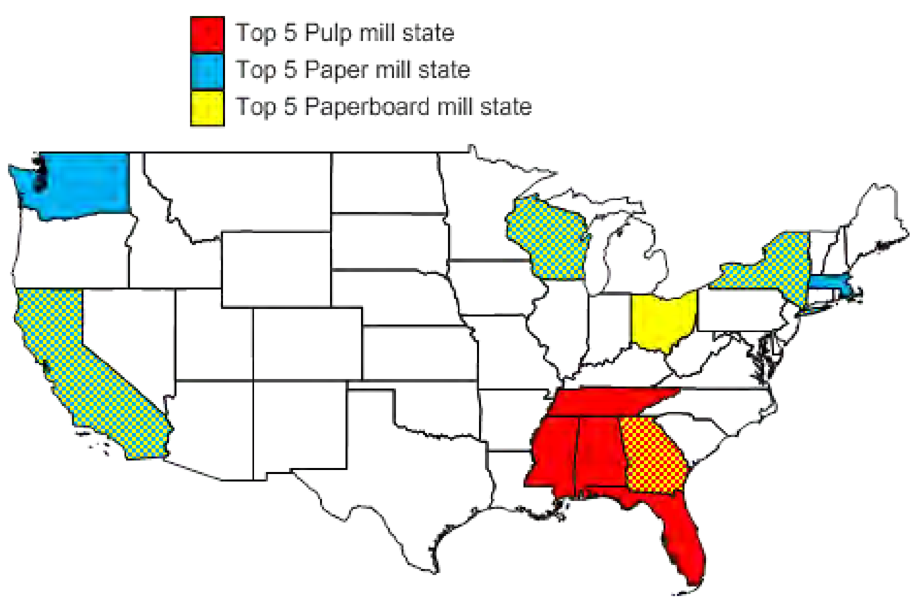

Figure 1
Top 5 Pulp, Paper, and Paperboard Mill States, 2007
Source: US Census Bureau, 2007

Table 2
Pulp, Paper, and Paperboard Mills – Top 10 States for 2007 Value of Shipments with Number of Employees and Number of Establishments

State	2007 Value of Shipments ($1,000)	2007 Rank	2007 Number of Employees	2007 Rank	2007 Number of Establishments	2007 Rank
Wisconsin	*$7,768,362*	*1*	*14,483*	*1*	*49*	*1*
Alabama	*$7,156,365*	*2*	*9,229*	*2*	*21*	*6*
Georgia	*$5,181,897*	*3*	*8,034*	*3*	*24*	*4*
Louisiana	*$4,642,223*	*4*	*5,565*	*8*	*11*	*19*
South Carolina	*$4,459,808*	*5*	*6,001*	*5*	*12*	*15*
Pennsylvania	*$4,457,074*	*6*	*5,958*	*6*	*20*	*8*
Washington	*$3,773,366*	*7*	*6,106*	*4*	*18*	*10*
Maine	*$3,157,237*	*8*	*5,715*	*7*	*12*	*16*
Oregon	*$2,893,937*	*9*	*3,871*	*13*	*12*	*17*
Michigan	*$2,576,866*	*10*	*4,816*	*9*	*21*	*7*
Total US	***$80,114,225***	**–**	***124,747***	**–**	***488***	**–**

Source: US Bureau of the Census, American Fact Finder 2007.

margin in number of employees and number of establishments. One fact that is depicted in Figure 1 but is not discernable from Table 2 is that while Wisconsin has 49 paper and paperboard mills, it has no pulp mills. This means that all of Wisconsin's mills are fully integrated.

The number of facilities is not always analogous with output. There is moderate correlation (r = 0.55) between the number of mills and the value of the output. When looking at just the top 10 states for number of establishments, the correlation is weaker (r = 0.33). This can be seen clearly when comparing Wisconsin and New York. New York has 41 mills, which is 13% less than Wisconsin. Yet, New York's production is $2.1 million, which is 72% lower than Wisconsin's – meaning that the value production per mill in New York is about one-third that of Wisconsin.

Pulp Mills

Pulp mills convert wood chips or other plant fibers into pulp, which is the resulting slurry of cellulose fibers suspended in water. The pulp is manufactured by either mechanically or chemically separating the cellulose fibers from the lignin polymer that binds the fibers.

Mechanical pulping typically involves steaming and grinding wood chips in a vessel called a refiner – a process called thermomechanical pulping or TMP. Mechanical pulping results in shorter length fibers. Adding steam helps to break down the lignin in the chips, which in turn reduces the amount of energy needed to grind the chips. Steam also helps to preserve fiber length, which adds strength to the paper. Because the fibers in mechanical pulp are shorter than those in chemical pulp, it is typically used for paper products that require less strength, such as newsprint and paperboards.

Chemical pulping involves the use of chemicals to break down the lignin without damaging the cellulose fibers. The most commonly used chemical pulping method is the kraft process. In this process, a mixture of sodium hydroxide and sodium sulfide, known as white liquor, is fed into a digester vessel along with the wood chips. There the chips are cooked under high heat and pressure to break down the lignins holding the cellulose fibers together. Pulp produced using the kraft process is stronger than that made by other processes. Kraft pulp is also darker than other pulp types, but it can be bleached for use in white paper. Bright white, high quality and strength papers with resistance to yellowing are usually made using kraft pulp. These include papers commonly used in homes and offices, such as copy paper, printer paper, and note paper.

In 2007, there were 39 pulp mills in the US, according to the 2007 Census of Business. The five states with the most pulp mills – shown in Figure 1 – are Florida, Georgia, Alabama, Mississippi, and Tennessee. Pulp mills employed almost 7,300 people nationwide in 2007; one-quarter of those people work in Georgia. Total shipments of pulp in 2007 were just over $5 billion.

Paper Mills

Paper mills are factories where paper is made from pulp. Paper mills can be categorized as either fully-integrated or non-integrated. Fully-integrated paper mills produce pulp on-site, while non-integrated paper mills purchase pulp from an off-site pulp mill.

Paper mills, like pulp mills, are very energy intensive. Paper is made in a paper machine. Almost all modern paper mills use a machine based on the Fourdrinier process. A Fourdrinier machine consists of a wide plastic mesh belt – called the "wire" – upon which the pulp is spread and the paper is formed. Fourdrinier-based machines have four sections:

- **Forming section** – Typically called the "wet end," this is where the pulp is applied to the wire to form a wet web of fiber. It is called the wet end because the wire soon runs under a roller that forces out water from the pulp in great quantities, making the forming section a wet area of the machine.
- **Press section** – This is where the still-wet fiber web passes between large rolls loaded under high pressure to squeeze out as much additional water as possible.
- **Drying section** – At this point, the pulp looks like paper. Here, the pressed sheet passes through a series of steam-heated drying cylinders in a serpentine manner. The drying section reduces the water content down to a level of about 6%, where it will remain at typical indoor atmospheric conditions.
- **Calendar section** – This is where heavy steel rolls smooth the dried paper, to give it a glossy finish and ensure uniform thickness. The finished paper is wound onto a reel. When the reel is full, the reel is automatically replaced by an empty reel, which begins taking up the paper that is continuously emerging from the machine.

From the reel, the paper is cut into various widths and lengths, and then packaged according to requirements of the final product.

Paper machines vary in size and production speed. The largest paper machines can be over 1,400 feet long and have wires over 27 feet wide. In the fastest paper machines the paper can move through the machine at speeds up to 114 miles per hour.

In 2007, there were 262 paper mills in the US, according to the 2007 Census of Business. The five states with the most paper mills – shown in Figure 1 – are Wisconsin, New York, California, Massachusetts, and Washington. Paper mills employed almost 82,000 people nationwide in 2007; 16% of those people work in Wisconsin. Total shipments of finished paper in 2007 were just over $50 billion.

Paperboard Mills

Paperboard mills are essentially the same as paper mills, except that the paper produced is thicker. This thicker paper is typically used to make paper cartons such as food containers or as stock for containerboard, which is used in products like corrugated cardboard boxes. Containerboard is produced in greater quantity than any other kind of paper in the world.

In 2007, there were 187 paperboard mills in the US, according to the 2007 Census of Business. The five states with the most paperboard mills – shown in Figure 1 – are New York, California, Ohio, Georgia, and Wisconsin. Paperboard mills employed over 36,000 people nationwide in 2007. Total shipments of finished paperboard in 2007 were just over $25 billion.

To simplify the discussion, paper mills (NAICS 32212) and paperboard mills (NAICS 32213) are collectively referred to as "paper mills" from this point forward.

Energy Use Characteristics

Pulp and paper mills are among the most energy-intensive of all industries. In 2002, the total energy use for the industry was 2,227 TBtu (see Table 3). This energy use was made up of multiple fuel types including black liquor,[1] natural gas, wood, and bark ("hog fuel"), coal, net electricity,[2] residual oil, and distillate oil in descending order. Of total energy consumption, 1,917 TBtu (86%) was used as boiler fuel, 134 TBtu (6%) was used directly, and 177 TBtu (8%) was in the form of net electricity. Of the energy used for boiler fuel, 54% was consumed as process steam, 9% as on-site generated electricity, and 38% was lost to parasitic loads (e.g., boiler cleaning and auxiliary systems), conversion losses, and other losses.

As Table 3 shows, electricity consumed in pulp and paper mills is both self-generated and purchased. Nearly 90% of electricity consumed is used in motor-driven systems. About 8% is consumed by lighting and HVAC systems. Figure 2 illustrates the major motor end-uses in the pulp and paper industry, which suggests that pump, materials processing, and fan systems are the major consumers.

The following sections summarize the energy use characteristics of pulp and paper mills by process.

Table 3
End-Use Energy Breakdown of the US Pulp and Paper Industry (NAICS 3221), 2002

Industry Use	**TBtu**	**Percent**
Direct fuel	134	6%
Boiler fuel	1,917	86%
Electricity	166	9%
Process steam	1,026	54%
Losses	725	38%
Net electricity	177	8%
Total	**2,227**	**100%**

Source: Kramer, et al. 2009.

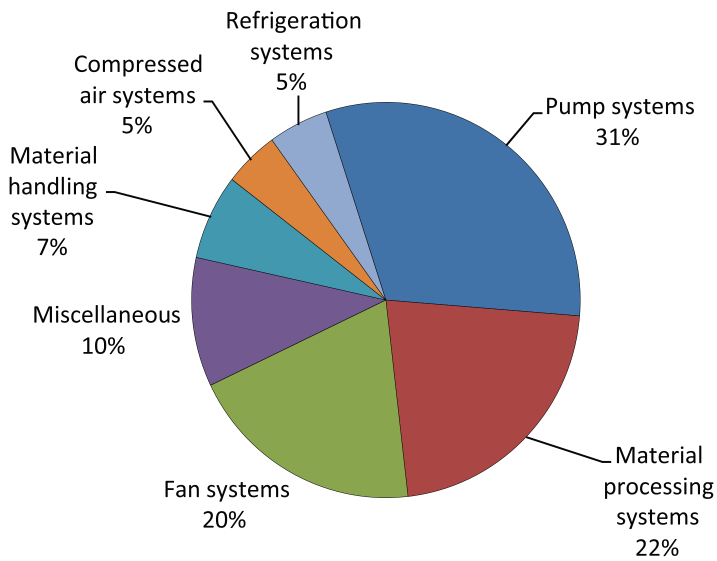

Figure 2
Motor System End-Uses in US Pulp and Paper Mills (NAICS 3221)
Source: Kramer, et al. 2009

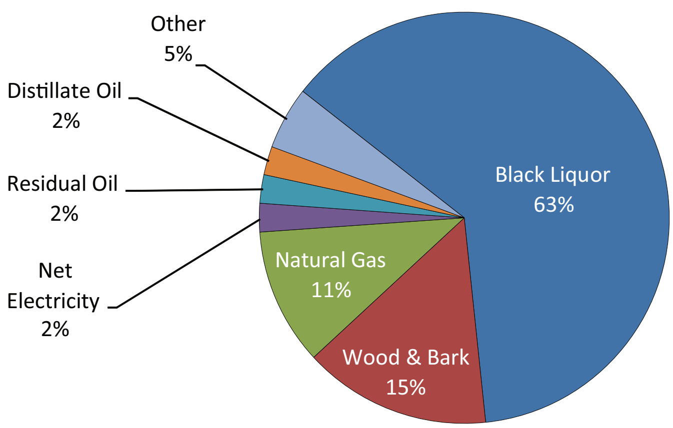

Figure 3
Energy Use in US Pulp Mills (NAICS 32211)
Source: Kramer, et al. 2009

Pulp Mills

Pulp mills in the US use a variety of fuels. However, by-products of pulp manufacturing (black liquor, wood, and bark ["hog fuel"]) provide over three-quarters of the industry's energy requirements (see Figure 3). Most of the fuel is used for steam production, followed by electricity generation, and then direct use processes such as drying or chemical processes. Electricity generated on-site is augmented by purchased electricity to meet the site's requirements. However, in some cases, electricity generated on-site exceeds the site's requirements (such as at kraft pulp mills), so the excess electricity is sold and net electricity is negative.

Pulp mills convert wood chips into pulp using either mechanical or chemical processes. The energy use characteristics of each are distinct and vary considerably by pulping process. The majority of pulp is produced in the US with chemical processes.

Thermomechanical Pulping

Of the mechanical pulping processes, thermomechanical (TMP) pulping is the most common process in use today. The most energy-intensive step in thermomechanical pulping is refining. Refiners are huge grooved metal plates between which the steamed wood chips are fed and where they are ground under heat and pressure. The motors that drive the refiners are very large – often as large as 12,000 horsepower – and operate continuously. Table 4 lists the primary energy-consuming processes in a TMP pulp mill, where the refiners can represent as much as 88% of the total electricity consumption.[3] Actual refiner energy consumption is defined by wood species and paper grade to be manufactured from the pulp.

Heat recovery, which is noted in Table 4, is often used in TMP mills to recover some of the refining energy in the form of clean, pressurized steam. The recovered steam is used either to generate electricity or used in processes, such as the TMP refiners.

Kraft Process

Chemical pulping mills – specifically kraft process mills – produce the majority of US pulp. While TMP mills rely heavily on electricity, kraft mills rely more on steam. Due to its high energy content, most kraft mills burn black liquor in recovery boilers to produce steam and recover the cooking chemicals. Excess steam is often used to generate electricity. Excess electricity is fed to the local grid or used in other processes.

Table 5 details the stages of the kraft process and the energy consumed during each stage. The most electricity intensive stage is the pulp machine, where much of the liquid is driven off using motor-driven rollers. The kraft process consumes 605 kWh for each ton of wood chips pulped. Table 6 shows that the process produces

Table 4
TMP Mill Steam and Electricity Consumption

Process	Steam (MMBtu/Ton[1])	Electricity (kWh/Ton[1])
Chip handling		40
Refiners		2,160
Pumps, screens, agitators, blowers		240
Heat recovery	-5.2	10
Total Consumption	**-5.2**	**2,450**

Note: 1) Air-dried ton

Table 5
Kraft Process – Steam and Electricity Consumption

Kraft Process Stages	Steam (MMBtu/Ton[1])	Electricity (kWh/Ton[1])
Chip conveying	0.0	19
Digester	1.6	38
Washing and screening	0.0	28
Oxygen delignification	0.5	71
Bleaching	2.2	95
Pulp machine	2.2	134
Black liquor evaporators	2.9	28
Power plant	2.2	57
Kiln and recausticizing	0.0	47
Hot water supply	0.0	30
Wastewater treatment	0.0	28
Miscellaneous	0.0	28
Losses	3.4	–
Totals	**15.0**	**605**

Note: 1) Air-dried ton

Table 6
Kraft Process – Disposition of Steam and Electricity Consumed

Disposition of Energy	Steam (MMBtu/Ton[1])	Electricity (kWh/Ton[1])
Consumed by pulping process	15.0	605
Generated by recovery boiler	15.0	621
Purchased (Excess)	0.0	(16)

Note: 1) Air-dried ton

621 kWh for each ton of wood chips processed by using the recovered black liquor to generate electricity. Therefore, there is an excess of 16 kWh for every ton of wood chips pulped. For an average sized kraft mill processing 1,000 tons per day, 16 MWh of excess electricity are generated.

Paper Mills

Paper mills in the US, like pulp mills, use a variety of fuels. Due to the number of fully-integrated paper mills, by-products of pulp manufacturing (black liquor and hog fuel) provide almost half of the paper mill industry's energy requirements, as shown in Figure 4. As in pulp mills, most of the fuel is used for steam production, followed by electricity generation, and then direct use processes such as drying or chemical processes. Electricity generated on-site is augmented by net electricity to meet the site's requirements.

Paper mills represent 97% of the electricity consumed by the pulp and paper industry. Ninety-one percent of the electricity is used by process-related systems including motors and drives, process heating and cooling, and electrical-chemical processes. Figure 5 shows that the vast majority of electricity consumed in paper mills is for motor systems, in particular those that drive the wires and rollers on paper machines. Within the paper machine, electricity use is evenly split between the pulp preparation at the wet end of the machine, forming, and drying. It is clear, therefore, that motor systems and controls should be a major focus of any efficiency activities in paper mills.

Efficient Electric Technology Alternatives

Several electric technology options are available for operators of pulp and paper mills that can improve the energy efficiency of the operations. The discussion below begins by presenting a number of well-established technologies that have been adopted to some extent by the pulp and paper industry, but still show potential for greater adoption. The discussion concludes with some lesser-known technologies that have limited or no market penetration in the industry, but that show considerable promise for improving operations.

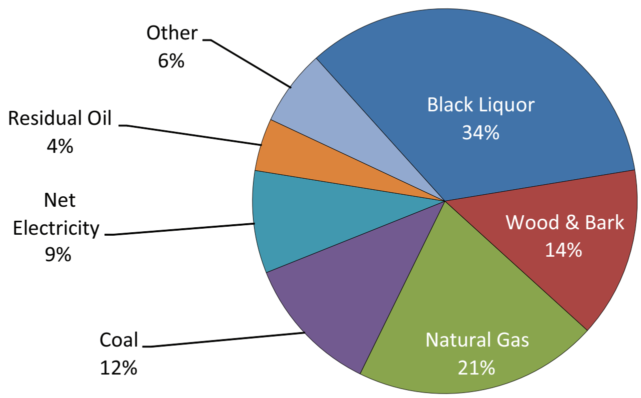

Figure 4
Energy Use in US Paper Mills (NAICS 32212 and 32213)
Source: Kramer, et al. 2009

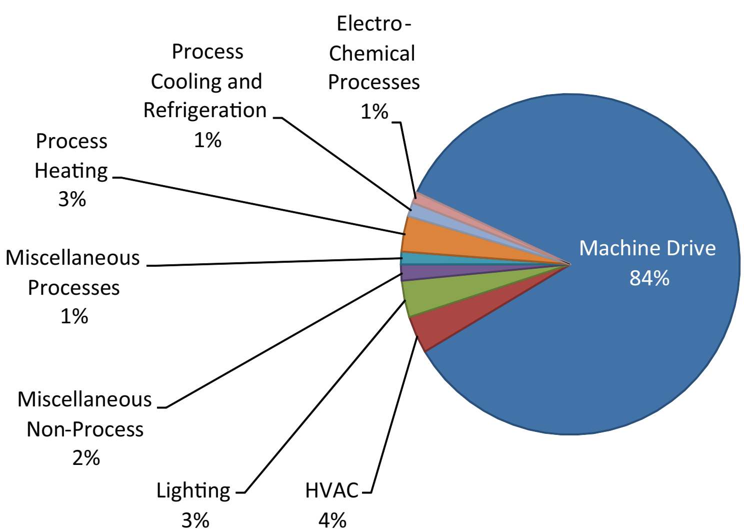

Figure 5
Electricity End-Uses in US Paper Mills (NAICS 32212 and 32213)
Source: DOE EIA, 2006 MECS, Table 5.1

Established Technologies

Adjustable Speed Drives

As discussed previously, motors are the major consumers of electricity in pulp and paper mills. Adjustable speed drives (ASDs) enable a continuous range of electric motor speed control, thereby matching motor speed with load. Variable frequency drives (VFDs), the most common type of ASD, meet process requirements by adjusting the frequency and voltage of the power supplied to an AC motor to allow it to operate over a large range of speeds.

ASDs can be applied to existing motor-driven equipment to improve the efficiency of the drive portion of the system. Alternatively, ASDs can be installed along with new motor-driven equipment in retrofit or new construction applications to optimize the efficiency and operation of the entire motor-driven system. ASDs are applicable to a wide variety of motor-driven applications, such as pumps, fans, compressors, and a myriad of process loads such as conveyors, presses, grinders, rollers, winders, rotary kilns, machine tools, etc. They are best suited to applications that require partial loads for long periods of time.

In general, annual energy savings from ASDs range from "~2%" to as high as 50%. ASDs applied to pumps and fans generally yield savings on the order of 30-35%; ASDs on compressors and refrigeration systems typically achieve savings of 18-23%; and ASDs on material handling equipment and machinery often result in savings of about 7%. Figure 6 illustrates how energy consumed by the vacuum motor is reduced by almost one-half with a 20% reduction in motor speed due to the cubic relationship between the two values.

The installed cost for an ASD depends on several factors including the size and type of drive, the size and complexity of the installation, and whether or not the ASD is installed on existing equipment or as a package with new motor-driven equipment. Generally, the cost per horsepower decreases with an increase in drive size. Installation costs are on the order of $100-300/hp for typical applications (~5-50 hp). However, large-scale ASDs (~500 hp) may cost as little as $50/hp and small-scale ASDs (~1hp) may cost as much as $500/hp. Payback periods generally range from one to three years.

High Efficiency Motors

Due to the enormity of energy use by motors in pulp and paper mills, improving motor efficiency can have substantial benefits in terms of reduced operating costs. Replacing standard efficiency motors with premium or high efficiency motors, which are generally 2% to 8% more efficient, can lead to significant energy savings. In general, high efficiency motors should replace failed standard efficiency motors that are used for 4,000 hours per year or more. Too often, however, motors are run until they fail and then replaced with a motor on hand of the same or higher rated horsepower to avoid

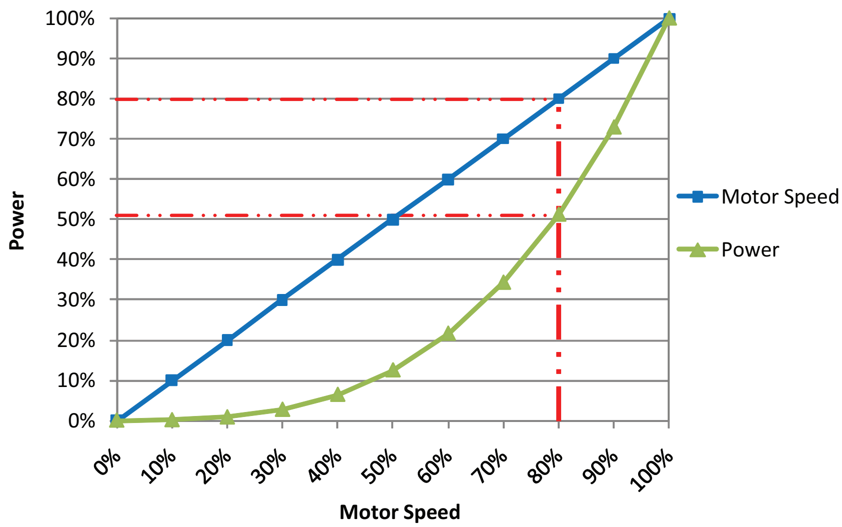

Figure 6
Cubic Relationship between Power and Motor Speed

equipment downtime. This replacement strategy often leads to the installation of over-sized motors. Additionally, facilities may not install premium efficiency motors due to misconceptions about durability.

Of the lifetime cost of owning a motor, only about 1% to 5% is the initial purchase cost; the remaining 95% to 99% is energy cost. Therefore spending a bit more to purchase a higher efficiency motor will return lower operating costs over the life of the motor. When purchasing a motor, the most energy-efficient and affordable motor possible should be chosen. Premium efficiency motors can cost about 20% more, but have a payback period of less than four years with one-shift operation and a cost of $0.05/kWh. Payback will be even shorter for a 24-hour, seven-day-per-week operation, or a facility with higher electricity costs.

Proper motor sizing is important, too. For optimum efficiency, motors should be sized to operate with a load factor between 65% and 100%. Oversizing results in less efficient motor operation. For example, a motor operating at a 35% load is less efficient than a smaller motor that is matched to the same load.

Table 7
Recommended Lighting Levels for Various Area Types

Area Type	Light Level (foot-candles)[5]
Material processing – Coarse	10
Material processing – Medium	30
Component production – Large	30
Component production – Medium	50
Assembly – Simple	50
Shipping and receiving	50
Control panel/Computer viewing	30 (vertical)

Source: Highbay Industrial Lighting Knowhow

Energy-Efficient Lighting

Lighting represents only about 3% of electricity use in pulp and paper mills and typically consists of high-bay fixtures.[4] The purpose of lighting is to provide a safe and efficient working environment, so it is important that the levels of lighting be appropriate, but not wasteful. Lighting levels in industrial facilities are often found to be higher than necessary. Table 7 shows the lighting levels recommended for areas typically found in industrial facilities. Table 8 lists the maximum power levels in watts per square foot for a variety of industrial spaces.

Commonly used lamps can be categorized into three types: incandescent, fluorescent, and high-intensity discharge (HID). There is a significant amount of literature available about these technologies and their relative efficacies. Facilities that increase the efficiency of lighting not only decrease lighting electricity use, but they also reduce space cooling and ventilation loads because more efficient lights produce less waste heat. A common rule-of-thumb is one watt of air conditioning savings results from every three watts of lighting power reductions. This rule is changing over time as CFLs and LEDs replace incandescent lamps in even greater numbers.

High-bay spaces are typically lit by high intensity discharge (HID) fixtures such as metal halide (MH) lamps. High pressure sodium (HPS) lamps have been losing favor in HID high-bay applications due to the yellow light they emit. Lately, more lamp manufacturers have introduced advanced high-output fluorescent systems as alternatives to HID lamps for illuminating high-bay spaces. At one manufacturing facility, replacing MH lamps with T5 high-output fluorescent lamps reduced lighting energy consumption and demand by 20%. Depending on the type of facility, the necessary lighting levels, and the type of existing lamps, retro-fitting high-bay spaces with high-output fluorescent lamps can lead to savings as high as 70%.

Table 8
Power Limits for Industrial Spaces

Whole Building Method	Watts/Sq Ft
Manufacturing facility	2.2
Warehouse	1.2
Space Method	**Watts/Sq Ft**
General lighting high-bay	3.0
Active storage/bulky	1.1
Transition/Corridors	0.7
Equipment room	0.8
Workshop	2.5
Control room	0.5

Source: ASHRAE/IESNA Standard 90.1-1999

Emerging Technologies

There are a number of new and emerging technologies – listed in Table 9 – that have applications in pulp and paper mills. All of these technologies are likely to be applicable within the next 5 to 10 years. Some are as yet unproven in the pulp and paper industry, but their success in other industries points to their potential for success in the pulp and paper industry. Two of the seven technologies in Table 9 are desirable replacements for fossil-fueled alternatives, namely microwaving logs and impulse drying.

Other Process Improvements

In addition to the efficient electric technologies presented in the previous section, there are five process improvements with the potential to add value to pulp and paper mills.

Table 9
Emerging Technologies for Pulp and Paper Mills

Technology	Description	Application
Magnetically-coupled ASDs	A type of adjustable-speed drive where the connection between the motor and its load is a gap of air, rather than a physical connection. The torque is transferred by rare-earth magnets on one side to induce magnetic fields on the other. The amount of torque transferred is varied by controlling the width of the air gap. The benefits are greater tolerance for misalignment, little impact on power quality, reduced vibration, and longer equipment life. Energy and demand impacts would be similar to standard ASDs.	Pumps, fans, conveyors, etc.
Laser-ultrasonic web stiffness sensor	Researchers at Lawrence Berkeley Laboratory have developed this sensor that measures a paper's bending stiffness and shear strength in real time, rather than requiring samples from finished rolls of paper. It will allow paper mills to manufacture paper closer to specifications as opposed to over engineering paper to make sure it is strong enough. Wasted paper will be reduced and some minor energy savings are also expected.	Quality assurance
Steam cycle washer for unbleached pulp	This technology provides a new method for washing pulp that uses 70% to 75% less water, up to 21% less electricity, and up to 49% less fuel for steam production. According to the US DOE, current pulp washing equipment age averages almost 50 years. This provides a major energy savings opportunity, because much of this equipment is nearing the end of its useful life and must be replaced.	Pulp washing
Microwaving logs	Microwaving logs prior to pulping softens the lignins, which has the potential to reduce the energy requirements of the TMP process. Initial tests indicate energy savings of 15% and improved pulp quality.	TMP process
Electrohydraulic contaminant removal	Non-water soluble adhesives on paper (called "stickies") – such as those found on "Post-It" notes – cause problems with the quality of recycled paper products. This technology, based on the principle of electrohydraulic discharge, may effectively remove stickies in an energy-efficient manner. Trials have shown that direct energy consumption reductions of 10% to 15% are possible.	Recycled paper and paperboard manufacturing
Impulse drying	Pressing paper between a very hot rotating roll and a static concave press over a short contact time can quickly dry paper entering the drying section of a paper machine. Studies estimate steam energy savings of 20% to 75%. This process would increase electricity consumption by 5% to 10%.	Paper drying
Industrial heat pumps	There are many opportunities for waste heat recovery at pulp and paper mills. Using industrial heat pumps to leverage waste heat from TMP or paper drying for use in other process heating applications is extremely energy-efficient relative to other electric or fossil-fueled process heating technologies.	Lumber drying, paper drying, space heating, process water heating

- **Reduced Compressed Air System Pressure** – Compressed air is used extensively in pulp and paper mills for many pneumatically-operated systems. Electric motors operate compressors that increase the pressure of air. Distribution systems take that compressed air to the various points of use with, ideally, minimal pressure loss.

  There is a direct relationship between compressed air system operating pressure and energy consumption, since it takes more energy to maintain a higher pressure. Therefore, reducing system pressure can lead to energy savings. A rule-of-thumb states that for systems operating around 100 psi, every decrease of 2 psi in operating pressure will reduce energy costs by 1%. The issue is to determine whether system pressure is too high and therefore appropriate for reduction. Other benefits of reduced system pressure include reduced leakage rates, increased system capacity, and longer component life.

  Compressed air systems are often operated at higher pressures than necessary for several reasons, including the comparatively wide control band used on most compressors and the belief that extra pressure provides a cushion against pressure drops. Pressure drops are the result of the compressed air losing pressure as it travels from the compressor through the various system components (e.g., aftercoolers, separators, air driers, valves, and filters) to the point of use. Pressure drops can be mitigated by thoughtful system design and selection of components, including:

  1. Avoiding the addition of new components and end-uses in a jumbled manner,
  2. Keeping filters and other components clean,
  3. Selecting components that minimize pressure drop,
  4. Providing the shortest path for the distribution system between compressor and end-use, and
  5. Placement of storage tanks and pressure regulators closer to larger end-uses.

- **Compressed Air Leak Sealing** – A commonly-cited figure is that 20% to 30% of the energy expended to compress air is lost through leaks in the system. Even a well-maintained compressed air system can leak as much as 10% of its compressor's output. Leaks also contribute to system operating troubles, such as irregular system pressure, the need to oversize compressors, and decreased service life of compressed air system equipment. Leaks can occur anywhere in the system, but are most commonly found in couplings, hoses, fittings, quick-connects, valves, and point-of-use equipment.

  Rates of leakage are a function of supply pressure and are proportional to the square of the diameter of the hole. For example, at a system pressure of 90 psig, a hole with a diameter of 1/32nd inch will leak 1.5 CFM. Assuming an electricity cost of $0.05/kWh, electricity consumption of 18 kW/100 CFM, and 7,000 operating hours per year, a single air leak 1/32nd inch in diameter will waste about $58 per year.

  The best method for detecting leaks is to use an ultrasonic acoustic detector. These portable tools use directional microphones to locate the source of the high frequency sound caused by air leaks. While easy to use, ultrasonic detectors are very expensive and best used by trained personnel. They are often able to estimate the rate of leakage based on the volume and frequency of the sound emitted by the leak.

  The final step is the establishment of a leak prevention program, of which there are two types. The first is the "leak tag" program in which leaks are marked with a tag when they are identified and repaired at a later time. The second is the "seek and repair" program in which leaks are fixed as soon as they are identified.

- **Power Factor Correction** – Inductive loads like transformers, electric motors, and HID and fluorescent lighting may cause a low power factor. A low power factor may result in increased power consumption and increased electricity costs. A low power factor can be improved by minimizing idling of electric motors, avoiding operating equipment above its rated voltage, replacing standard efficiency motors with premium-efficiency motors, and installing capacitors on AC circuits to decrease the magnitude of reactive power in the system.

- **Minimizing Voltage Unbalances** – Voltage unbalances degrade the performance and shorten the life of three-phase motors. A voltage unbalance causes a current unbalance, which will result in torque pulsations, increased vibration and mechanical stress, increased losses, and motor overheating. All these work to reduce winding insulation life. Voltage unbalances can be caused by incorrect operation of power factor correction equipment, an unbalanced transformer bank, or an open circuit. A rule of thumb is that the voltage unbalance at the motor terminals should not exceed 1%. Even a 1% unbalance will reduce motor efficiency at part load operation, while a 2.5% unbalance will reduce motor efficiency at full load operation.

  For a 100 hp motor operating 8,000 hours per year, a correction of the voltage unbalance from 2.5% down to 1% will result in electricity savings of 9,500 kWh or almost $500 at an electricity rate of $0.05/kWh.

- **Pinch Analysis Process Integration** – Pinch analysis is one of the most widely used process integration techniques. Process integration is now an established methodology for improving the energy efficiency of continuous industrial processes, such as those found in pulp and paper mills.

  Pinch analysis takes a systematic approach to identifying and correcting the performance-limiting constraint (or "pinch") in any manufacturing process system. Pinch analysis involves the development of "composite curves" for heating and cooling, which represent the overall thermal energy demand and availability profiles for the process as a whole. When the two curves are drawn on a temperature-enthalpy graph, they reveal the location of the process pinch (the point of closest temperature approach), and the minimum thermodynamic heating and cooling requirements, which are called the energy targets. The next step is to identify the energy targets and then follow a procedure for designing heat exchanger networks to achieve the targets.

Potential energy savings from using pinch analysis to identify opportunities are far greater than from applying conventional energy saving techniques alone. For example, EPRI has conducted more than fifty pinch studies in the last 20 years that, on average, have identified energy cost savings of more than 20% with one-to-three year payback periods. An EPRI pinch analysis of a TMP mill in Canada found two energy-saving options with paybacks of 2.1 and 2.5 years.[6] Another EPRI pinch study of a newsprint mill in Mississippi estimated a payback of just 1.7 years.[7]

Pinch analysis that includes the optimization of both energy and water are desirable because the pulp and paper industry relies so heavily on both resources.

Benefits of Expanding End-Use Applications of Electricity

The previous two sections identified efficient electric technologies and process improvements. Several of the opportunities presented above decrease electricity requirements by using electricity more efficiently. A few such examples include ASDs, magnetically-coupled ASDs, high efficiency motors, and compressed air system improvements. Two other opportunities presented (microwaving logs and industrial heat pumps) replace a conventional fossil-fueled process with more efficient electric process, thereby decreasing overall energy use and associated greenhouse gas emissions, while increasing productivity. Microwaving logs also improves pulp quality. A third type of opportunity discussed – electrohydraulic contaminant removal – represents a new application of electricity. Together, the latter two categories of opportunities, in essence, expand end-use applications of electricity. Expanding end-use applications of electricity can yield four main types of benefits, as described below.

Energy Savings

Highly efficient electric alternatives (e.g., microwaving logs and industrial heat pumps) can decrease primary energy use[8] relative to fossil-fueled alternatives (e.g., steam production with natural gas). For example, microwaving logs introduces the microwave generator as a new energy-consuming component into the TMP process. However, the reduced energy requirements of the refiner can still result in a primary energy savings with the added benefit of improved pulp quality. In addition, industrial heat pumps are very efficient for leveraging waste heat for use in other process heating applications, thereby lowering primary energy requirements.

- **Reductions in Greenhouse Gas Emissions** – Decreasing primary energy use correspondingly reduces greenhouse gas (GHG) emissions associated with the combustion of fossil fuels. That is, if a natural gas process were replaced with a very efficient electric process so that primary energy use was reduced, GHG emissions would also be reduced.

  Switching to electric processes can also shift GHG and other air emissions from the end-use site to an off-site power plant, making control of emissions more viable. However, this depends on how and where the electricity is generated. For pulp and paper mills that obtain much of their electricity from traditional power plants, switching from fossil fuels such as natural gas to electricity shifts the emissions off-site.

  However, much of the electricity used at pulp and paper mills is generated on-site with steam produced from combustion of black liquor and hog fuel. This presents a unique opportunity for pulp and paper mills since GHG emissions associated with on-site combustion of black liquor and hog fuel are considered carbon neutral. In other words, they typically are not counted in GHG emissions inventories of mill operations. As a result, the GHG emissions factor is zero for electricity generated on-site. In contrast, the GHG emission factor is roughly 178,300 metric tons of CO2 per TBtu for net electricity. With much of the electricity used in the mills generated on-site, the average GHG emissions factor associated with mill electricity consumption is far lower than if all of a mill's electricity requirements were purchased. Due to the "watering down" of the electricity GHG emissions factors by electricity generated on-site, maximizing the use of electric technologies powered by on-site generated electricity in place of fossil fueled technologies would result in lower GHG emissions per ton of paper produced.

- **Process Improvements** – Many electric technologies offer improved productivity. Efficient lighting, which is typically better quality lighting, can improve worker productivity by 3% to 15%. Electrohydraulic contaminant removal improves the quality of recycled paper products. Magnetically-coupled ASDs are not affected by vibration or misalignment, so they can operate with fewer interruptions, which is critical in continuous industrial processes, such as pulp and paper manufacturing.

Economic Advantages

Energy savings, improved product quality, and increased productivity all translate to cost savings for pulp and paper manufacturers. Electric technologies also offer the ability to take advantage of off-peak rates for certain processes, which can further reduce operating costs. Depending on local tax laws, there may be tax advantages to investing in energy-efficient technologies as well.

Additional Resources

Energy Efficiency Improvement and Cost Saving Opportunities for the Pulp and Paper Industry. http://www.energystar.gov/ia/business/industry/downloads/Pulp_and_Paper_Energy_Guide.pdf

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Notes

1. "Black liquor," named for its color, is a byproduct of pulp mills using the kraft process. It is a solution of lignin residues and inorganic chemicals used in the kraft process and contains about half the energy content of the wood fed into the digester. Due to its high energy content, most kraft mills burn black liquor in recovery boilers to produce steam and recover the cooking chemicals.

2. Net electricity is the sum of purchased electricity, transfers in, and generation from noncombustible renewable resources minus the quantities of electricity sold and transferred offsite. Thus, net electricity excludes the quantities of electricity generated or cogenerated onsite from combustible energy sources. (US DOE EIA).

3. The figures shown in Table 4 are for a TMP mill producing 500 bone-dry metric tons/day.

4. "High-bay" lighting is typically found in facilities with ceilings higher than 25 feet.

5. For comparison, an overcast day would produce about 100 foot-candles of illumination.

6. *Minimizing Process Energy Use for a Large TMP Mill with Pinch Technology,* EPRI, Palo Alto, CA: 2000. 1000370.

7. *Energy Targeting Scoping Study Using Pinch Analysis: Bowater Newsprint, Grenada, MS,* EPRI, Palo Alto, CA: 2004. 1007503.

8. Primary energy is energy before any transformation to secondary or tertiary forms of energy. Primary energy includes any losses due to generation, transmission, or other system inefficiencies. This is distinct from delivered energy, which is only energy delivered to the point of use, which does not take losses into account.

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Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com