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# **Energy Efficiency Improvement and Cost Saving Opportunities for the Pulp and Paper Industry**

## **An ENERGY STAR<sup>®</sup> Guide for Energy and Plant Managers**

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**Sponsored by the U.S. Environmental  
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### **ABSTRACT**

The U.S. pulp and paper industry—defined in this Energy Guide as facilities engaged in the manufacture of pulp, paper, and paperboard—consumes over \$7 billion worth of purchased fuels and electricity per year. Energy efficiency improvement is an important way to reduce these costs and to increase predictable earnings, especially in times of high energy price volatility. There are a variety of opportunities available at individual plants in the U.S. pulp and paper industry to reduce energy consumption in a cost-effective manner. This Energy Guide discusses energy efficiency practices and energy-efficient technologies that can be implemented at the component, process, facility, and organizational levels. This Energy Guide begins with an overview of the trends, structure, and energy consumption characteristics of the U.S. pulp and paper industry, along with descriptions of the major process technologies used within the industry. Next, a wide variety of energy efficiency measures applicable to pulp and paper mills are described. Many measure descriptions include expected savings in energy and energy-related costs, which are based on case study data from real-world applications in pulp and paper mills and related industries worldwide. Typical measure payback periods and references to further information in the technical literature are also provided, when available. Given the importance of water use in pulp and paper mills, a summary of basic measures for improving plant-level water efficiency is also provided. The information in this Energy Guide is intended to help energy and plant managers in the U.S. pulp and paper industry reduce energy and water consumption in a cost-effective manner while maintaining the quality of products manufactured. Further research on the economics of all measures—as well as on their applicability to different production practices—is needed to assess their cost effectiveness at individual plants.



## Table of Contents

1	Introduction.....	1
1.1	Purpose of this Energy Guide .....	1
1.2	Organization of this Energy Guide .....	2
2	The U.S. Paper and Pulp Industry.....	4
2.1	Economic Trends .....	5
2.2	Sub-Sector Overviews .....	6
2.3	Pulp and Paper Processing Trends.....	8
2.4	Industry Structure and Characteristics.....	10
3	Overview of Pulp, Paper and Paperboard Processing Methods.....	12
3.1	Raw Materials Preparation.....	13
3.2	Pulping.....	14
3.3	Chemical Recovery.....	18
3.4	Bleaching .....	19
3.5	Pulp Drying.....	20
3.6	Papermaking .....	20
4	Energy Use in the U.S. Pulp and Paper Industry .....	22
4.1	Energy Costs .....	22
4.2	Energy Consumption and End Uses .....	24
4.3	Energy-Related Greenhouse Gas Emissions.....	29
5	Energy Efficiency Improvement Opportunities.....	32
6	Energy Management Programs and Systems.....	37
6.1	A Strategic Energy Management Program .....	37
6.2	Energy Teams .....	39
6.3	Energy Monitoring and Control Systems .....	40
7	Steam Systems .....	43
7.1	Boiler Energy Efficiency Measures .....	44
7.2	Steam Distribution System Energy Efficiency Measures.....	48
7.3	Process Integration.....	51
8	Combined Heat and Power (CHP) Systems.....	54
9	Motor Systems .....	60
10	Pumps.....	66
11	Fan Systems .....	73
12	Compressed Air Systems .....	76
13	Lighting.....	85
14	Energy Efficiency Measures for Raw Material Preparation.....	88
15	Energy Efficiency Measures for Chemical Pulping.....	90
15.1	Kraft Pulping.....	90
15.2	Bleaching .....	92
15.3	Chemical Recovery.....	93
16	Energy Efficiency Measures for Mechanical Pulping .....	96
17	Energy Efficiency Measures for Papermaking .....	100
18	Emerging Energy Efficiency Technologies .....	106
19	Water Efficiency Opportunities in the U.S. Pulp and Paper Industry .....	113
19.1	Water Use in Pulp and Paper Manufacturing .....	113

19.2 Pulp and Paper Manufacturing Water Efficiency Measures.....	116
20 Summary and Conclusions .....	125
21 Acknowledgements.....	126
References.....	127
Appendix A: Basic Energy Efficiency Actions for Plant Personnel.....	147
Appendix B: Guidelines for Energy Management Assessment Matrix.....	148
Appendix C: Teaming Up to Save Energy Checklist .....	152
Appendix D: Support Programs for Industrial Energy Efficiency Improvement .....	154
Appendix E: Additional Information Sources .....	163



# 1 Introduction

As U.S. manufacturers face an increasingly competitive environment, they seek out opportunities to reduce production costs without negatively affecting the yield or the quality of their finished products. The volatility of energy prices in today's marketplace can also negatively affect predictable earnings. The challenge of maintaining high product quality while simultaneously reducing production costs can often be met through investments in energy efficiency, which can include the purchase of energy efficient technologies and the implementation of plant-wide energy efficiency practices. Energy efficient technologies can often offer additional benefits, such as quality improvement, increased production, and increased process efficiency, all of which can lead to productivity gains. Energy efficiency is also an important component of a company's overall environmental strategy, because energy efficiency improvements can lead to reductions in emissions of greenhouse gases and other important air pollutants. Investments in energy efficiency are therefore a sound business strategy in today's manufacturing environment.

ENERGY STAR<sup>®</sup> is a voluntary program operated by the U.S. Environmental Protection Agency (EPA) in coordination with the U.S. Department of Energy (DOE). The primary purpose of the ENERGY STAR program is to help U.S. industry improve its competitiveness through increased energy efficiency and reduced environmental impact. ENERGY STAR stresses the need for strong and strategic corporate energy management programs and provides a host of energy management tools and strategies to help companies implement such programs. This Energy Guide reports on research conducted to support the U.S. EPA's ENERGY STAR Pulp and Paper Focus, which works with the U.S. pulp and paper industry to develop resources and reduce information barriers for energy efficiency improvement. For further information on ENERGY STAR and its available tools for facilitating corporate energy management practices, visit <http://www.energystar.gov/>.

## 1.1 Purpose of this Energy Guide

This Energy Guide provides an overview of available measures for energy efficiency in the U.S. pulp and paper industry. It is designed to address the interests of a wide audience: from beginning energy engineers and analysts to seasoned energy managers and experts in the pulp and paper industry.

Given the importance and rising costs of water as a resource in pulp and paper production, this Energy Guide also provides information on basic, proven measures for improving plant-level water efficiency. Moreover, water efficiency improvement can also reduce energy use for water heating, treatment, and pumping.

The U.S. pulp and paper industry—defined in this Energy Guide as facilities engaged in the manufacture of pulp, paper and paperboard—is an important industry from both an economic and an energy use perspective. In 2006, the industry generated nearly \$79 billion in product shipments and employed around 139,000 people directly in nearly 600 mills. The industry spent roughly \$7.5 billion on purchased fuels and electricity in 2006; around \$4.7 billion of this was for purchased fuels and around \$2.8 billion of this was for purchased electricity. Because the costs of electricity and natural gas are rising rapidly in the United States, energy

efficiency improvements are becoming an increasingly important focus area in the U.S. pulp and paper industry for managing costs and maintaining competitiveness.

## **1.2 Organization of this Energy Guide**

This Energy Guide begins with an overview of the trends, structure, and production characteristics of the U.S. pulp and paper industry in Chapter 2. A description of the main production processes employed in pulp and paper manufacture is provided in Chapter 3. In Chapter 4, the use of energy in the U.S. pulp and paper industry is discussed along with an overview of the main end uses of energy in typical pulp and paper mills.

Chapters 5 through 17 describe many available measures for improving energy efficiency in the U.S. pulp and paper industry, with a focus on energy-efficient technologies and practices that have been successfully demonstrated in facilities in the United States and abroad.

Although new energy-efficient technologies are developed continuously (see for example Martin et al. 2000), this Energy Guide focuses primarily on those technologies and practices that were both proven and currently commercially available at the time of this writing. However, because emerging technologies can often play an important role in reducing industrial energy use, Chapter 18 offers a brief overview of selected promising emerging energy-efficient technologies of relevance to pulp and paper making.

Given that the U.S. pulp and paper industry manufactures a wide variety of products and employs a diversity of production methods, it is impossible to address every possible end use of energy within the industry. This Energy Guide therefore focuses on only the most important end uses of energy in U.S. pulp and paper mills.

In recognition of the importance of water as a resource in pulp and paper mills—as well as the rising costs of water—this Energy Guide offers information on basic measures for improving plant-level water efficiency in Chapter 19. Many of the water efficiency strategies discussed in Chapter 19 can lead to energy savings as well.

The material in the Energy Guide was compiled primarily from publicly available information sources and communications with experts in industrial energy efficiency and pulp and paper mill operations. A full bibliography of the information sources used in developing this Energy Guide is provided in the references section.

Lastly, this Energy Guide also includes several appendices that contain useful information on available energy management tools, information resources, incentive programs at the state and national levels, and summary tables of additional energy and water efficiency measures obtained from several in-depth resources that were leveraged in the development of this Energy Guide.

Table 1.1 provides a summary of some key U.S. pulp and paper industry economic and energy use data that are presented in this Energy Guide.

**Table 1.1: Key economic and energy use data for the U.S. pulp and paper industry**

<b>NAICS Code</b>	<b>Value of Product Shipments (2006)</b>	
32211	Pulp mills	\$5.6 billion
322121	Paper (except newsprint) mills	\$46.6 billion
322122	Newsprint mills	\$4.1 billion
32213	Paperboard mills	\$22.6 billion
	<b>Total</b>	<b>\$78.8 billion</b>
<b>NAICS Code</b>	<b>Employment (2006)</b>	
32211	Pulp mills	7,394
322121	Paper (except newsprint) mills	88,141
322122	Newsprint mills	5,521
32213	Paperboard mills	37,700
	<b>Total</b>	<b>138,756</b>
<b>NAICS Code</b>	<b>Number of Establishments (2006)</b>	
32211	Pulp mills	44
322121	Paper (except newsprint) mills	325
322122	Newsprint mills	23
32213	Paperboard mills	205
	<b>Total</b>	<b>597</b>
<b>NAICS Code</b>	<b>Electricity Expenditures (2006)</b>	
32211	Pulp mills	\$0.1 billion
32212	Paper mills	\$1.7 billion
32213	Paperboard mills	\$1.0 billion
	<b>Total</b>	<b>\$2.8 billion</b>
<b>NAICS Code</b>	<b>Electricity Use (Purchases + Generated – Sold) (2006)</b>	
32211	Pulp mills	5.7 TWh
32212	Paper mills	52.2 TWh
32213	Paperboard mills	31.8 TWh
	<b>Total</b>	<b>89.7 TWh</b>
<b>NAICS Code</b>	<b>Fuel Expenditures (2006)</b>	
32211	Pulp mills	\$0.3 billion
32212	Paper mills	\$2.6 billion
32213	Paperboard mills	\$1.8 billion
	<b>Total</b>	<b>\$4.7 billion</b>
<b>Top 5 States for Pulp and Paper Industry Value of Shipments (2006)</b>		
(1) Wisconsin, (2) Alabama, (3) Pennsylvania, (4) Georgia, (5) South Carolina		

## 2 The U.S. Paper and Pulp Industry

The U.S. pulp and paper industry is comprised of three primary types of producers: (1) pulp mills, which manufacture pulp from wood and other materials (such as wastepaper); (2) paper mills, which manufacture paper from wood pulp and other fiber pulp; and (3) paperboard mills, which manufacture paperboard products from wood pulp and other fiber pulp.

The North America Industry Classification System (NAICS) codes associated with these three industry sub-sectors are summarized in Table 2.1, along with some of the key products that are manufactured by each sub-sector. The paper mill sub-sector (NAICS 32212) is further subdivided into paper mills that make newsprint (NAICS 322122) and paper mills that manufacture all other paper products (NAICS 322121).

**Table 2.1: NAICS codes and key products of the U.S. pulp and paper industry**

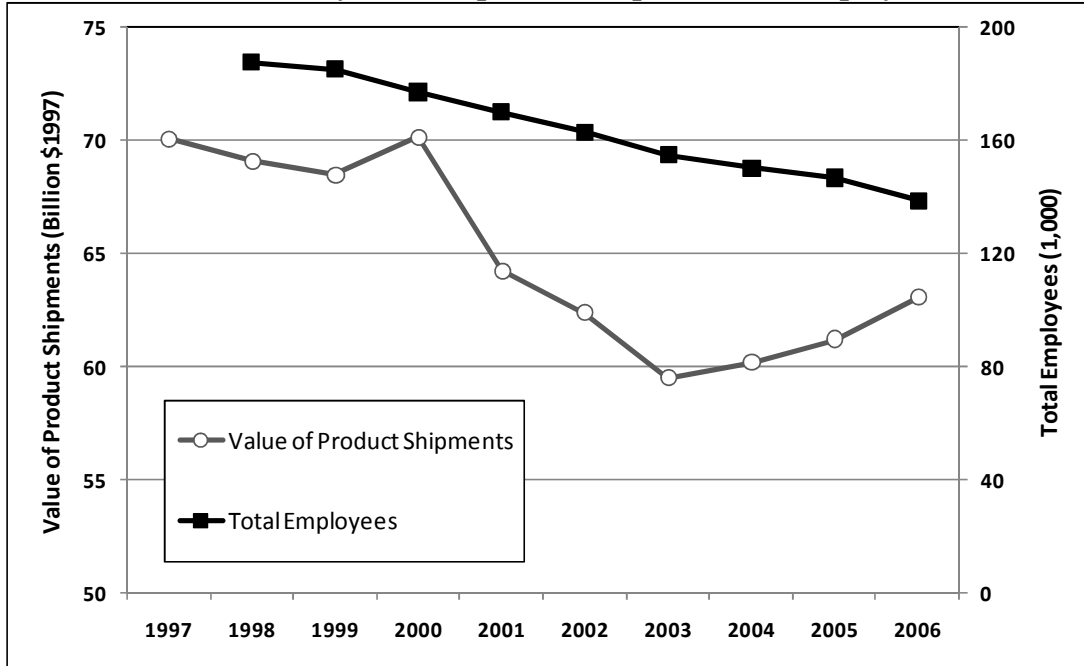
NAICS Code	Sub-sector description	Key products
32211	Pulp mills	Deinked recovered paper, groundwood pulp, pulp manufacturing (i.e., chemical, mechanical, or semichemical processes)
32212	Paper mills	
322121	Paper (except newsprint) mills	Bond paper, book paper, cigarette paper, diapers, facial tissues, napkins, sanitary paper, office paper, writing paper, paper towels
322122	Newsprint mills	Groundwood paper products (e.g., publication and printing paper, tablet stock, wallpaper base), newsprint
32213	Paperboard mills	Binder's board, cardboard stock, container board, folding boxboard stock, milk carton board

The scope of this Energy Guide is limited to the NAICS industry sub-sectors listed in Table 2.1, which represent the most energy-intensive sub-sectors of the U.S. paper manufacturing industry (NAICS 322). The less energy-intensive converted paper products sub-sector (NAICS 3222), which comprises establishments primarily engaged in converting paper or paperboard without manufacturing paper or paperboard, is not covered in this Energy Guide.

## 2.1 Economic Trends

In 2006, the U.S. pulp and paper industry generated nearly \$79 billion in product shipments, or around 1.6% of the total value of product shipments of the U.S. manufacturing sector as a whole (U.S. Census Bureau 2008a). This number is up from around \$70 billion in product shipments in 1997 (U.S. Census Bureau 2002). In real (i.e., inflation adjusted) dollars, however, the economic output of U.S. pulp, paper, and paperboard mills declined by roughly 10% between 1997 and 2006, as depicted in Figure 2.1.<sup>1</sup>

**Figure 2.1 Trends in industry value of product shipments and employment, 1997-2006**



Sources: U.S. Census Bureau (2008a, 2008b, 2005, 2003a, 2002)

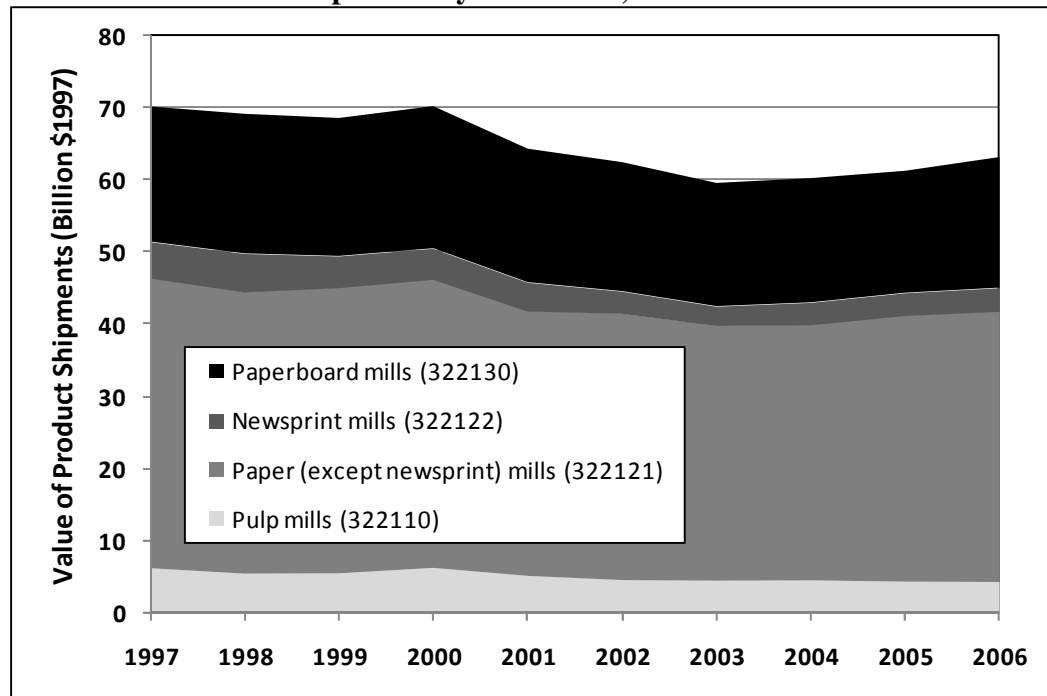
Also shown in Figure 2.1 is a decline in total industry employment over roughly the same period. In 2006, the industry employed around 139,000 people directly, down from around 188,000 employees in 1998 (U.S. Census Bureau 2008b). These recent declines in shipments and employment might be explained in part by market and economic pressures facing the U.S. pulp and paper industry. Such pressures include increasing consolidation, strong competition from imports, rising labor costs, and rising energy costs.

Figure 2.2 depicts the trends in value of product shipments by sub-sector of the U.S. pulp and paper industry between 1997 and 2006, in 1997 dollars. The paper (excluding newsprint) mill sub-sector is the largest economic contributor to the industry by a significant margin, and accounts for roughly 60% of industry value of product shipments. The newsprint mill sub-sector is the smallest economic contributor, accounting for only roughly 5% of product shipments. In real dollars, the value of product shipments in all four industry sub-sectors has

<sup>1</sup> Value of shipments data in Figure 2.1 were adjusted for inflation using producer price index data for the U.S. pulp and paper industry from the U.S. Bureau of Labor Statistics (2008).

declined since 1997. The largest decline in product shipments (a decline of roughly 35%) was seen in the newsprint mills sub-sector.

**Figure 2.2: U.S. pulp and paper industry value of product shipments by sub-sector, 1997-2006**



Sources: U.S. Census Bureau (2008a, 2005, 2003a)

## 2.2 Sub-Sector Overviews

### 2.2.1 Pulp mills (NAICS 32211)

Pulp mills are primarily engaged in manufacturing pulp without manufacturing paper or paperboard. The pulp is made by separating cellulose fibers from other components in wood using chemical, semi-chemical, or mechanical pulping processes. Pulp is also commonly manufactured using recovered wastepaper as a raw material. Less commonly, pulp can also be manufactured from other fibrous materials such as used or recycled rags, lintens, scrap paper, and straw.

Pulp mills produce what is often referred to as “market pulp,” which is pulp that is sold on the open market for the production of paper at separate facilities. Only around 15% of the pulp currently produced in the United States is market pulp (Li et al. 2004). Thus, the majority of U.S. pulp production occurs at integrated mills that produce both pulp and paper products

In 2006, there were 44 pulp mills in operation in the United States. These pulp mills employed around 7,400 people directly and generated roughly \$5.6 billion in product shipments (U.S. Census Bureau 2008a, 2008b). The pulp mill sub-sector currently accounts

for around 5% of industry employment and around 7% of industry value of product shipments (U.S. Census Bureau 2008a).

Major North American producers of market pulp include Weyerhaeuser, Tembec, Canfor, AbitibiBowater, and Daishowa-Marubeni (Sweet 2009a; Anonymous 2005a).

### **2.2.2 Paper mills (NAICS 32212)**

Paper mills are engaged in the manufacture of paper products from pulp. An integrated paper mill is one that manufactures its own pulp in house; however, paper mills may also purchase market pulp. Some paper mills may also convert the paper that they make into final products (e.g., boxes or bags). Paper mills are further classified by the U.S. Census Bureau as newsprint mills (NAICS 322122) and paper mills that make all other paper types (NAICS 322121).

#### **2.2.2.1 Newsprint mills (NAICS 322122)**

Newsprint mills are paper mills whose production is limited to newsprint and uncoated groundwood paper from pulp. Newsprint mills represent the smallest sub-sector of the U.S. pulp and paper industry. In 2006, there were 23 newsprint mills in operation in the United States with a total employment of around 5,500 (U.S. Census Bureau 2008b). With an annual value of product shipments of around \$4.1 billion, newsprint mills account for roughly 5% of U.S. pulp and paper mill shipments (U.S. Census Bureau 2008a).

Newsprint production is highly consolidated, with only a few companies accounting for the majority of North American production (MacKenzie 2001). Major North American producers include AbitibiBowater, SP Newsprint, Stora Enso, and Catalyst (Sweet 2009a).

#### **2.2.2.2 Paper (except newsprint) mills (NAICS 322121)**

Paper mills that make all other paper types besides newsprint and uncoated groundwood sheet are classified as paper (except newsprint) mills. Paper mills of this type represent the largest sub-sector of the U.S. pulp and paper industry by a significant margin. There were 325 such paper mills in operation in the United States in 2006, with a total employment of over 88,000 and \$46.6 billion in product shipments (U.S. Census Bureau 2008a, 2008b). This industry sub-sector accounts for roughly 60% of total industry employment and product shipments, and nearly 55% of its operating mills.

Paper (except newsprint) mills manufacture a wide variety of products, including paper for books and cigarettes, writing paper, office paper, napkins, paper towels, tissues, sanitary paper, and diapers. Major North American producers in this industry sub-sector include International Paper, MeadWestvaco, Smurfit-Stone, Georgia Pacific, Kimberly-Clark, Procter & Gamble, Domtar, NewPage, and White Birch Paper (Anonymous 2005b, 2006; Deking 2002; Mies 2003; Sweet 2009a).

### **2.2.3 Paperboard mills (NAICS 32213)**

Paperboard mills are primarily engaged in the manufacture of paperboard from pulp. Major paperboard products produced in the United States include cardboard stock, container board, Kraft liner board, and milk carton board. Many paperboard mills manufacture their own pulp, but some may purchase market pulp. Paperboard mills are the second largest sub-sector in the U.S. pulp and paper industry.

There were 205 paperboard mills in operation in the United States in 2006 (U.S. Census Bureau 2008b). Nearly 38,000 people were employed at these mills, which generated around \$23 billion in product shipments (U.S. Census Bureau 2008a). Major North American producers include Smurfit-Stone, International Paper, Temple-Inland, Packaging Corporation of America, and Caraustar (Sweet 2009a).

## **2.3 Pulp and Paper Processing Trends**

Virgin wood is used to manufacture a variety of pulps in the United States, most importantly chemical wood pulp, mechanical wood pulp, semi-chemical wood pulp, and dissolving wood pulp. Total U.S. production of wood pulp increased from 40 million tons (Mt) in 1976 to 56 Mt in 2006; however, current U.S. wood pulp production is around 15% lower than its 1994 peak of 66 Mt (FAOSTAT 2007).

In 1976, chemical pulping accounted for 78% of U.S. wood pulp production, while mechanical and other pulping accounted for 10% and 12%, respectively. While total wood pulp production has increased significantly since 1976, the composition of U.S. wood pulp production has changed little. Today, chemical wood pulp production has become more dominant and comprises nearly 85% of U.S. wood pulp production, while mechanical pulping now represents only around 8% of production.

In addition to the various types of wood pulp, recovered paper is used as a raw material in producing paper products. Recovered paper use in the United States pulp and paper industry has grown from 14 Mt in 1976 to nearly 47 Mt in 2006 (a growth of more than 200%) (FAOSTAT 2007).

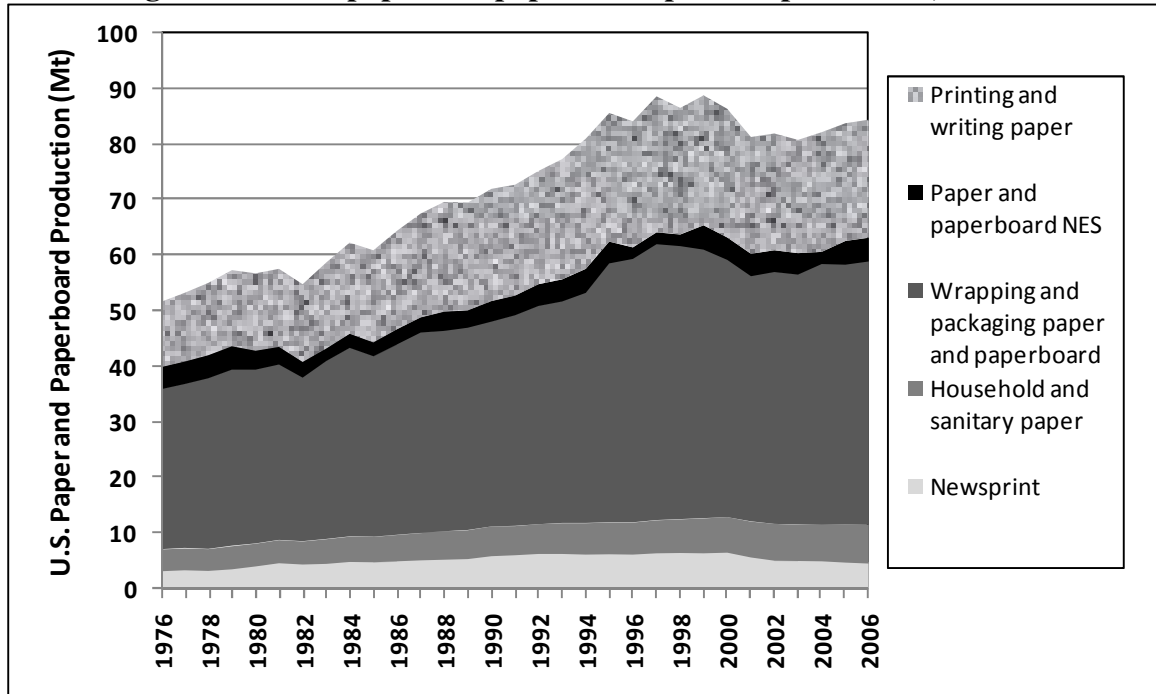
Figure 2.2 depicts the trends in the production of paper and paperboard products in the United States between 1976 and 2006 (FAOSTAT 2007). Printing and writing paper, wrapping and packaging paper, and paperboard accounted for around 80% of total U.S. production by mass in 2006. The remaining production was made up by newsprint, household and sanitary paper, and paper and paperboard not elsewhere specified (NES). The NES category is a catch-all that includes Kraft paper, construction paper, blotting paper, filter paper, and other miscellaneous paper types.

Figure 2.2 also shows that U.S. production of all paper products has increased significantly over the past 30 years. However, U.S. production has fluctuated between 84 Mt and 88 Mt since 1999. The most significant growth in production since 1976 occurred in the printing and writing paper and household and sanitary paper categories, which both grew by around 80%.



Newsprint production peaked at nearly 7 Mt in 2000, but has since decreased by 30% (to 4.7 Mt in 2006). This steep reduction in newsprint production can be explained in part by a continued decline in newsprint consumption by U.S. newspapers, which are experiencing steady declines in advertising revenues and readership (Garcia 2008).

**Figure 2.3: U.S. paper and paperboard product production, 1976 -2006**



Source: FAOSTAT 2007

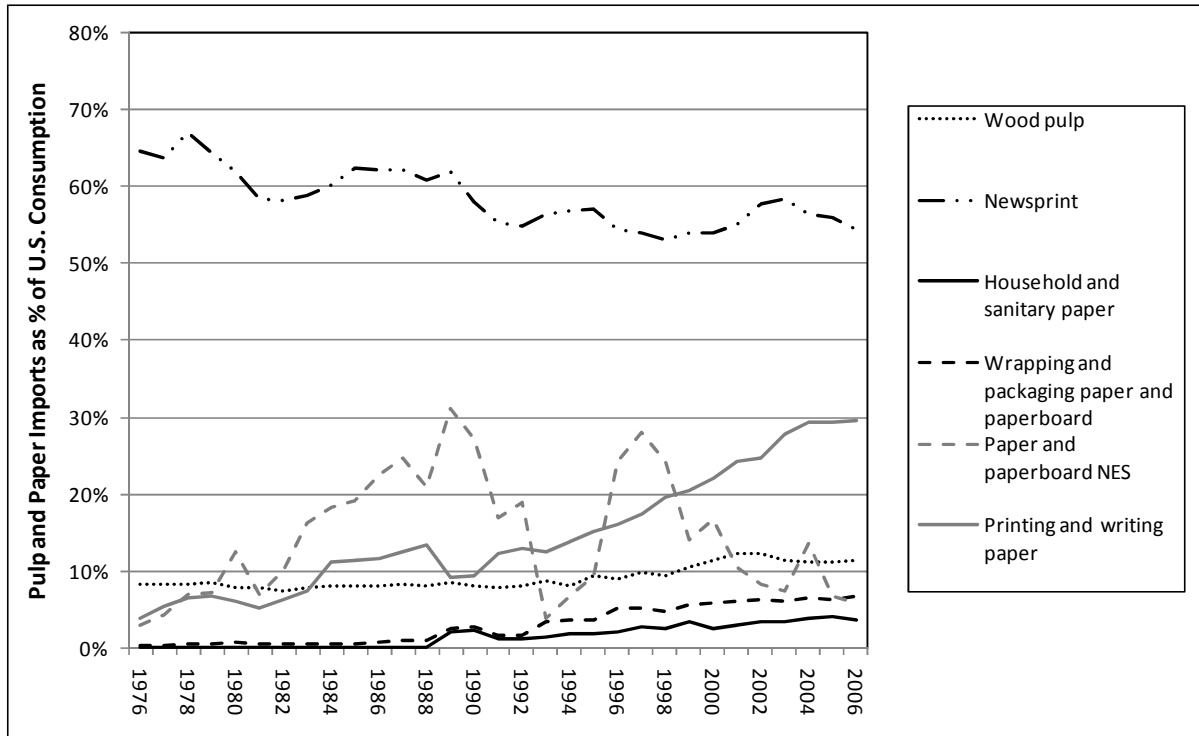
The United States has several advantages over the rest of the world market, including a highly skilled work force, a large domestic market, and an efficient transportation infrastructure (U.S. EPA 2002). As a result, the U.S. pulp and paper industry is a significant exporter of market pulp and paper products. In 2006, the United States exported 6 Mt of pulp (11% of U.S. pulp production) and around 10 Mt of paper and paperboard products (11% of U.S. paper and paperboard production) (FAOSTAT 2007). Major export markets for pulp are Japan, Italy, Germany, Mexico and France (U.S. EPA 2002). Major export markets for paper and paperboard products are Canada, Mexico, Japan, and China (U.S. Census Bureau 2008c).

The United States is also a major importer of pulp and paper products. Figure 2.4 depicts the trends in U.S. imports of pulp and paper products as a percentage of apparent consumption over the period 1976 to 2006.<sup>2</sup> Since 1976, the United States has steadily increased its imports of printing and writing paper to meet domestic demand. Currently, nearly 30% of U.S. printing and writing paper demand is met by imports. Domestic demand for newsprint is also largely met by imports, although the importance of imports has declined slightly in recent years. The U.S pulp and paper industry faces significant competition from countries

<sup>2</sup> Apparent consumption is defined as U.S. production plus imports minus exports.

such as Brazil, Chile, and Indonesia, which have modern pulp facilities, fast-growing trees, and lower labor costs (U.S. EPA 2002). Latin American and European countries also are adding papermaking capacity, which may increase import competition in the future.

**Figure 2.4: U.S. pulp and paper imports as a percentage of apparent consumption, 1976 to 2006**



Source: FAOSTAT 2007

## 2.4 Industry Structure and Characteristics

Table 2.2 illustrates the geographical concentration of the U.S. pulp and paper industry. Listed are the top ten U.S. States based on industry value of shipments in 2006, along with the number of employees and establishments in each state (U.S. Census Bureau 2008a, 2008b). Wisconsin ranked first by a significant margin in all the three categories. As of 2006, Wisconsin accounted for 10% of U.S. value of shipments, 11% of U.S. employment, and 10% of U.S. establishments in the pulp and paper industry.

The geographical distribution of U.S. pulp and paper mills varies according to the type of mill. As there are large variations in the production capacities of individual mills, the total number of establishments in a state might not correlate well to its level of economic activity, as can be observed in Table 2.2.

**Table 2.2: Top ten states in the U.S. pulp and paper industry  
by value of shipments, 2006**

State	2006 Value of Shipments (\$1,000)	2006 Rank	Number of Employees in 2006	2006 Rank	Number of Establishments in 2006	2006 Rank
Wisconsin	7,665,959	1	14,319	1	57	1
Alabama	6,449,731	2	9,154	2	22	9
Pennsylvania	5,383,703	3	5,927	6	28	5
Georgia	5,226,589	4	7,977	3	27	6
South Carolina	4,010,302	5	5,790	7	14	14
Louisiana	3,940,684	6	5,124	9	13	16
Washington	3,927,506	7	6,783	4	19	12
Maine	2,746,503	8	6,101	5	12	20
Oregon	2,664,831	9	3,983	15	13	18
Arkansas	2,634,474	10	4,438	12	11	21

Sources: U.S. Census Bureau (2008a, 2008b)

Pulp mills are located in regions of the United States where trees are harvested from abundant forests or tree farms. More than 70% of U.S. wood pulp capacity is located in the South Atlantic and South Central regions, close to the source of wood fibers (Kincaid 1998). Other key pulp mill locations include the Northwest, Northeast, and North Central regions (U.S. EPA 2002). Pulp mills that process recycled fiber are generally located near large population centers, which are key sources of wastepaper.

Paper and paperboard mills are more widely distributed. In general, they are located near pulping operations and/or close to large population centers where final consumers are located. Over 50% of paper and paperboard mills are located in the Northeast and North Central regions, close to final consumers (Kincaid 1998).

Pulp and paper are commodities and therefore their prices are vulnerable to global competition. In order to maintain market share in an increasingly competitive global market, U.S. pulp and paper companies have undergone a significant number of acquisitions and mergers in recent years. For example, between 1997 and 2002 at least 12 important mergers occurred with a combined value of around \$55 billion (U.S. EPA 2002). Table 2.3 illustrates the high level of consolidation of today's U.S. pulp and paper industry. In all four industry sub-sectors, the four largest companies account for at least half of industry shipments.

**Table 2.3: U.S. pulp and paper industry consolidation, 2002**

Sub-sector	NAICS Code	Percentage of 2002 Value of Industry Shipments Accounted for by:		
		4 Largest Companies	8 Largest Companies	20 Largest Companies
Pulp mills	32211	61%	88%	N/A <sup>3</sup>
Paper (except newsprint) mills	322121	53%	70%	85%
Newsprint mills	322122	54%	78%	100%
Paperboard mills	32213	49%	68%	88%

Source: U.S. Census Bureau (2001)

<sup>3</sup> Data withheld by the U.S. Census Bureau to avoid disclosing data of individual companies.

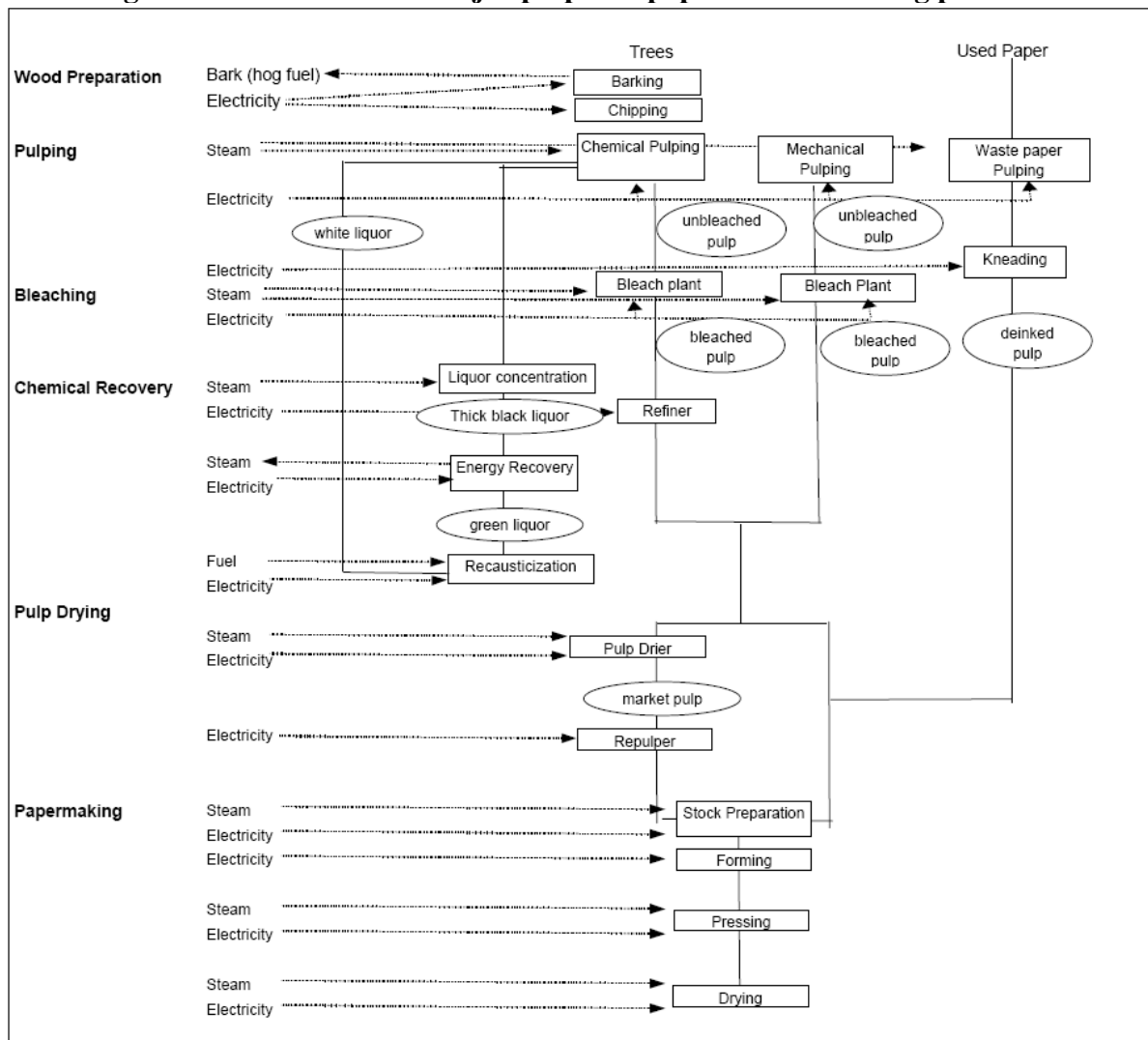
### 3 Overview of Pulp, Paper and Paperboard Processing Methods

The pulp and paper industry converts fibrous raw materials into pulp, paper, and paperboard products. Pulp mills manufacture only pulp, which is then sold and transported to paper and paperboard mills. A paper and paperboard mill may purchase pulp or manufacture its own pulp in house; in the latter case, such mills are referred to as integrated mills.

The major processes employed in the pulp and paper industry include raw materials preparation, pulping (chemical, semi-chemical, mechanical, and waste paper), bleaching, chemical recovery, pulp drying, and paper making. This chapter provides a brief overview of each major process.

Figure 3.1 provides a flow diagram of these processes and their use of fuels, steam, and electricity.

**Figure 3.1: Schematic of major pulp and paper manufacturing processes**



Source: Martin et al. (2000)

### 3.1 Raw Materials Preparation

Wood is the primary source of fiber in the production of paper products, and is typically delivered to the mill in the form of logs or wood chips. Both softwoods and hardwoods are used in the production of wood pulp. The primary processes used to convert logs into a size and shape suitable for pulping are size reduction, debarking, chipping, and screening. Wood chips are normally free of bark and are often only subjected to screening (U.S. DOE 2005a).

Logs typically arrive at the mill on trucks or rail cars. For ease of handling, large logs are sometimes sent to a slasher deck for size reduction prior to debarking.

Debarkers are used to remove bark from logs prior to chipping, since bark is a contaminant in the pulping process. Commonly, bark is removed from logs by placing them in a large rotating steel drum, where the logs rub against one another and the bark is removed by friction (Saltman 1978). In some cases, hydraulic debarkers are used, in which high-pressure water jets blast bark from the surface of the log. However, hydraulic debarkers are more energy-intensive than mechanical debarkers; they also require the bark to be pressed before it can be used as a fuel (Martin et al. 2000) as well as costly wastewater treatment (U.S. EPA 2002). As a result, hydraulic debarkers are being phased out of operation in the United States (U.S. DOE 2005a).

After debarking, the logs are sent to a chipping machine (most commonly a radial chipper). These machines produce wood chips of a consistent size and shape to maximize the efficiency of the pulping process. The optimal size of wood chip depends on the species of wood and method of pulping to be employed (e.g., chemical or mechanical) (U.S. DOE 2005a).

Wood chips are then passed over a series of vibrating screens to remove chips that are either oversized or undersized. Chips that are too small—often called “fines”—are subsequently burned as hog fuel to generate steam. Chips that are too large are typically recovered for further size reduction. The chips are then transported to the pulping stage using belt conveyors (Martin et al. 2000).

Wood provides roughly 72% of the fiber used for paper production in the United States. The majority of remaining fiber (i.e., secondary fiber) comes from waste paper and paperboard (U.S. DOE 2005a). According to the American Forest and Paper Association (AF&PA), approximately 80% of U.S. pulp and paper manufacturers use some secondary fiber in the production of pulp, and around 40% of U.S. mills rely exclusively on secondary fibers to produce pulp (AF&PA 1999a, U.S. EPA 2002).

Because waste paper products can contain inks and other contaminants, they are often used as pulping feedstock for low-purity paper and paperboard products, such as corrugating paper used to produce corrugated cardboard (U.S. EPA 2002). However, deinking and other contaminant removal technologies exist that allow the U.S. pulp and paper industry to recycle waste paper products into high-quality paper and paperboard. The use of waste paper products as raw materials for pulping is discussed in the next section.

### 3.2 Pulping

The primary goals of pulping are to free fibers in wood from the lignin that binds these fibers together, and then to suspend the fibers in water into a slurry suitable for paper making. Typical North American wood consists of around 60%-65% cellulose and hemicelluloses, which are the key fibrous ingredients in paper. The remaining materials mass consists primarily of lignin, with small amounts of extractives (e.g., terpenes) and ash (U.S. DOE 2005a; Biermann 1996). Pulp with longer fibers and less lignin will generally produce the strongest papers with the greatest resistance to aging.

The three main processes for producing wood pulp are mechanical pulping, chemical pulping, and semi-chemical pulping. Of these, the Kraft chemical pulping process accounts for the majority of U.S. wood pulp production today (Kincaid 1998). Also significant is recycled or secondary fiber pulping, which is primarily a mechanical pulping process with heat and chemicals added for contaminant removal and paper dissolution (U.S. EPA 2002).

The type of pulping process that is employed depends on a number of different factors, including the wood source (hardwood or softwood), the desired pulp properties (e.g., fiber length, strength, and purity), and the paper products to be manufactured (e.g., newsprint, packaging, or writing paper). Table 3.1 summarizes the major attributes of each pulping process. Each of these processes is discussed briefly below.

**Table 3.1: Summary of pulping process characteristics**

<b>Pulping Process</b>	<b>Primary Fiber Separation Mechanism</b>	<b>Yield (mass of pulp/mass of original fiber source)</b>	<b>Pulp Properties</b>	<b>Typical Products</b>
Mechanical	Mechanical energy	High (85-95%) lignin not removed	Short, weak, unstable, high opacity fibers; good print quality	Newsprint, magazines, books, container board
Chemical	Chemicals and heat	Lower (45-50% for bleachable/bleached pulp; 70% for brown papers)	Long, strong, stable fibers	Kraft: bags, wrapping, linerboard, newsprint  Sulfite: fine paper, tissue, glassine, newsprint
Semi-chemical	Combination of chemical and mechanical treatments	Intermediate (55-85%)	“Intermediate” pulp properties	Corrugated board, food packaging, newsprint, magazines
Recycled	Mechanical energy with some heat and chemicals	Depends on waste paper source. Up to 95% for waste packaging and as low as 60% for waste hygienic papers.	Mixture of fiber grades; properties depend on waste paper source	Newsprint, writing paper, tissue, packaging

Source: Adapted from U.S. DOE 2005a

### 3.2.1 Mechanical Pulping

Mechanical pulping is the oldest form of pulping. The process employs mechanical energy to weaken and separate fibers from wood and waste paper feedstock via a grinding action. The advantage to mechanical pulping is that it produces much higher yields than chemical pulping processes (up to 95%). However, because this process does not dissolve lignin, the fiber strength and age resistance of the resulting pulp are low (U.S. DOE 2005a). The weakness of the resulting pulp is compounded by the fact that the mechanical grinding process also produces shorter fibers (Kincaid 1998). As a result, most mechanical pulp is used for lower grade papers such as newsprint, magazines, and catalogues (Biermann 1996). Mechanical pulping also requires more raw materials screening to remove contaminants such as dirt, shives,<sup>4</sup> and knots than chemical pulping processes (U.S. DOE 2005a).

As of 2006, mechanical pulp accounted for roughly 8% of U.S. wood pulp production (FAOSTAT 2007). There are four primary types of mechanical pulping: (1) stone groundwood pulping, (2) refiner mechanical pulping, (3) thermomechanical pulping, and (4) chemi-thermomechanical pulping.

*Stone groundwood pulping (SGW)* is the oldest and least energy-intensive mechanical pulping process (Martin et al. 2000). In the SGW process, small logs are ground against artificial bonded stones made of silicon carbide or aluminum oxide grits. These stones can be submerged (pit grinding) or sprayed with water to keep them cool while maintaining grinding performance and fiber quality. The advantage of the SGW process is its very high yield. However, the fibers produced by the SGW process can be very short and often must be combined with expensive chemical fibers to be strong enough to pass through the paper machine and subsequent coating and printing processes.

*Refiner mechanical pulping (RMP)* keeps the high yield advantages of the SGW process, while producing somewhat longer fibers with greater strength. The RMP process was introduced to allow the use of wood feedstock other than logs, such as wood scraps and sawdust from lumber mills (U.S. DOE 2005a). Wood feedstock is ground between two grooved discs. The RMP process produces longer and stronger fibers that permit lighter weight paper to be used for printing and result in more print media per ton of feedstock.

In the *thermomechanical pulping (TMP)* process, wood chips are first steamed to soften them before being ground in the same manner as the RMP process. The TMP process generates the highest grade mechanical pulp but is also a high energy intensity process due to its steam use. This process can also produce a darker pulp that is more costly to bleach (Martin et al. 2000). Despite these drawbacks, TMP is the most common mechanical process in use today.

*Chemi-thermomechanical pulping (CTMP)* involves the application of chemicals to wood chips prior to refiner pulping. The process begins with an impregnation of sodium sulfite and chelating agents. The mixture is then preheated to 120-130 °C and ground in the refiner. The chemical pre-treatment of wood chips allows for less destructive separation of fibers from the feedstock, resulting in longer fibers, higher fiber content, and far fewer shives. The CTMP

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<sup>4</sup> Shives are small bundles of fibers that are not fully separated in the pulping operation.

process also produces more flexible fibers (which provide higher sheet density, burst strength, and tensile strength) and higher pulp brightness than the TMP process. Its primary drawback, like TMP, is that it is a high energy intensity process (Martin et al. 2000).

### 3.2.2 Chemical Pulping

Chemical pulping is by far the most common method of producing wood pulp in the United States. As of 2006, nearly 85% of U.S. wood pulp was produced by chemical pulping processes (FAOSTAT 2007). Chemical pulping processes have low yields (see Table 3.1) but generate pulp with strong and stable fibers for high quality products such as office paper.

Chemical pulping separates the fibers in wood feedstock by dissolving the lignin bonds that hold these fibers together, often at elevated temperatures and pressures. There are two primary forms of chemical pulping: (1) the Kraft (or sulfate) pulping process, and (2) the sulfite pulping process. According to the American Forest and Paper Association (AF&PA), around 98% of today's U.S. chemical pulping capacity uses the Kraft process (AF&PA 2002).

In the *Kraft pulping process*, wood chips are first steamed to soften them and to force out any trapped air. The wood chips are then combined with a highly alkaline solution – called white liquor – which contains sodium hydroxide (NaOH), and sodium sulfide (Na<sub>2</sub>S). These ingredients are pressurized and cooked at 160-170°C in a digester over several hours, which allows the liquid to permeate the wood chips and dissolve most of the non-fibrous constituents in the wood.

There are two primary types of digesters— batch digesters and continuous digesters—which cook wood chips on batch and continuous bases, respectively. Batch digesters offer lower capital costs and more product flexibility (U.S. DOE). Continuous digesters are more space efficient and less labor intensive; because they reuse process steam, they are also more energy efficient (U.S. DOE 2005a; Biermann 1996).

After digestion, hot pulp and spent liquor are discharged into low-pressure blow tanks, which separate the wood chips into fibers. The spent liquor and its dissolved contaminants—referred to as “black liquor”—are washed away and sent to the chemical recovery process (discussed later in this section) for use as boiler fuel and to regenerate white liquor. The resulting Kraft pulp is dark brown and can be used to make unbleached cardboard products and grocery bags. For Kraft pulp that is used for white products, the next step in the process is the bleaching phase.

The *sulfite pulping process* is used on a much smaller scale in the United States, and accounts for around two percent of U.S. chemical pulping capacity (AF&PA 2002). The sulfite process uses a mixture of sulfurous acid (H<sub>2</sub>SO<sub>3</sub>) and bisulfate ion (HSO<sub>3</sub><sup>-</sup>) as its solvent, which is produced by burning sulfur and mixing the resulting gases with a basic solution (U.S. DOE 2005a; Martin et al 2000). Similar to the Kraft pulping process, the sulfite process allows the pulping chemicals to be reused for energy recovery and solvent regeneration.



Kraft and sulfite pulping processes can be used to produce similar types of paper. However, the Kraft process dominates U.S. chemical pulp production due to several key advantages over the sulfite process. Such advantages include its applicability to a wider variety of tree species, its superior fiber strength, its ability to tolerate wood contaminants, its high lignin removal rates (up to 90%), and the high efficiency of its chemical recovery process (U.S. EPA 2002; U.S. DOE 2005a). In contrast, the sulfite process produces a pulp with shorter fiber length and its chemical recovery process is inefficient. As a result, the sulfite process is mostly used for specialty product applications such as very smooth papers (Elaahi and Lowitt 1988).

Extended delignification and oxygen delignification are two process modifications that can be employed to reduce the lignin content of chemical pulp even further. Both methods can reduce the amount of chemicals required during the bleaching phase, while extended delignification can also reduce cooking liquor consumption by 5-10% (U.S. DOE 2005a).

### **3.2.3 Semi-Chemical Pulping**

Semi-chemical pulping uses a combination of chemical and mechanical pulping processes whereby wood chips are subjected to a mild chemical digestion process before they are mechanically pulped. This pulping method is primarily used for hardwoods, which have short narrow fibers that can be used to make a smoother, denser, and more opaque sheet of paper (Martin et al. 2000). The major differences between semi-chemical and chemical digestion processes are that semi-chemical digestion uses lower temperatures, more dilute cooking liquors, and shorter cooking times (U.S. EPA 2002). Semi-chemical pulping processes generate a pulp yield higher than chemical pulping processes due to higher lignin content, but lower than the yields achievable with mechanical pulping. Approximately 6% of U.S. wood pulp production is from semi-chemical pulping processes (U.S. EPA 2002).

### **3.2.4 Recycled/Secondary Fiber Pulping**

As discussed in Chapter 2, the use of recovered paper as feedstock in the U.S. pulp and paper industry has grown significantly over the last 30 years. According to the AF&PA, nearly 200 U.S. mills rely exclusively on recovered paper for pulp production, and roughly 80% of U.S. mills use recovered paper in some fashion (AF&PA 2001). The main types of recovered paper include post-consumer (or “old”) corrugated cardboard (OCC) boxes, newspapers, and miscellaneous mixed papers such as office paper. Nearly half of recovered paper fiber is in the form of OCC (U.S. DOE 2005a).

The typical process for generating pulp from recovered paper feedstock involves blending the feedstock with water in a large tank. Pulping chemicals and heat are sometimes added to the process to aid in the production of a fibrous slurry (U.S. EPA 2002). Large contaminants and contaminants that float are removed from the slurry with a ragger mechanism, while heavy objects such as nuts and bolts exit the process via a chute at the lower end of the pulping tank (Martin et al. 2000; Biermann 1996). Inks and other fiber contaminants can be removed during the process using chemical surfactants. The combined application of heat, dissolution

of chemical bonds, and mechanical shear action liberates fibers and produces a pulp with desired properties and consistency (U.S. EPA 2002).

Producing pulp from recycled and secondary fibers typically requires less energy than mechanical or chemical pulping processes. However, the energy intensity of the process can vary significantly depending on the extent and types of contamination and final pulp yields. Moreover, the availability of recycled and secondary fiber inputs is also an issue, since supplies can fluctuate over time. Still, modern contaminant removal techniques have made recycled pulp a competitive option for many types of paper, excluding only the highest grades of papers for which long fiber length is essential (Martin et al. 2000).

### 3.3 Chemical Recovery

The primary purpose of the chemical recovery process is to recover pulping chemicals from spent cooking liquor (i.e., black liquor) for reuse in subsequent pulping processes. Chemical recovery allows a mill to regenerate pulping chemicals at a rate of up to 98% (U.S. EPA 2002), which significantly reduces the costs of purchased process chemicals. An added benefit is that chemical recovery allows a mill to generate a significant portion of its steam requirements by combusting the pulp residue contained in black liquor as part of the refining process.

The chemical recovery process for Kraft pulping consists of four key stages: (1) black liquor concentration, (2) black liquor combustion (recovery boiler), (3) recausticizing, and (4) calcining (lime burning).

*Black liquor concentration* is the process of evaporating water from black liquor to increase its solids content, which makes the recovery boiler combustion process far more efficient. Most mills employ multiple effect evaporators to concentrate black liquor using indirect heat from steam. Some mills may also use direct contact evaporators, which use the exhaust gases from the recovery boiler to drive up the final solids concentration. Evaporation is the single largest use of steam in the production of Kraft pulp. Multiple effect evaporators can maximize the efficiency of this steam use; the use of seven effects is currently considered industry best practice (Ackel 2009). Further, much of this steam can be reused in the form of condensate or hot water in other facility applications (U.S. DOE 2005a).

After concentration, black liquor will typically have a fuel value between 6,000 Btu/lb and 7,000 Btu/lb (Biermann 1996). It is then combusted in a *recovery boiler* to produce steam for mill process heating applications and/or electricity generation. During combustion, organic constituents burn to generate useful heat while the inorganic process chemicals are reduced to a molten smelt. This smelt is removed from the bottom of the boiler for further refining in the recausticizing stage (U.S. DOE 2005a). Recovery boilers typically have a thermal efficiency of around 65%; steam generation typically increases by 2% for each 5% increase in solids content above 65% (Gullichsen 1999; Smook 1992).

In the *recausticizing* process, the smelt from the recovery boiler is first mixed with weak white liquor to form an intermediate solution known as green liquor. This green liquor

consists mostly of sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) and sodium sulfide ( $\text{Na}_2\text{S}$ ). The green liquor is then recausticized by adding calcium hydroxide  $\text{Ca}(\text{OH})_2$  under controlled temperature and agitation. The recausticizing process converts the sodium carbonate in the green liquor into sodium hydroxide ( $\text{NaOH}$ ) and a calcium carbonate ( $\text{CaCO}_3$ ) precipitate. The calcium carbonate precipitate—also known as lime mud—is then removed, leaving behind white liquor (i.e.,  $\text{NaOH}$  and  $\text{Na}_2\text{S}$ ) that can be reused in the pulping process.

The lime mud is then sent to the *calcining* process, where it is heated in a kiln to produce lime ( $\text{CaO}$ ) with carbon dioxide ( $\text{CO}_2$ ) as a by-product. The lime is then dissolved in water to produce the calcium hydroxide  $\text{Ca}(\text{OH})_2$  that is used in the mill's recausticizing process.

### 3.4 Bleaching

Raw pulp can range in color from brown to crème due to the remaining lignin that was not removed during the pulping process. For paper products for which brightness and resistance to color reversion are important, such as office and printing paper, the pulp must be whitened by a bleaching process prior to the paper making phase. According to the AF&PA, around 50% of the pulp produced in the United States is bleached pulp (U.S. EPA 2002). Unbleached pulp is typically used to make products such as corrugated boxes and grocery bags for which brightness is not required.

Bleaching can be defined as any process that chemically alters pulp to increase its brightness (U.S. EPA 2002). The pulping process (i.e., chemical or mechanical) is a major driver of the type of bleaching that is required. Mechanical and semi-chemical pulping process will generate pulps with high lignin content, which requires a chemical-intensive bleaching process to decolorize the remaining lignin. The bleaching process for chemical pulps—which have low lignin content—focuses on the removal of remaining lignin from the pulp (U.S. DOE 2005a; U.S. EPA 2002).

Mechanical pulp is often bleached using hydrogen peroxide and/or sodium hydrosulfite. Bleaching chemicals can be added into the mechanical pulping process, or added to the pulp in multi-stage reactions which occur in a series of post-pulping bleaching towers. The number of bleaching reactions employed depends on the brightness requirements of the final paper product.

The bleaching of chemical pulp comprises multiple stages that alternate between washing the pulp and treating it with chemicals in bleaching towers (U.S. DOE 2005a). In the past, elemental chlorine was commonly used as a bleaching agent in this process. Increasingly stringent effluent limitations have led to the adoption of elemental chlorine free (ECF) bleaching processes at most U.S. pulp and paper mills. Today, over 95% of bleached chemical pulp production in the United States uses ECF processes (AF&PA 2005). The totally chlorine free (TCF) process eliminates the use of chlorine altogether. As of 2001, TCF processes accounted for roughly 1% of U.S. bleached pulp production (U.S. EPA 2002).

The specific chemicals that are applied in bleaching processes for chemical pulp, and the number of stages, vary by mill and depend on a number of factors including local

environmental regulations, costs, and desired pulp properties (U.S. DOE 2005a). The most common chemicals employed in ECF and TCF processes in the United States are summarized in Table 3.2, along with a description of their primary purpose.

**Table 3.2: Common ECF and TCF bleaching chemicals**

<b>Bleaching Chemical</b>	<b>Chemical Formula</b>	<b>Primary Purpose</b>
Chlorine dioxide	ClO <sub>2</sub>	An oxidizer that selectively destroys lignin without extensive damage to pulp fibers
Ozone	O <sub>3</sub>	A chlorine free oxidizer used to destroy lignin. Less selective to lignin than chlorine compounds, and must be used in low charges to prevent pulp strength loss.
Hypochlorite	HClO, NaOCl, Ca(OCl) <sub>2</sub>	An oxidizer used to destroy lignin that is typically used for sulfite pulps. Hypochlorite is being phased out due to increasing environmental concerns related to chloroform formation.
Sodium hydroxide	NaOH	An alkali that is mixed with oxidized pulp and steam to displace lignin that was made soluble during oxidation so that lignin can be extracted from the pulp.
Oxygen	O <sub>2</sub>	Used under pressure in combination with an alkali to enhance lignin extraction
Hydrogen peroxide	H <sub>2</sub> O <sub>2</sub>	Can be used to bleach lignin fibers in mechanical pulp or as a delignification agent for chemical pulp to reinforce alkaline extraction

*Source: Adapted from U.S. EPA 2002 and U.S. DOE 2005a*

### 3.5 Pulp Drying

In situations where pulping and papermaking operations are not located at the same facility, or when a temporary imbalance between pulp production and paper machine requirements exists, pulp is dried to reduce its moisture content. On average, market pulp is dried to around 10% water before being shipped to a paper mill. The process for re-pulping of dried pulp at a paper mill is similar to that employed for pulping recovered paper. Pulp drying is energy intensive (about 4.2 MMBtu of steam per ton of pulp) (Martin et al. 2000) and is not essential to the papermaking process. Thus, significant energy savings are realized by co-locating pulping and paper making operations at one facility.

### 3.6 Papermaking

The papermaking process can be divided into three basic stages: (1) stock preparation, (2) “wet end” processing where sheet formation occurs, and (3) “dry end” processing where sheets are dried and finished.

The purpose of stock preparation is to process the pulp into a homogenous slurry with properties suitable for introduction into the paper machine. Stock preparation involves the following processes: mechanical homogenization of pulp, dispersion in water, fiber declustering, introduction of wet additives, blending, and contaminant screening (U.S. DOE 2005a, U.S. EPA 2002). The purpose of wet additives is to provide the final paper product with specific desirable properties (such as color and water repellence) and to improve the quality and efficiency of the paper making process.

The slurry is then fed into the so-called wet end of the papermaking machine where a paper web (i.e., sheet) is formed. Fourdrinier machines are the most common type of papermaking machines in use today. In a Fourdrinier machine, the slurry first enters a headbox, which creates a uniform layer of slurry and deposits this layer onto a moving fabric (also called wire or forming fabric). This fabric forms the fibers into a continuous web while allowing water removal via gravity and the application of vacuum pressure.

Once the fibers have been sufficiently dewatered that they begin to bond to form paper, they move on to the press section of the paper machine. Here the paper is pressed to remove water, which promotes further bonding between fibers. As it moves through the press section, the paper is supported by rolls and press fabrics which absorb water from the sheet at the press nips. The bonded and dewatered sheet then proceeds to the so-called dry end of the paper machine for further drying and finishing operations. The press section has historically been the target of many energy efficiency improvements in papermaking, because the drier the paper is leaving the press section, the less energy it consumes in the drying section.

Dry end processes include drying, calendering, and reeling. In the drying section, steam heated rollers compress and further dry the sheet through evaporation, which facilitates additional bonding of fibers. The drying section represents the largest user of energy in the papermaking stage. In the middle of this section is the size press, which can apply coating to the paper. The size press must be placed so that the paper can continue drying after coating because the coating itself must dry as well. The next step is calendering, which involves a series of carefully spaced rollers that control the thickness and smoothness of the final paper. After calendering, the finished paper is wound on a large reel for storage and transportation.

## 4 Energy Use in the U.S. Pulp and Paper Industry

Energy use represents a significant cost to the U.S. pulp and paper industry. In 2006, the industry spent roughly \$7.5 billion on purchased fuels and electricity (U.S. Census Bureau 2008a). Around \$4.7 billion of this was for purchased fuels and around \$2.8 billion of this was for purchased electricity. Energy costs are a sizeable fraction of operating costs, equal to roughly 20% of the industry's total cost of materials in 2006.

The U.S. pulp and paper industry is also among the largest energy consuming industries in the United States. As of 2006, the industry (NAICS 3221) accounted for over 8% of the purchased fuels and over 9% of the electricity consumption of the entire U.S. manufacturing sector (U.S. Census Bureau 2008a). Moreover, purchased fuels represent less than half of the fuels consumed by U.S. pulp and paper mills, since much on-site thermal energy and electric power are produced using waste wood and bark (i.e., hog fuel) and spent cooking chemicals (i.e., black liquor) (U.S. EPA 2002; U.S. DOE 2005a).

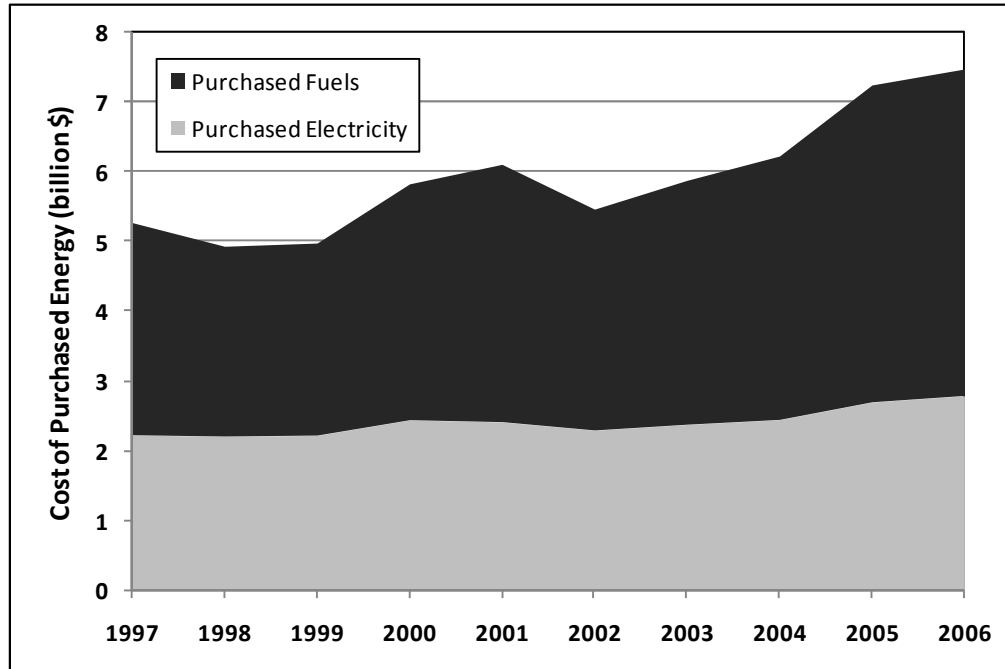
Electricity is used throughout the typical pulp and paper mill to power motors and machine drives, conveyors, and pumps, as well as building operations such as lighting and ventilation systems. The largest use of fuels is in boilers to generate steam for use in pulping, evaporation, papermaking, and other operations. Black liquor is the dominant fuel for boilers in the pulp and paper industry, followed by hog fuel and natural gas, and to a lesser extent, coal (EEA 2005). Natural gas and oil are typically used in lime kilns (U.S. DOE 2005a).

### 4.1 Energy Costs

Figure 4.1 plots the costs of purchased electricity and fuels in the U.S. pulp and paper industry over the period 1997 to 2006 (U.S. Census Bureau 2008a, 2006, 2003b). While the total cost of purchased electricity remained fairly steady over this period, the total cost of purchased fuels increased by around 50% (in nominal dollars). Natural gas accounts for over one-half of the fuel purchased by the U.S. pulp and paper industry, with coal and fuel oil comprising most of the remaining fuel purchases (U.S. DOE 2007a). The steep rise in purchased fuel cost may therefore be explained in part by the similarly steep rise in U.S. industrial natural gas prices that occurred over the same period (\$3.59 per 1000 ft<sup>3</sup> in 1997 versus \$7.86 per 1000ft<sup>3</sup> in 2006) (U.S. DOE 2008a).

The data in Figure 4.1 demonstrate the negative economic impacts that energy price volatility can have on the U.S. pulp and paper industry. These data also underscore the importance of energy efficiency as a means of reducing the industry's susceptibility to rising energy prices.

**Figure 4.1: Cost of purchased fuels and electricity in the U.S. pulp and paper industry, 1997 to 2006**



Source: U.S. Census Bureau (2008a, 2006, 2003b)

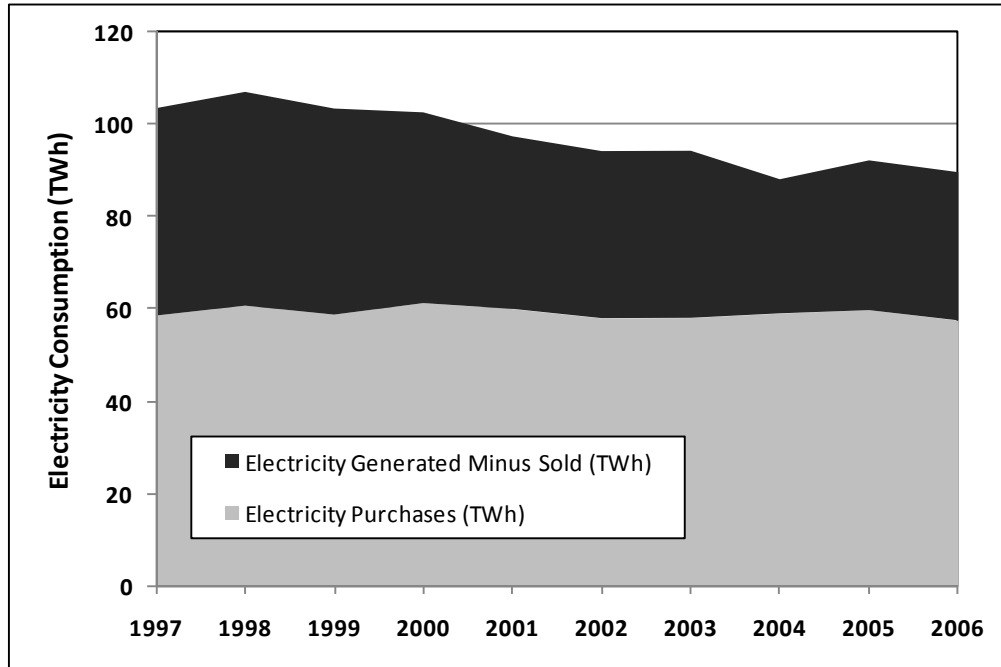
The paper (except newsprint) mills sub-sector (NAICS 322121) is the largest purchaser of energy in the industry, accounting for roughly 45% of the industry’s purchased electricity and fuel costs (U.S. Census Bureau 2004). Paperboard mills (NAICS 32213) are the next largest purchasers of energy, accounting for around 40% of the industry’s purchased fuel costs and around 35% of its purchased electricity costs.

As of 2002, the U.S. pulp and paper industry was the largest self-generator of electricity in the U.S. manufacturing sector (U.S. DOE 2007a). Thus, the electricity purchases illustrated in Figure 4.1 represent only a portion of the industry’s electricity use. In 2002, the industry generated over 50 billion kWh of electricity on-site, which accounted for around 40% of total industrial on-site electricity generation in the United States (U.S. DOE 2007a). Figure 4.2 illustrates the trends in electricity consumed at U.S. pulp and paper mills from purchased and self-generated sources over the period 1997 to 2006.<sup>5</sup> On average over this period the industry met around 40% of its annual electricity needs through self-generation.

Additional information on the use of combined heat and power systems in the U.S. pulp and paper industry is provided in Chapter 8.

<sup>5</sup> The quantity “electricity generated minus sold” equals the total amount of electricity generated on-site minus the amount of electricity sold or transferred for off-site consumption.

**Figure 4.2: U.S. pulp and paper industry electricity consumption by source, 1997 to 2006**



Source: U.S. Census Bureau (2008a, 2006, 2004, 2003b)

## 4.2 Energy Consumption and End Uses

Table 4.1 summarizes estimates of the total energy use of the U.S. pulp and paper industry as of 2002, which is the latest year for which detailed industry fuel use data are available from the U.S. Department of Energy (U.S. DOE 2007a). In 2002, the industry consumed over 2,200 trillion British thermal units (TBtus) of energy, which accounted for around 14% of all the fuel consumed by the U.S. manufacturing sector. The data in Table 4.1 are ranked in order of fuel type use importance from left to right.<sup>6</sup>

It can be seen that two by-products of the pulp and paper production process—black liquor and hog fuel (i.e., wood and bark)—meet over 50% of the industry’s annual energy requirements. The use of these by-products as fuels significantly reduces the industry’s dependence on purchased fossil fuels and electricity, with the added benefits of reduced raw material costs (i.e., avoided pulping chemical purchases) and reduced waste generation. Natural gas and coal comprise the majority of the remaining fuel used by the industry.

<sup>6</sup> The data in Table 4.1 were derived from 2002 MECS Tables 3.2, 3.5, 3.6, and 7.7 (U.S. DOE 2007a). The “Other” field presented here includes an estimated 6 TBtu of waste gas and waste materials, 4 TBtu of coke and breeze, 1 TBtu of LPG and NGL, 58 TBtu of purchased steam, and 69 TBtu of other non-specified fuels. MECS defines net electricity as follows: “Net electricity is obtained by summing purchases, transfers in, and generation from noncombustible renewable resources, minus quantities sold and transferred out. It does not include electricity inputs from onsite cogeneration or generation from combustible fuels because that energy has already been included as generating fuel (for example, coal).” Data in italics were withheld in the 2002 MECS but estimated for 2002 using 1998 MECS fuel use data (U.S. DOE 2001a) for specific U.S. pulp and paper sub-sectors.



**Table 4.1: Energy use of the U.S. pulp and paper industry in 2002 (TBtu)**

NAICS Code	Sub-Sector	Total	Black Liquor	Natural Gas	Wood & Bark	Coal	Net Electricity	Residual Oil	Distillate Oil	Other
32211	Pulp mills	224	140	24	33	1	5	5	5	11
322121	Paper (except newsprint) mills	1,002	336	206	114	139	78	47	4	78
322122	Newsprint mills	94	9	16	14	11	38	7		
32213	Paperboard mills	907	335	188	158	83	56	34	4	49
<b>Total</b>		<b>2,227</b>	<b>820</b>	<b>434</b>	<b>319</b>	<b>234</b>	<b>177</b>	<b>93</b>	<b>13</b>	<b>138</b>
<b>% of Total</b>			<b>37%</b>	<b>19%</b>	<b>14%</b>	<b>11%</b>	<b>8%</b>	<b>4%</b>	<b>1%</b>	<b>6%</b>

Source: Adapted from U.S. DOE (2007a, 2001a)

Black liquor, hog fuel, coal, and residual oils are used exclusively as boiler fuels to generate power and to produce steam for use in various pulping and papermaking processes (Jacobs and IPST 2006). Black liquor is combusted in a recovery boiler, which is designed for the dual purpose of generating steam and recovering inorganic smelt for regeneration into white liquor. Because of the low heat contents of black liquor and hog fuel, the efficiencies of boilers that combust these fuels are around 65% (U.S. DOE 2005a). Natural gas is also used as a boiler fuel, but it is also used in significant quantities for direct process heating in lime kilns and in limited drying applications (e.g., coating and tissue drying) (Jacobs and IPST 2006).

Table 4.2 provides an estimated breakdown of the industry's use of fuels in terms of the final form of end use energy that is provided within mills (i.e., electricity, steam, and direct fuel). The data in Table 4.2 were derived from the fuel use data in Table 4.1 and an industry-level energy use model developed by Jacobs Engineering Group and the Institute of Paper Science and Technology at the Georgia Institute of Technology (Jacobs and IPST 2006). The data in Table 4.2 suggest that of the 2,051 TBtu of combustible fuels (i.e., all but net electricity) used by the industry in 2002, only around 7% (134 TBtu) was for direct process use. The remaining 1,917 TBtu of fuels were combusted in boilers to generate 1,287 TBtu of net steam output.<sup>7</sup> Of the net steam output, ultimately 166 TBtu (48 TWh) of electricity and 1,026 TBtu of process steam were generated for use in facility processes and systems.<sup>8,9</sup> In other words, of the 1,917 Btu of fuels combusted in boilers, around 725 TBtu of energy losses occurred in the generation and distribution of electricity and process steam.

<sup>7</sup> Net boiler output is the amount of useful steam generated after taking into consideration boiler efficiency losses and use of steam by parasitic uses such as boiler cleaning and auxiliary systems.

<sup>8</sup> These calculations take into consideration electrical generation, conversion, and transformation losses for electricity and steam system distribution losses (e.g., radiation and leaks) for steam. The "other" category in Table 4.2 is a simplified composite of several fuels (LPG, waste gas, and other fuels) that are modeled separately in the Jacobs and IPST (2006) model.

<sup>9</sup> For more details on the industry end use model used to derive these results, the reader is referred to Chapter 4 in Jacobs and IPST (2006).

**Table 4.2: End use energy breakdown of the U.S. pulp and paper industry, 2002 (TBtu)**

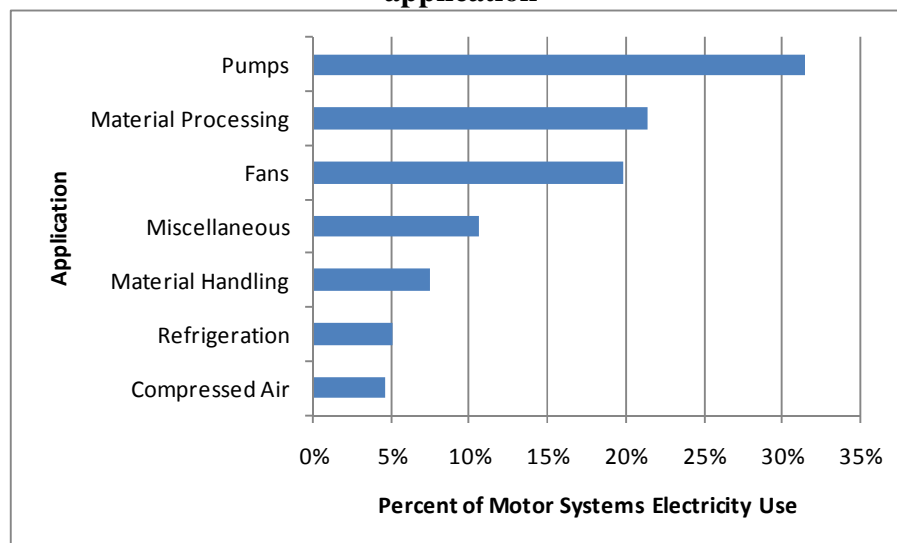
	<b>Black Liquor</b>	<b>Natural Gas</b>	<b>Wood &amp; Bark</b>	<b>Coal</b>	<b>Net Electricity</b>	<b>Residual Oil</b>	<b>Distillate Oil</b>	<b>Other</b>	<b>Total</b>
<b>Industry total use</b>	<b>820</b>	<b>434</b>	<b>319</b>	<b>234</b>	<b>177</b>	<b>93</b>	<b>13</b>	<b>138</b>	<b>2,227</b>
<b>Direct fuel</b>		<b>130</b>					<b>4</b>		<b>134</b>
Boiler fuel	820	304	319	234		93	9	138	1,917
Boiler efficiency	64%	87%	69%	86%		86%	86%	69%	
Parasitic loads	12%	3%	7%	9%		4%	3%	4%	
Net boiler output	464	256	206	184		77	8	91	1,287
% to power generation	19%	5%	19%	19%		19%	0%	3%	
Electrical system losses	15%	15%	15%	15%	2%	15%	15%	15%	
<b>Electricity</b>	<b>76</b>	<b>11</b>	<b>34</b>	<b>30</b>	<b>173</b>	<b>13</b>	<b>0</b>	<b>2</b>	<b>339</b>
Process steam output	375	244	166	149		62	8	89	1,092
Steam system losses	6%	6%	6%	6%		6%	6%	6%	
<b>Process steam</b>	<b>352</b>	<b>229</b>	<b>156</b>	<b>140</b>		<b>58</b>	<b>7</b>	<b>83</b>	<b>1,026</b>

*Source: derived from Table 4.1 and Jacobs and IPST (2006)*

Table 4.2 also shows that process steam is by far the largest end use of energy in the U.S. pulp and paper industry. The next largest end use of energy is electricity. An estimated 339 TBtu of electricity (99 TWh) (purchased and self-generated) were consumed by the industry in 2002. Nearly 90% of this electricity use is attributable to motor-driven systems, while around 8% is attributable to facility lighting and heating, ventilation, and air conditioning (HVAC) systems (U.S. DOE 2007a). Figure 4.3 provides an estimated breakdown of the electricity used by motor-driven systems in the U.S. pulp and paper industry. These data suggest that pumps, fans, and materials processing equipment account for the majority (over 70%) of motor-driven systems electricity use in the typical U.S. mill (U.S. DOE 2002a).

Energy efficiency initiatives that are targeted at reducing steam system losses and improving the efficiency of process steam using equipment are therefore likely to reap the greatest savings in a typical U.S. mill. Electrical energy efficiency initiatives targeted at pumps, fans, and equipment drives are also likely to generate significant energy savings. Furthermore, since a significant fraction of the industry's electricity is self-generated, efficiency improvements to electricity using systems may also lead to reductions in facility boiler fuel demand and/or increased electricity exports to the grid. Energy efficiency measures for each of these key end use areas are offered in later chapters of this Energy Guide.

**Figure 4.3: Breakdown of U.S. pulp and paper industry motor-system electricity use by application**



Source: U.S. DOE (2002a)

Jacobs and IPST (2006) estimated the uses of steam, electricity, and direct fuels by major process stage in the manufacture of pulp and paper in the United States in 2002. These estimates are summarized in Figure 4.4 for pulp manufacturing and Figure 4.5 for paper manufacturing.<sup>10</sup>

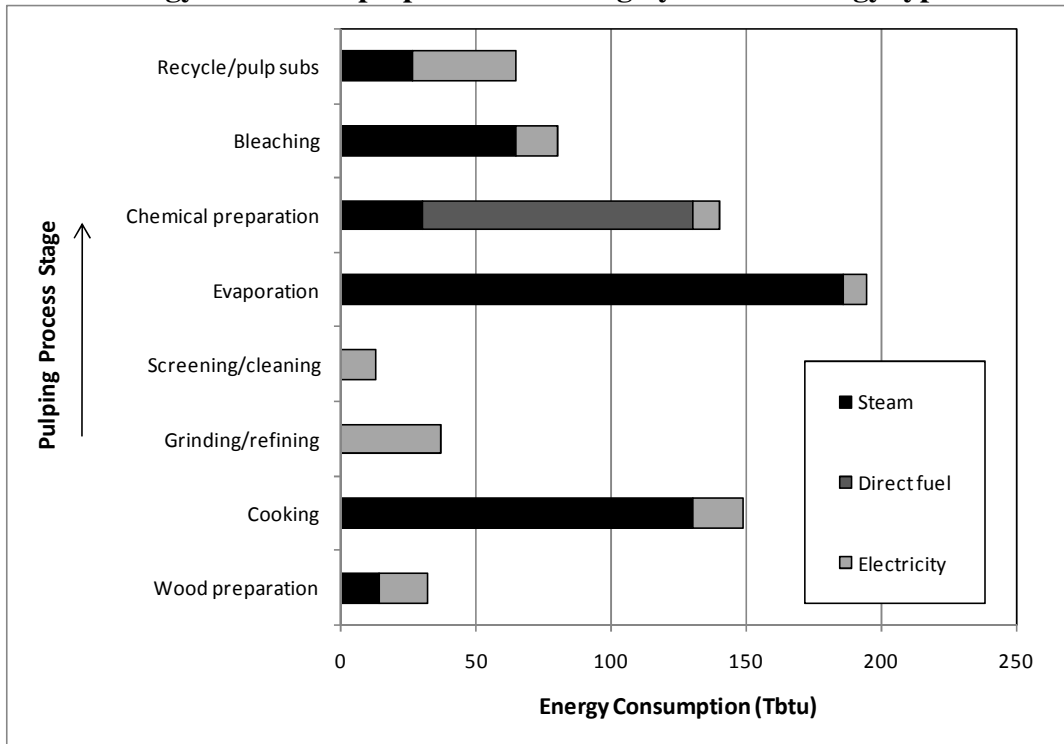
Figure 4.4 shows that evaporation, cooking (which includes digestion through washing for chemical pulps), and chemical preparation are the largest total consumers of energy in U.S. pulp manufacturing. Steam is used in significant quantities for nearly every process, but most notably in the evaporation, cooking, and bleaching processes for process heat. The sole use of direct fuel is the chemicals preparation process (i.e., in the lime kiln).

The amount and type of energy used in pulping varies widely by pulping process. Kraft pulping relies heavily on steam, with some direct fuel use in the chemical recovery process. Mechanical (SGW) and TMP rely mostly on electricity. Jacobs and IPST (2006) estimates that Kraft pulps require in total (i.e., steam, electricity, and direct fuel) 10-12 million Btu (MMBtu) per ton, mechanical and TMP pulps require in total 10-11 MMBtu per ton, and recycled pulps require in total around 1-4 MMBtu per ton. Of the total steam, electricity, and direct fuel used in U.S. pulp manufacturing, Kraft pulp production accounts for nearly 80% (Jacobs and IPST 2006).

It can be seen in Figure 4.5 that drying is by far the most energy intensive step associated with paper manufacturing, accounting for roughly two-thirds of total papermaking energy use. Wet end operations in Figure 4.5 include stock preparation through forming; dry end operations include calendering through winding. U.S. papermaking requires in total between around 6-9 MMBtu per ton in integrated mills, depending on the paper grade.

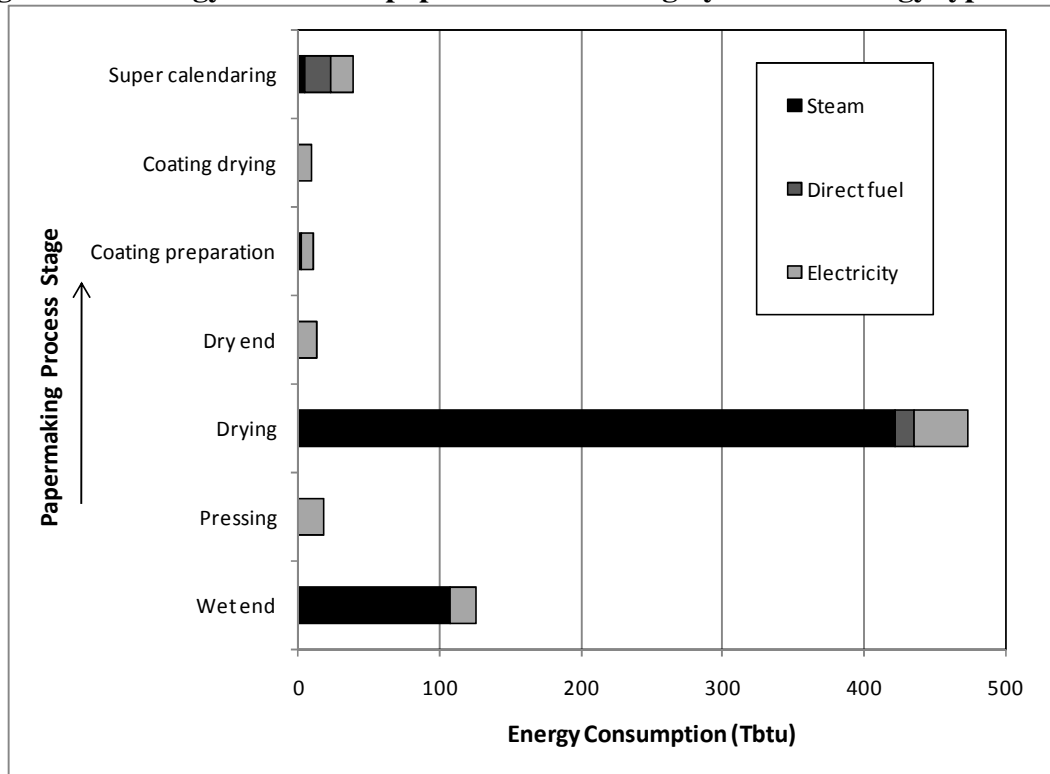
<sup>10</sup> The data in Figures 4.4 and 4.5 do not include the energy losses associated with on-site steam and electricity production, which are estimated to have totaled around 725 TBtu in 2002.

**Figure 4.4: Energy use of U.S. pulp manufacturing by end use energy type in 2002**



Source: Jacobs and IPST (2006)

**Figure 4.5: Energy use of U.S. paper manufacturing by end use energy type in 2002**



Source: Jacobs and IPST (2006)

### 4.3 Energy-Related Greenhouse Gas Emissions

The greenhouse gas (GHG) emissions associated with pulp and paper mill operations can be attributed to: (1) the combustion of on-site fuels; (2) the off-site generation of steam and electricity that are purchased by or transferred into the mill; and (3) non-energy related emissions sources such as by-product carbon dioxide (CO<sub>2</sub>) emissions from lime kiln chemical reactions and methane emissions from wastewater treatment. Of these mill emissions sources, energy-related GHG emissions (i.e., those arising from on-site fuel combustion and energy purchases/transfers) are by far the most significant (NCASI 2008). Greenhouse gas emissions associated with on-site combustion of black liquor, hog fuel, and other biomass energy sources are generally treated as carbon neutral and are typically not counted in energy-related GHG emissions inventories of mill operations (NCASI 2005).

Based on the fuel input data in Table 4.1, it is possible to roughly estimate the energy-related GHG emissions associated with pulp and paper mill operations in the United States using the energy source-specific GHG emission factors listed in Table 4.3. The emission factors for fuels in Table 4.3 account for the CO<sub>2</sub> emissions arising from fuel combustion, but do not take into account the CO<sub>2</sub> emissions associated with the production of these fuels and their distribution to the mill. The emission factor for net electricity use is based on the national grid average CO<sub>2</sub> emissions associated with electricity generation in the United States (U.S. DOE 2008b).

**Table 4.3: Carbon dioxide emission factors for U.S. fuels and electricity**

<b>Fuels</b>	<b>Metric tons of CO<sub>2</sub> per TBtu</b>
Distillate fuel	73,276
Residual fuel	78,951
Natural gas	52,346
Coal (U.S. average)	97,701
Coke	102,209
LPG	63,124
Purchased steam (U.S. average)	86,850
<b>Net Electricity</b>	<b>Metric tons of CO<sub>2</sub> per TBtu</b>
U.S. average grid generation	178,300

*Source: Adapted from U.S. DOE (2008b)*

Figure 4.6 plots the estimated energy-related GHG emissions of U.S. pulp and paper mills in 2002, based on the data in Tables 4.1 and 4.3. Total energy-related GHG emissions in 2002 are estimated at around 94 million metric tons of CO<sub>2</sub> equivalents (Tg CO<sub>2</sub>e). Note that the emissions associated with electricity use in Figure 4.6 are limited to emissions due to net electricity use only (see definition in Footnote 6); the emissions associated with electricity that is self-generated from non carbon-neutral combustible fuels are included in the emissions attributable to those fuels.

Figure 4.6 shows that natural gas, purchased electricity, and coal are the major energy-related GHG emissions sources of U.S. pulp and paper mills. Combined, these three energy sources accounted for over 80% of the industry's energy-related GHG emissions in 2002. As

expected, the top two energy-using sub-sectors—paper (except newsprint) mills (NAICS 322121) and paperboard mills (NAICS 32213)—account for the vast majority of energy-related GHG emissions. These two sub-sectors accounted for nearly 82 Tg of energy-related CO<sub>2</sub> emissions, or roughly 87% of the industry’s total in 2002.<sup>11</sup>

**Figure 4.6: Estimated energy-related GHG emissions of the U.S. pulp and paper industry, 2002**

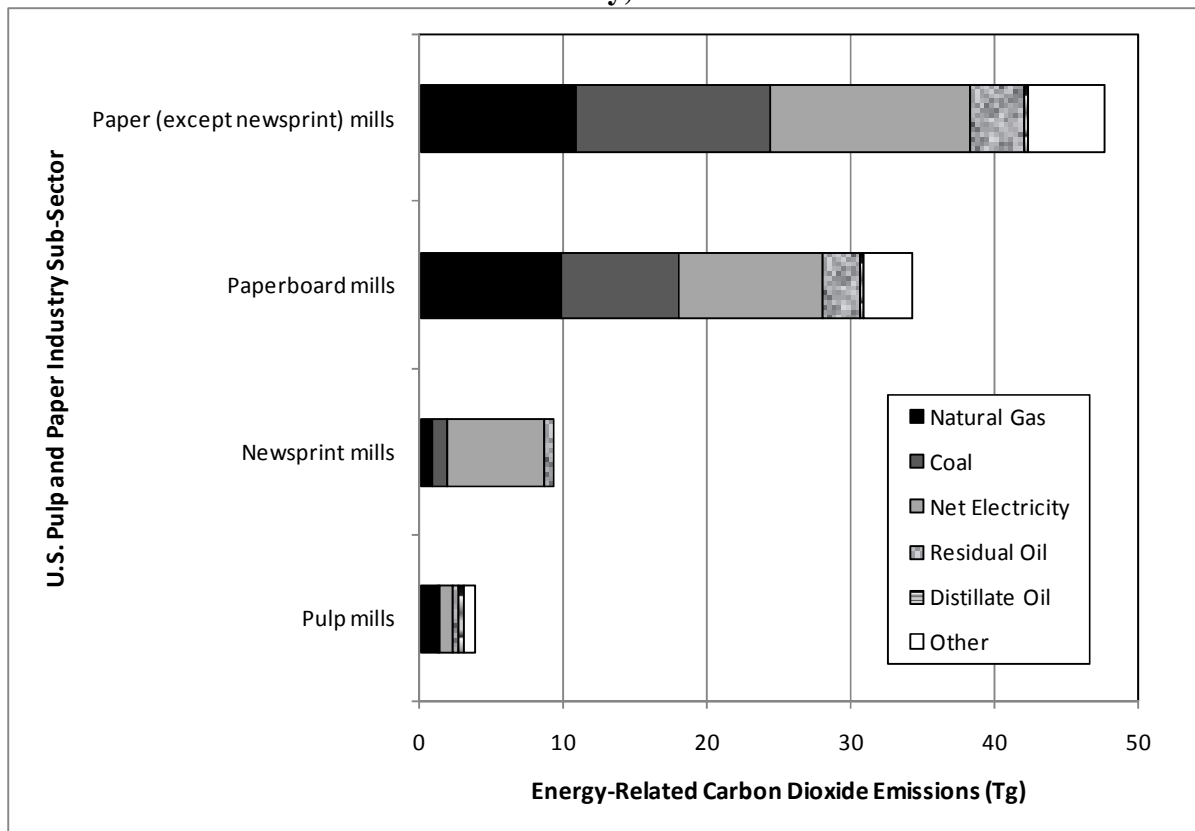


Figure 4.6 also shows that while coal only accounts for 11% of the industry’s total energy inputs (see Table 4.1), its use generates around 25% of the industry’s energy-related GHG emissions due to its high carbon content per unit of energy (see Table 4.3). Improvements to the energy efficiency of U.S. pulp and paper mills, and the corresponding reductions in fuel use, can clearly lead to significant reductions to the industry’s energy-related GHG emissions (especially when coal use is reduced).

<sup>11</sup> In a 2008 report by the NCASI, the total energy-related GHG emissions of U.S. pulp and paper mills was estimated at around 83 Tg CO<sub>2</sub>e in 2004 (NCASI 2008). In addition to a difference in the analysis year (i.e., 2002 versus 2004), the NCASI results differ from the results in Figure 4.6 in the underlying data sources that were used to estimate quantities and types of annual fuel consumption. The results in NCASI (2008) are based on U.S. mill survey data compiled by the American Forest and Paper Association, while the results in Figure 4.6 are based on national-level data provided publicly by the U.S. Department of Energy (DOE). The 2002 U.S. DOE data are used to derive GHG emissions estimates in this Energy Guide to maintain consistency with the fuel use information in Section 4.2. However, the reader is referred to the NCASI (2008) report for a more recent and alternative analysis of energy-related GHG emissions.

The estimates in Figure 4.6 do not include GHG emissions arising from non-energy related sources (i.e., lime kiln chemical reactions<sup>12</sup> and methane emissions from mill wastewater treatment). Furthermore, the estimates do not include energy-related GHG emissions associated with transporting raw materials and finished products. A spreadsheet tool has been developed by the National Council for Air and Stream Improvement (NCASI) that allows pulp and paper mills to generate comprehensive GHG emissions inventories based on their specific operating conditions (NCASI 2005).

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<sup>12</sup> Miner and Upton (2002) discusses how the vast majority of CO<sub>2</sub> emissions arising from lime kiln chemical reactions is of biomass origin and should therefore not be counted in pulp and paper industry GHG emissions inventories.

## 5 Energy Efficiency Improvement Opportunities

Many opportunities exist within the U.S. pulp and paper industry to reduce energy consumption while maintaining or enhancing productivity. Ideally, energy efficiency opportunities should be pursued in a coordinated fashion at multiple levels within a facility. At the component and equipment level, energy efficiency can be improved through regular preventative maintenance, proper equipment loading and operation, and replacement of older components and equipment with higher efficiency models (e.g., high efficiency motors) whenever feasible. At the process level, process control and optimization can be pursued to ensure that production operations are running at maximum efficiency. At the facility level, the efficiency of space lighting and ventilation can be improved while total facility energy inputs can be minimized through process integration, where feasible. Lastly, at the level of the organization, energy management systems should be implemented to ensure a strong corporate framework exists for energy monitoring, target setting, employee involvement, and continuous improvement.

The remaining chapters in this Energy Guide discuss a number of significant energy efficiency measures applicable to pulp and paper making at the component, process, facility, and organizational levels. This focus of this Energy Guide is on energy efficiency measures that are proven, cost effective, and available for implementation today. Whenever possible, measure descriptions include case studies of pulp and paper mills that have successfully implemented the measure, both in the United States and abroad. Many case studies include energy and cost savings data as well as typical investment payback periods. For measures where data are not available for pulp and paper mills, this Energy Guide presents case study data from other similar industries. Lastly, for most measures references to the technical literature and online resources are provided, which can be consulted for further information.

At individual pulp and paper mills, the actual payback period and savings associated with a given measure will vary depending on facility activities, configuration, size, location, and operating characteristics. Thus, the values presented in this Energy Guide are offered as guidelines. Further research on the economics of all measures—as well on as their applicability to different production practices—is needed to assess their cost effectiveness at individual plants. It is particularly important to quantify and consider the impacts of energy efficiency improvements on production efficiencies, product quality, materials use, labor and maintenance requirements, and water use to ensure that economic and energy savings benefits are realized at the facility level.

This Energy Guide also presents a brief overview of selected emerging energy-efficient technologies. An emerging technology is defined as one that has recently been developed or commercialized and holds promise for reducing energy use in the U.S. pulp and paper industry in the near future.

While the focus of this Energy Guide is on energy efficiency improvement measures, a chapter on basic measures for water efficiency in pulp and paper mills is also provided. Water is a critical input in the pulping process, and is becoming an increasingly expensive



and scarce resource in the United States. Water savings can also lead to energy savings through reduced demand for water heating, treatment, and pumping services.

To enable easy access to information, this Energy Guide is organized into chapters that focus on specific areas of opportunity for energy and water efficiency:

- Chapters 6 through 13 are focused on cross-cutting energy efficiency measures, which are defined as energy efficiency measures that are applicable across all manufacturing industries. Table 5.1 summarizes the cross-cutting energy efficiency measures presented in this Energy Guide and the respective chapters in which the measure descriptions appear.
- Chapters 14 to 17 present a variety of energy efficiency measures that are applicable to specific process stages in the manufacture of pulp and paper, including raw material preparation, chemical and mechanical pulping, chemical recover, and papermaking. These process-specific energy efficiency measures are summarized in Table 5.2.
- Chapter 18 provides an overview of selected, promising emerging energy efficient technologies applicable to the pulp and paper industry. These measures are summarized in Table 5.3. An emerging technology is defined as a technology that was recently developed or commercialized with little or no market penetration in the pulp and paper industry at the time of this writing.
- Chapter 19 discusses some basic measures for water efficiency in the pulp and paper industry. While this Energy Guide is primarily focused on energy efficiency measures, water is a critical resource throughout all industry sub-sectors that should be used wisely in the face of increasing water prices and scarcity. The water efficiency measures presented in this Energy Guide are summarized in Table 5.4.
- Appendices A-D contain useful information on available energy management tools, information resources, and incentive programs at the state and national levels.

Pulp and paper manufacturing in the United States is a mature, energy-intensive industry. As such, there is a wide body of information available on industry best practices, technologies, and research for energy and water efficiency. It follows that this Energy Guide could not include all possible energy and water efficiency measures that might be applicable to an individual mill. However, several excellent resources exist that can offer the reader more details and rationale for a number of the measures described in this Energy Guide, as well as for measures that are not included in this Energy Guide. Appendix E contains summary information from several additional resources that can be considered by mill personnel when researching and evaluating energy and water efficiency improvement projects.

**Table 5.1: Summary of cross-cutting measures presented in this Energy Guide**

<b>Energy Management Programs and Systems (Chapter 6)</b>	
Energy management programs	Energy teams
Energy monitoring and control systems	
<b>Steam Systems (Chapter 7)</b>	
<b>Boilers</b>	
Boiler process control	Boiler maintenance
Reduction of flue gas quantities	Minimizing blow down
Reduction of excess air	Blow down steam recovery
Improved boiler insulation	Flue gas heat recovery
Condensate return	Burner replacement
<b>Steam Distribution Systems</b>	
Steam distribution controls	Steam trap maintenance
Improved insulation	Steam trap monitoring
Insulation maintenance	Leak repair
Steam trap improvement	Flash steam recovery
<b>Process Integration</b>	
<b>Combined Heat and Power Systems (Chapter 8)</b>	
Combined cycle	STIG turbines
Replacement of pressure reducing valves	Operations and maintenance
<b>Motor Systems (Chapter 9)</b>	
Motor management plan	Adjustable-speed drives (ASDs)
Strategic motor selection	Power factor correction
Maintenance	Minimizing voltage unbalance
Properly sized motors	
<b>Pump Systems (Chapter 10)</b>	
Pump system maintenance	Avoiding throttling valves
Pump system monitoring	Replacement of belt drives
Pump demand reduction	Proper pipe sizing
Controls	Precision casting, surface coating or polishing
High-efficiency pumps	Sealings
Properly sized pumps	Curtailing leakages through clearance reduction
Multiple pumps for variable loads	Adjustable-speed drives (ASDs)
Impeller trimming	
<b>Fans (Chapter 11)</b>	
Maintenance	High efficiency belts (cog belts)
Properly sized fans	Duct leakage repair
ASDs and improved control	
<b>Compressed Air Systems (Chapter 12)</b>	
System improvements	Improved load management
Maintenance	Pressure drop minimization
Monitoring	Inlet air temperature reduction
Leak reduction	Controls
Turning off unnecessary compressed air	Properly sized pipe diameter
Modification of system in lieu of increased pressure	Heat recovery
Replacement by alternative sources	Natural gas engine-driven compressors
<b>Lighting (Chapter 13)</b>	
Lighting controls	Replacement of mercury lamps
Exit signs	HID voltage reduction
Electronic ballasts	High-intensity fluorescent lights
Replacement of T-12 tubes with T-8 tubes	Daylighting

**Table 5.2: Summary of process-specific energy efficiency measures presented in this Energy Guide**

<b>Raw Material Preparation (Chapter 14)</b>	
Cradle debarkers	Automatic chip handling and screening
Replace pneumatic chip conveyors with belt conveyors	Bar-type chip screening
Use secondary heat instead of steam in debarking	Chip conditioning
<b>Chemical Pulping (Chapter 15)</b>	
<i>Pulping</i>	
Use of pulping aids to increase yield	Digester improvement
Optimize the dilution factor control	Digester blow/flash heat recovery
Continuous digester control system	
<i>Bleaching</i>	
Heat recovery from bleach plant effluents	Chlorine dioxide (ClO <sub>2</sub> ) heat exchange
Improved brownstock washing	
<i>Chemical Recovery</i>	
Lime kiln oxygen enrichment	Improved composite tubes for recovery boiler
Lime kiln modification	Recovery boiler deposition monitoring
Lime kiln electrostatic precipitation	Quaternary air injection
Black liquor solids concentration	
<b>Mechanical Pulping (Chapter 16)</b>	
Refiner improvements	Increased use of recycle pulp
Refiner optimization for overall energy use	Heat recovery from de-inking plant
Pressurized groundwood	Fractionation of recycled fibers
Continuous repulping	Thermopulping
Efficient repulping rotors	RTS pulping
Drum pulpers	Heat recovery in TMP
<b>Papermaking (Chapter 17)</b>	
Advanced dryer controls	Waste heat recovery
Control of dew point	Paper machine vacuum system optimization
Optimization of water removal in forming and pressing	Shoe (extended nip) press
Reduction of blowthrough losses	Gap forming
Reduction air requirements	CondeBelt drying
Optimizing pocket ventilation temperature	Air impingement drying

**Table 5.3: Summary of emerging energy-efficient technologies discussed in this Energy Guide**

<b>Emerging Energy-Efficient Technologies (Chapter 18)</b>	
Black liquor gasification	Biotreatment
Magnetically coupled ASDs	Electrohydraulic contaminant removal
Laser-ultrasonic web stiffness sensor	Lateral corrugator
Steam cycle washer for unbleached pulp	Multiport dryer technology
Microwaving logs	Direct green liquor utilization pulping
Gas-fired paper dryer	Impulse drying
Advanced fibrous fillers	

**Table 5.4: Summary of water efficiency measures presented in this Energy Guide**

<b>Basic Water Efficiency Measures (Chapter 19)</b>	
<i>General and Facilities Water Efficiency Measures</i>	
Strategic water management program	Once-through cooling water reuse
Good housekeeping	Minimizing hose water use
Cooling towers	Use of water efficient building fixtures
Reducing cooling tower bleed-off	
<i>Process Water Savings</i>	
Dry debarking	Direct white water reuse
Optimizing shower water use	Mechanical pump seals
Water efficient bleaching	Chemi (belt) washer
Improving white water quality	Carbon dioxide brownstock washing
Vacuum pump seal water conservation	

## **6 Energy Management Programs and Systems**

### **6.1 A Strategic Energy Management Program**

One of the most successful and cost-effective ways to bring about energy efficiency improvements is to fundamentally change how energy is managed by implementing an organization-wide energy management program.

Continuous improvements to energy efficiency typically only occur when a strong organizational commitment exists. A sound energy management program is required to create a foundation for positive change and to provide guidance for managing energy throughout an organization. Energy management programs help to ensure that energy efficiency improvements do not just happen on a one-time basis, but rather are identified and implemented in an ongoing process of continuous improvement. Without the backing of a sound energy management program, energy efficiency improvements might not reach their full potential due to lack of a systems perspective and/or proper maintenance and follow-up.

In companies without a clear program in place, opportunities for improvement may be known but may not be promoted or implemented because of organizational barriers. These barriers may include a lack of communication among plants, a poor understanding of how to create support for an energy efficiency project, limited finances, poor accountability for measures, or organizational inertia to changes from the status quo. Even when energy is a significant cost, many companies still lack a strong commitment to improve energy management.

The U.S. EPA, through the ENERGY STAR program, works with leading industrial manufacturers to identify the basic aspects of effective energy management programs.<sup>13</sup> The major elements in a strategic energy management program are depicted in Figure 6.1.

Other environmental management frameworks, such as ISO 14001, can be used to complement energy management programs to ensure optimal organizational management of energy. One ENERGY STAR partner noted that using energy management programs in combination with the ISO 14001 program has had a greater impact on conserving energy at its plants than any other strategy.

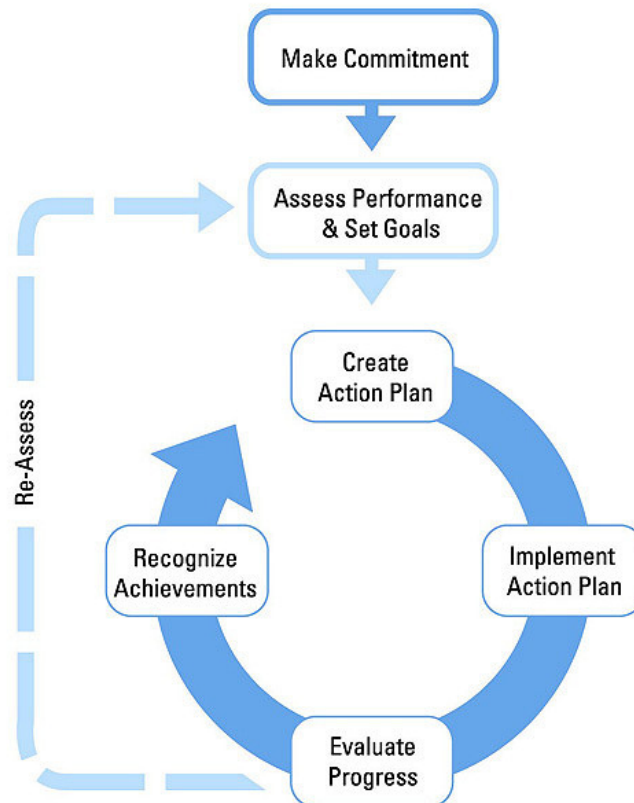
A successful program in energy management begins with a strong organizational commitment to continuous improvement of energy efficiency. This involves assigning oversight and management duties to an energy director, establishing an energy policy, and creating a cross-functional energy team (see Section 6.2). Steps and procedures are then put in place to assess performance through regular reviews of energy data, technical assessments, and benchmarking. From this assessment, an organization is able to develop a baseline of energy use and set goals for improvement. Performance goals help to shape the development and implementation of an action plan.

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<sup>13</sup> Read more about strategic energy management at <http://www.energystar.gov/industry>.

An important aspect for ensuring the success of the action plan is the involvement of key personnel throughout the organization. Personnel at all levels should be aware of energy use and goals for efficiency. Staff should be trained in both skills and general approaches to energy efficiency in day-to-day practices. Some examples of simple tasks employees can do are outlined in Appendix A. In addition, performance results should be regularly evaluated and communicated to all personnel, and high achievement should be rewarded and recognized.

**Figure 6.1: Main elements of a strategic energy management program**



For example, ENERGY STAR Partner ConAgra Foods has recognized outstanding employee contributions to energy efficiency as part of its corporate Sustainable Development program since 1993. Each year, several ConAgra production facilities are given a monetary award for outstanding plant-initiated projects that led to energy savings and other environmental improvements. The monetary awards are used by the production facilities as charitable donations to their communities for local sustainability projects. In addition to providing its employees with recognition and incentives for continuous improvement, ConAgra's Sustainable Development program has also reduced facility operating expenses by over \$60 million since 2000 (Pehanich 2005; Halberstadt 2006).

Evaluating progress on the action plan involves a regular review of both energy use data and the activities carried out as part of the action plan. Information gathered during the formal review process helps in setting new performance goals and action plans, and in revealing best

practices. Once best practices are established, the goal of the cross-functional energy team should be to replicate these practices throughout the organization. Establishing a strong communication program and seeking recognition for accomplishments are also critical steps; both help to build support and momentum for future activities.

A quick assessment of an organization's efforts to manage energy can be made by comparing its current energy management program against the ENERGY STAR Energy Program Assessment Matrix provided in Appendix B.

Internal support for a business energy management program is crucial; however, support for business energy management programs can come from outside sources as well. Facility audits can be a particularly effective form of outside support. For example, the U.S. Department of Energy (DOE) sponsors 26 Industrial Assessment Centers (IACs) at universities across the United States. These IACs offer small and medium sized manufacturing facilities free assessments of plant energy and waste management performance and recommend ways to improve efficiency. Since the early 1980s, IAC assessments of U.S. pulp and paper mills have identified over 6,000 efficiency and productivity improvement opportunities, with an average annual savings of around \$21,000 and an average simple payback of 1.1 years per recommendation (IAC 2008).

The U.S. DOE sponsors similar audits for large manufacturing plants under its *Save Energy Now* program. As of 2009, nearly 100 *Save Energy Now* audits were conducted for the U.S. paper industry (NAICS 322) (U.S. DOE 2009). The 34 audits conducted as of 2006 alone identified energy saving opportunities totaling over \$120 million (Wright et al. 2007). Appendix D provides additional information on these two U.S. DOE programs, as well as a host of other external resources that can aid in identifying energy efficiency opportunities.

## 6.2 Energy Teams

The establishment of an energy team is an important step toward solidifying a commitment to continuous energy efficiency improvement.<sup>14</sup> The energy team should primarily be responsible for planning, implementing, benchmarking, monitoring, and evaluating the organizational energy management program. However, its duties can also include delivering training, communicating results, and providing employee recognition (U.S. EPA 2006).

In forming an energy team, it is necessary to establish the organizational structure, designate team members, and specify roles and responsibilities. Senior management needs to perceive energy management as part of the organization's core business activities. Thus, ideally the energy team leader will be someone at the corporate level who is empowered by support from senior-level management. The energy team should also include members from each key operational area within an organization and be as multi-disciplinary as possible to ensure a diversity of perspectives. It is crucial to ensure adequate organizational funding for the

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<sup>14</sup> For a comprehensive overview of establishing, operating, and sustaining an effective energy management team, please consult the U.S. EPA's *Teaming Up to Save Energy* guide available at <http://www.energystar.gov/> (U.S. EPA 2006).

energy team's activities, preferably as a line item in the normal budget cycle as opposed to a special project.

Prior to the launch of an energy team, a series of team strategy meetings should be held to consider the key initiatives to pursue as well as potential pilot projects that could be showcased at the program's kickoff. The energy team should then perform facility audits with key plant personnel at each facility to identify opportunities for energy efficiency improvements. As part of the facility audits, the energy team should look for best practices in action to help highlight success stories and identify areas for inter-plant knowledge transfer.

A key function of the energy team is to develop mechanisms and tools for tracking and communicating progress and for transferring the knowledge gained through facility audits across an organization. Examples of such mechanisms and tools include best practice databases, facility benchmarking tools, intranet sites, performance tracking scorecards, and case studies of successful projects. Corporate energy summits and employee energy fairs are also effective means of information exchange and technology transfer.

To sustain the energy team and build momentum for continuous improvement, it is important that progress results and lessons learned are communicated regularly to managers and employees. It is also important that a recognition and rewards program is put in place.

A checklist of key steps for forming, operating, and sustaining an effective energy management team is offered in Appendix C.

### **6.3 Energy Monitoring and Control Systems**

The use of energy monitoring and process control systems can play an important role in energy management and in reducing energy use. These systems may include sub-metering, monitoring, and control systems. They can reduce the time required to perform complex tasks, often improve product and data quality and consistency, and can optimize process operations.

Typically, energy and cost savings are around 5% or more for many industrial applications of process control systems. These savings apply to plants without updated process control systems; many pulp and paper mills may already have modern process control systems in place to improve energy efficiency.

Although energy management systems are already widely disseminated in various industrial sectors, the performance of the systems can still be improved, which will reduce costs and increase energy savings further.

Specific energy savings and payback periods for overall adoption of energy monitoring and control systems vary greatly from plant to plant and company to company. A variety of process control systems are available for virtually any industrial process, and a wide body of



literature is available assessing control systems in most industrial sectors. Table 6.1 provides an overview of classes of process control systems.

**Table 6.1. Classification of control systems and typical energy efficiency improvement potentials**

System	Characteristics	Typical energy savings (%)
Monitoring and Targeting	Dedicated systems for various industries, well established in many countries and sectors	Typical savings 4-17%, average 8% , based on experiences in the UK
Computer Integrated Manufacturing (CIM)	Improvement of overall economics of process, e.g. stocks, productivity and energy	> 2%
Process control	Moisture, oxygen and temperature control, air flow control “Knowledge based, fuzzy logic”	Typically 2-18% savings

*Note: The estimated savings are valid for specific applications (e.g. lighting energy use). The energy saving cannot be added, due to overlap of the systems. Sources: (Caffal 1995, Martin et al. 2000).*

Modern control systems are often not solely designed for energy efficiency, but rather for improving productivity, product quality, and the efficiency of a production line. Applications of advanced control and energy management systems are in varying development stages and can be found in all industrial sectors. Control systems result in reduced downtime, reduced maintenance costs, reduced processing time, and increased resource and energy efficiency, as well as improved emissions control. Many modern energy-efficient technologies depend heavily on precise control of process variables, and applications of process control systems are growing rapidly. Modern process control systems exist for virtually any industrial process. Still, large potentials exist to implement control systems and more modern systems enter the market continuously.

Process control systems depend on information of many stages of the processes. A separate but related and important area is the development of sensors that are inexpensive to install, are reliable, and will analyze in real-time. Development aims at the use of optical, ultrasonic, acoustic, and microwave systems that should be resistant to aggressive environments (e.g. oxidizing environments in a furnace or chemicals in chemical processes) and withstand high temperatures. Information from the sensors is used in control systems to adapt the process conditions, based on mathematical (“rule”-based) or neural networks and “fuzzy logic” models of the industrial processes.

Neural network-based control systems have successfully been used in the cement (kilns), food (baking), non-ferrous metals (alumina, zinc), pulp and paper (paper stock, lime kiln), petroleum refineries (process, site), and steel industries (electric arc furnaces, rolling mills). New energy management systems that use artificial intelligence, fuzzy logic (neural network), or rule-based systems mimic the “best” controller, by using monitoring data and learning from previous experiences.

Process knowledge based systems (KBS) have been used in design and diagnostics, but are still not widely used in industrial processes. KBS incorporates scientific and process information and applies reasoning processes and rules in the management strategy. A recent demonstration project in a sugar beet mill in the UK using model based predictive control system demonstrated a 1.2% reduction in energy costs, while increasing product yield by almost one percent and reducing off-spec product from 11% to 4%. This system had a simple payback period of 1.4 years (CADDET 2000a).

Research for advanced sensors and controls is ongoing in all sectors, and is funded with both public and private research funds. Several projects within U.S. DOE's Industrial Technologies Program (ITP) are attempting to develop more advanced control technologies. Outside the United States, there is much attention in Japan and Europe to the development and demonstration of advanced controls. Future steps include further development of new sensors and control systems, demonstrations at a commercial scale, and dissemination of the benefits of control systems in a wide variety of industrial applications.

## 7 Steam Systems

Steam is used in a number of important applications throughout the typical pulp and paper mill, but by far most significantly in the cooking, bleaching, evaporation, and drying processes. As discussed in Chapter 4, over 80% of the energy consumed by the industry is in the form of boiler fuel. According to a recent study by the U.S. DOE, the U.S. pulp and paper industry could reduce its fuel use by 12.5%, and save 278 TBtu, by implementing best practice steam system improvement opportunities (U.S. DOE 2002b).<sup>15</sup> Energy efficiency improvements to steam systems therefore represent the most significant opportunities for energy savings in pulp and paper mills.

Two primary sources of steam in pulp and paper mill operations are recovery boilers and power boilers. As discussed in Chapter 3, recovery boilers are fired with black liquor to recover pulping chemicals and produce steam for mill process heating applications, and often for co-generation of on-site electricity. Power boilers can be fired with multiple fuels and operate at high pressures for co-generation of both electrical power and steam (U.S. DOE 2005a).

The steam system configuration for each type of boiler will vary by facility, but there is an overall pattern that many systems follow on the steam side. Treated cold feed water is fed into the boiler, where it is heated to form steam. Chemical treatment of the feed water is required to remove impurities, which would otherwise collect on the boiler walls. Even though the feed water has been treated, some impurities still remain and can build up in the boiler water. As a result, water is periodically purged from the boiler in a process known as blow down.

The generated steam travels along the pipes of the distribution system to get to the process where the heat will be used. Sometimes the steam is passed through a pressure reduction valve if the process requires lower pressure steam. As the steam is used to heat processes, and even as it travels through the distribution system to get there, the steam cools and some is condensed into hot water. This hot condensate is removed by a steam trap, which allows condensate to pass through, but blocks the passage of steam. The condensate can be recirculated to the boiler, thus recovering some heat and reducing the need for fresh treated feed water. The recovery of condensate and blow down will also reduce the costs of boiler feed water treatment.<sup>16</sup>

In mills that generate on-site electrical power using combustion turbines, waste heat is recovered to generate process steam. Whatever the use or the source of the steam, efficiency improvements in steam generation, distribution, and end-use are possible. It is

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<sup>15</sup> This U.S. DOE report, entitled *Steam System Opportunity Assessment for the Pulp and Paper, Chemical Manufacturing, and Petroleum Refining Industries*, contains an assessment of the potential savings associated with a number of best practice steam system efficiency measures. This chapter discusses some of the most important measures analyzed in this U.S. DOE report. The reader is referred to the U.S. DOE report for more details on specific measures.

<sup>16</sup> However, systems that supply steam for direct use in processes such as digesting and cooking do not require condensate return and are therefore generally less capital intensive (U.S. DOE 2005).

important to take a system approach in evaluating steam systems. As a first step, it is important to identify where and how steam is used.

This chapter describes a number of key opportunities available for improving steam system efficiency in a typical industrial plant.<sup>17</sup> First, energy efficiency measures applicable to boilers—the heart of most steam systems—are presented.<sup>18</sup> Next, measures that are applicable to a facility’s steam distribution network are discussed. Finally, this chapter provides a brief discussion of pinch technology and process integration as applied to steam systems. Combined heat and power (CHP) systems are discussed in Chapter 8.

In analyzing the opportunities for improving the energy efficiency of steam systems, a systems approach, in which both steam demand (i.e., end uses) and steam supply systems are optimized, is essential.

## 7.1 Boiler Energy Efficiency Measures

The boiler energy efficiency measures presented below focus primarily on improved process control, reduced heat loss, and improved heat recovery. In addition to the measures below, it is important to note that lower pressure boiler systems (which might be used in addition to recovery and power boilers) should be designed and installed in a custom configuration that meets the needs of a particular plant. Often, pre-designed boiler packages cannot be fine tuned to meet the steam generation and distribution system requirements unique to any given plant in the most efficient manner (Ganapathy 1994).

**Boiler process control.** Flue gas monitors maintain optimum flame temperature and monitor carbon monoxide (CO), oxygen, and smoke. The oxygen content of the exhaust gas is a combination of excess air (which is deliberately introduced to improve safety or reduce emissions) and air infiltration. By combining an oxygen monitor with an intake airflow monitor, it is possible to detect even small leaks. A small 1% air infiltration will result in 20% higher oxygen readings. A higher CO or smoke content in the exhaust gas is a sign that there is insufficient air to complete fuel burning. Using a combination of CO and oxygen readings, it is possible to optimize the fuel/air mixture for high flame temperature (and thus the best energy efficiency) and lower air pollutant emissions.

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<sup>17</sup> The U.S. DOE’s Industrial Technologies Program provides a variety of resources for improving industrial steam system efficiency, which can be consulted for more detailed information on many of the measures presented in this chapter. The U.S. DOE’s *Improving Steam System Performance, A Sourcebook for Industry* (U.S. DOE 2004a) is a particularly helpful resource. Also, many tips, tools, and industrial case studies on steam system efficiency can be found at the Industrial Technologies Program’s *BestPractices* steam systems website: <http://www1.eere.energy.gov/industry/bestpractices/steam.html>.

<sup>18</sup> Additionally, some information related to improving the efficiency of recovery boilers is offered in Chapter 14.

Typically, this measure is financially attractive only for large boilers, because smaller boilers often will not make up the initial capital cost as easily. Several case studies indicate that the average payback period for this measure is around 1.7 years (IAC 2008).

At the Appleton Paper mill in West Carrollton, Ohio, three boilers (two fired by coal, one by natural gas) produce 250,000 pounds per hour of steam for several heating and drying processes. An energy audit of the mill found that the mill's boiler control system did not provide continuous monitoring or control of combustion air. The audit team recommended that the mill install a control system to measure, monitor, and control oxygen and carbon monoxide levels on its coal-fired boilers, given that these boilers operated near full capacity and would reap the greatest benefits of improved control. This measure was estimated to save nearly \$475,000 in annual energy costs; at an investment cost of \$200,000, the payback period was less than six months (U.S. DOE 2002c).

**Reduction of flue gas quantities.** Often excessive flue gas results from leaks in the boiler and/or in the flue. These leaks can reduce the heat transferred to the steam and increase pumping requirements. However, such leaks are often easily repaired, saving 2% to 5% of the energy formerly used by the boiler (Galitsky et al. 2005a). This measure differs from flue gas monitoring in that it consists of a periodic repair based on visual inspection. The savings from this measure and from flue gas monitoring are not cumulative, as they both address the same losses.

**Reduction of excess air.** Boilers must be fired with excess air to ensure complete combustion and to reduce the presence of carbon monoxide in the unburned fuel in exhaust gases. When too much excess air is used to burn fuel, energy is wasted because excessive heat is transferred to the air rather than to the steam. Air slightly in excess of the ideal stoichiometric fuel-to-air ratio is required for safety and to reduce emissions of nitrogen oxides (NO<sub>x</sub>), but approximately 15% excess air (around 3% excess oxygen) is generally adequate (U.S. DOE 2004a; Ganapathy 1994). Most industrial boilers already operate at 15% excess air or lower, and thus this measure may not be widely applicable (Zeitz 1997). However, if a boiler is using too much excess air, numerous industrial case studies indicate that the payback period for this measure is less than one year (IAC 2008).

Examples of improvements to reduce excess air include changing automatic oxygen control set points, periodic tuning of single set point control mechanisms, installing automatic flue gas monitoring and control, fixing broken baffles, and repairing air leaks into the boiler. The U.S. DOE estimates that U.S. pulp and paper plants could reduce boiler fuel use by around 2.3% through application of this measure (it was assumed that this measure would be feasible at around one-third of U.S. pulp and paper mills) (U.S. DOE 2002b). The estimated average payback period for this measure was 5 months.

As part of the U.S. DOE's *Save Energy Now Program*, an audit was conducted at the Boise Cascade mill in Jackson, Alabama. This Kraft pulp mill produces around 1,000 tons of paper per day and uses (among other boilers) a combination fuel boiler that typically burns green wood and bark. Combustion tuning of this boiler reduced flue gas oxygen concentrations

from the 8-12% range to the 6- 7% range. The savings in green wood was reported to be around \$70,000 per year (U.S. DOE 2006a).

Similar benefits were predicted at the West Linn Paper Company's coated paper mill in West Linn, Oregon. A U.S. DOE audit found that by adjusting boiler oxygen trim controls to lower the oxygen levels to between 2.5-3%, boiler efficiency improvements would save 15,500 MMBtu per year at a cost savings of around \$118,000 (U.S DOE 2008c).

**Improved insulation.** New materials insulate better, and have a lower heat capacity. Savings of 6-26% can be achieved if this improved insulation is combined with improved heater circuit controls. This improved control is required to maintain the output temperature range of the old firebrick system. As a result of the ceramic fiber's lower heat capacity the output temperature is more vulnerable to temperature fluctuations in the heating elements (Caffal 1995). The shell losses of a well-maintained boiler should be less than 1%.

**Boiler maintenance.** A simple maintenance program to ensure that all components of a boiler are operating at peak performance can result in substantial savings. In the absence of a good maintenance system, burners and condensate return systems can wear or get out of adjustment. These factors can end up costing a steam system up to 30% of initial efficiency over two to three years (Galitsky et al. 2005a). On average, the energy savings associated with improved boiler maintenance are estimated at 10%. Improved maintenance may also reduce the emission of criteria air pollutants.

Fouling on the fire side of boiler tubes or scaling on the water side of boilers should also be controlled. Fouling and scaling are more of a problem with coal-fed boilers than natural gas or oil-fed boilers (boilers that burn solid fuels like coal should be checked more often as they have a higher fouling tendency than liquid fuel boilers do). Tests reported by CIPEC show that a fire side soot layer of 0.03 inches (0.8 mm) reduces heat transfer by 9.5%, while a 0.18 inch (4.5 mm) soot layer reduces heat transfer by 69% (CIPEC 2001). For water side scaling, 0.04 inches (1 mm) of buildup can increase fuel consumption by 2% (CIPEC 2001).

**Condensate return.** For indirect uses of steam, returning hot condensate to boilers for reuse saves energy and reduces the need for treated boiler feed water. Typically, fresh feed water must be treated to remove solids that might accumulate in the boiler; however, returning condensate to a boiler can substantially reduce the amount of purchased chemical required to accomplish this treatment. The fact that this measure can save substantial energy costs and purchased chemicals costs often makes building a return piping system attractive. The U.S. DOE estimates that this measure can lead to a 1.5% reduction in boiler fuel use at U.S. pulp and paper mills, at an average payback period of around 15 months (U.S. DOE 2002b). In a specific example, the U.S. DOE reports that a large specialty paper plant reduced its boiler makeup water rate from about 35% of total steam production to less than 20% by returning additional condensate; annual savings were around \$300,000 (U.S. DOE 2004a).

**Minimizing boiler blow down.** Boiler blow down is important for maintaining proper steam system water properties, and must be done periodically to minimize boiler deposit formation. However, excessive blow down will waste energy, as well as water and chemicals. The

optimum blow down rate depends on a number of factors—including the type of boiler and its water treatment requirements—but typically ranges from 4-8% of the boiler feed water flow rate (U.S. DOE 2004a). Automatic blow down systems can be installed to optimize blow down rates. Case studies from the pulp and paper industry suggest that automatic blow down systems can have a payback period of just six months (Focus on Energy 2006a).

The U.S. DOE estimates that around 20% of U.S. pulp and paper mills could improve blow down practices, which would lead to annual boiler fuel savings of around 1.1% (U.S. DOE 2002b).

**Blow down steam recovery.** Boiler blow down is important for maintaining proper steam system water properties. However, blow down can result in significant thermal losses if the steam is not recovered for beneficial use. Blow down steam is typically low grade, but can be used for space heating and feed water preheating. In addition to energy savings, blow down steam recovery may reduce the potential for corrosion damage in steam system piping. Examples of blow down steam recovery in the pulp and paper industry suggest a payback period of around 12 to 18 months for this measure (Focus on Energy 2006a).

The U.S. DOE estimates that the installation of continuous blow down heat recovery systems is feasible at around 20% of U.S. pulp and paper mills, and would reduce boiler fuel use by around 1.2% (U.S. DOE 2002b).

For example, a boiler blow down heat recovery project at Augusta Newsprint Company's Augusta, Georgia, mill led to significant energy and cost savings. An existing boiler blow down system was modified by installing a plate-and-tube heat exchanger and associated piping to recover energy from the mill's continuous blowdown stream from the boiler blow down flash tank. The project resulted in annual energy savings of 14,000 MMBtu, with annual fuel cost savings of over \$30,000. The period of payback for this project was about six months. (U.S. DOE 2002d)

Similarly impressive savings were identified by Boise Cascade at two different mills. At the company's mill in International Falls, Minnesota, a plant-wide assessment estimated that the pursuit of blow down heat recovery (as opposed to the current practice of venting blow down to atmosphere) could save the mill around \$370,000 per year (U.S. DOE 2006b). At the company's mill in Jackson, Alabama, it was estimated that a significant amount of additional thermal energy could be recovered from the liquid blow down rejected from the flash vessel. If a second stage of blow-down energy recovery were installed on the remaining boilers, additional blow down recover energy savings of \$100,000 per year were projected (U.S. DOE 2006a).

**Flue gas heat recovery.** Heat recovery from flue gas is often the best opportunity for heat recovery in steam systems (CIPEC 2001). Heat from flue gas can be used to preheat boiler feed water in an economizer. While this measure is fairly common in large boilers, there is often still room for more heat recovery. The limiting factor for flue gas heat recovery is that one must ensure that the economizer wall temperature does not drop below the dew point of acids contained in the flue gas (such as sulfuric acid in sulfur-containing fossil fuels).

Traditionally, this has been done by keeping the flue gases exiting the economizer at a temperature significantly above the acid dew point. In fact, the economizer wall temperature is much more dependent on feed water temperature than on flue gas temperature because of the high heat transfer coefficient of water. As a result, it makes more sense to preheat feed water to close to the acid dew point before it enters the economizer. This approach allows the economizer to be designed so that exiting flue gas is just above the acid dew point.

Typically, one percent of fuel use is saved for every 45°F (25°C) reduction in exhaust gas temperature (Ganapathy 1994). A conventional economizer would result in savings of 2-4%, while a condensing economizer could result in energy savings of 5-8% (Gardner 2008). However, the use of condensing economizers is limited to boilers using clean fuels due to the risk of corrosion.

The U.S. DOE estimates that the installation of boiler feedwater economizers is feasible at around 19% of U.S. pulp and paper mills, and would reduce boiler fuel use by around 3.5% (U.S. DOE 2002b).

One important caveat to the use of an economizer is that the formation of steam on the feed water side should be carefully avoided to avoid water hammer and boiler damage. Strategies for avoiding steam formation include supplying feed water constantly, venting steam out of the economizer, and re-circulating boiler water through the economizer (CIBO 1997).

**Burner replacement.** According to a study conducted for the U.S. DOE, roughly half of the U.S. industrial boiler population is over 40 years old (EEA 2005). Replacing old burners with more efficient modern burners can lead to significant energy savings. Energy and cost savings vary widely based on the condition and efficiency of the burners being replaced. For example, the payback time for a new burner that provides a boiler efficiency improvement of 2% will be around one year (U.S. DOE 2004a). In one example from the pulp and paper industry, replacing circular oil burners with more efficient parallel throat burners with racer type atomizers had a payback of approximately one year (Focus on Energy 2006a).

The U.S. DOE estimates that upgrading burners to more efficient models or replacing worn burners can reduce the boiler fuel use of U.S. pulp and paper mills by around 2.4% with a payback period of around 19 months (U.S. DOE 2002b).

As part of an energy use and energy efficiency opportunities case study of ten different pulp and paper mills in Illinois, it was shown that improving boiler combustion efficiency, using blow down steam energy rather than live steam to preheat makeup feedwater, and installation of stack economizers could save (on average) over 9,000 MMBtu and over \$50,00 per year (Chimack et al. 2003).

## 7.2 Steam Distribution System Energy Efficiency Measures

Steam systems are often quite extensive and can be major contributors to energy losses within a typical pulp and paper mill. Energy efficiency improvements to steam distribution systems are primarily focused on reducing heat losses throughout the system and recovering



useful heat from the system wherever feasible. The following measures describe a number of key opportunities for saving energy in industrial steam distribution systems.

**Steam distribution controls.** Steam demand can be interrupted due to changing operating procedures at steam using processes (e.g., paper machine or turbines), or due to operational failures (e.g., a sheet breakage). This can lead to the dumping of excess steam or additional fuel use for back-up boilers. Modern control systems have been deployed to better manage a steam system, reducing the need for back-up steam capacity or the need to dump steam.

For example, Aylesford Newsprint Ltd. in the United Kingdom implemented a second-generation control system for their steam system, which consisted of three paper machines, two natural gas-fired gas turbine based combined heat and power (CHP) units, one steam turbine, and a steam accumulator. The system is model-based predictive control system to manage steam loads better. The system resulted in a 95% reduction of steam venting and a 70% reduction in fuel use for back up steam generation, with a payback period of less than 6 months (Austin et al. 2008).

**Improved insulation.** Using more insulating material or using the best insulation material for the application can save energy in steam distribution systems. Crucial factors in choosing insulating material include low thermal conductivity, dimensional stability under temperature change, resistance to water absorption, and resistance to combustion. Other characteristics of insulating material may also be important depending on the application, such as tolerance of large temperature variations, tolerance of system vibrations, and adequate compressive strength where the insulation is load bearing (Baen and Barth 1994).

Removable insulating pads are commonly used in industrial facilities for insulating flanges, valves, expansion joints exchangers, pumps, turbines, tanks and other surfaces. Insulating pads can be easily removed for periodic inspection or maintenance, and replaced as needed. Insulating pads also contain built-in acoustical barriers to help control noise (U.S. DOE 2004a). The U.S. DOE estimates that the installation of removable insulation on valves, pipes, and fittings can reduce steam system energy use by 1-3% (U.S. DOE 2006c).

Case studies from the U.S. pulp and paper industry indicate that the payback period for improved insulation is typically less than one year (IAC 2008).

At a Georgia-Pacific mill in Madison, Georgia, 1,500 feet of saturated steam lines to the dryer were uninsulated. This led to significant losses of energy and process steam temperature and pressure. The addition of insulation reduced this heat loss and maintained the process temperature throughout the lines. In addition to adding insulation, the mill also replaced 70 steam traps, which resulted in a 10% increase in condensate return. Total energy savings amounted to about 63,000 MMBtu at a cost savings of over \$138,000. With implementation costs of \$69,280, the payback period was only six months (U.S. DOE 1999a).

As part of a plant-wide energy assessment at Boise Cascade's Jackson, Alabama mill, it was estimated that the repair of insulation could lead to annual energy savings of \$80,000 at a

repair cost of around \$25,000. The payback for insulation repair was around 4 months (U.S. DOE 2006a).

**Insulation maintenance.** It is often found that after heat distribution systems have undergone some form of repair, the insulation is not replaced. In addition, some types of insulation can become brittle or rot over time. As a result, a regular inspection and maintenance system for insulation can also save energy (Zeitz 1997).

The U.S. DOE estimates that (as of 2002) roughly half of U.S. pulp and paper mills could significantly benefit from insulation improvements and installation, and that these mills could reduce their boiler fuel use anywhere from 3% to 10% if such improvements were pursued (U.S. DOE 2002b).

As part of an energy use and energy efficiency opportunities case study of ten different pulp and paper mills in Illinois, it was shown that installing or improving insulation on pipes and valves could save (on average) over 3,600 MMBtu and over \$12,000 per year (Chimack et al. 2003).

**Steam trap improvement.** Using modern thermostatic element steam traps can reduce energy use while also improving reliability. The main efficiency advantages offered by these traps are that they open when the temperature is very close to that of saturated steam (within 4°F or 2°C), purge non-condensable gases after each opening, and are open on startup to allow a fast steam system warm-up. These traps also have the advantage of being highly reliable and useable for a wide variety of steam pressures (Alesson 1995).

A new steam trap design is the venturi orifice steam trap, which is better suited for varying loads than traditional mechanical steam traps (Gardner 2008). A mill owned by Smurfit Kappa in Europe changed 25 steam traps to the new type on a coating battery, which resulted in energy costs savings of nearly \$200,000 with a payback period of 2.5 months. Other projects saved 11% on steam demand in preheater and end corrugator rolls (10 steam traps), and a 30% savings on a flute machine (Gardner 2008).

**Steam trap maintenance.** A simple program of checking steam traps to ensure that they are operating properly can save significant amounts of energy for very little money. In the absence of a steam trap maintenance program, it is common to find up to 15% to 20% of steam traps malfunctioning in a steam distribution system (Jaber 2005). Annual failure rates are estimated at 10% or more (Gardner 2008). Energy savings for a regular system of steam trap checks and follow-up maintenance is conservatively estimated at 10% (Jones 1997; Bloss et al. 1997). Several industrial case studies suggest that investments for repair or replacement steam traps are very low, resulting in a payback period of only a few months or less (IAC 2008).

A plant-wide assessment at Boise Cascade's mill in DeRidder, Louisiana found opportunities for repairing failed steam traps that could save the mill about \$31,000 in fuel use and about \$3,900 in water use annually. The annual energy savings were estimated at 1,262 MMBtu of natural gas and 12,168 MMBtu of other fuels. The estimated costs to implement this measure

were between roughly \$7,400 and \$12,400, which implies a payback period of well under a year (U.S. DOE 2006d).

**Steam trap monitoring.** Attaching automated monitors to steam traps in conjunction with a maintenance program can save even more energy without significant added cost. This measure is an improvement over steam trap maintenance alone, because it gives quicker notice of steam trap failure and can detect when a steam trap is not performing at peak efficiency. Employing steam trap monitoring has been estimated to provide an additional 5% in energy savings compared to steam trap maintenance alone, at a payback period of around one year (Galitsky et al. 2005a). Systems that are able to implement steam trap maintenance are also likely to be able to implement automatic monitoring.

**Leak repair.** As with steam traps, steam distribution piping networks often have leaks that can go undetected without a program of regular inspection and maintenance. The U.S. DOE estimates that repairing leaks in U.S. pulp and paper mill steam distribution systems could lead to fuel savings of around 2% (U.S. DOE 2002b). Case studies of U.S. pulp and paper mills in the IAC database suggest a payback period for this measure of less than one year (IAC 2008).

A plant-wide assessment at Boise Cascade's mill in DeRidder, Louisiana found opportunities for repairing steam leaks around paper machines that could result in annual fuel and water cost savings of about \$20,000 with a payback of around one to 1.5 years (U.S. DOE 2006d)

**Flash steam recovery.** When a steam trap purges condensate from a pressurized steam distribution system to ambient pressure, flash steam is produced. As with flash steam produced by boiler blow down, steam trap flash steam can be recovered and used for low grade facility applications, such as space heating or feed water preheating (Johnston 1995).

The potential for this measure is site dependent, as its cost effectiveness depends on whether or not areas where low-grade heat is useful are located close to steam traps. Where feasible, this measure can be easy to implement and can save considerable energy. In an example from the food industry, an analysis of a U.S. based food processing facility predicted that the installation of a flash steam recovery system used for feed water preheating would save the plant around \$29,000 in fuel costs annually at a payback period of less than 1.8 years (Jordanova et al. 2000). Based on the reduction in boiler fuel use, it was further estimated that the plant's carbon emissions would be reduced by 173 tons per year.

### 7.3 Process Integration

Process integration can be an effective systems optimization approach to improve the energy efficiency of complex industrial facilities. Process integration is an analytical approach that can be used to optimize the selection and/or modification of processing steps, and of interconnections and interactions within the process, with the goal of minimizing resource use (CETC 2003). Developed in the early 1970s, process integration is now an established methodology for improving the energy efficiency of continuous industrial processes

(Linnhoff et al. 1992; CADDET 1993). Pinch analysis is one of the most widely used process integration techniques.

**Pinch analysis.** Pinch analysis takes a systematic approach to identifying and correcting the performance limiting constraint (or pinch) in any manufacturing process system. It was developed originally in response to the “energy crisis” and the need to reduce steam and fuel consumption in oil refineries and chemical plants by optimizing the design of heat exchanger networks. Since then, the pinch analysis approach has been extended to resource conservation in general, whether the resource is capital, time, labor, electrical power, water, or a specific chemical species such as hydrogen.

The critical innovation in applying pinch analysis was 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 these 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. These are called the energy targets. The pinch analysis methodology involves first identifying the targets and then following a systematic procedure for designing heat exchanger networks to achieve these targets. The optimum approach temperature at the pinch is determined by balancing capital and energy tradeoffs to achieve the desired payback. The procedure applies equally well to new designs and retrofits of existing plants.

The analytical approach to pinch analysis has been well documented in the literature (Smith 1995; Shenoy 1994). Energy savings potential using pinch analysis far exceeds that from well-known conventional techniques such as heat recovery from boiler flue gas, insulation, and steam trap management. For example, Natural Resource Canada estimates that pinch analyses can lead to energy savings of 10-35% in the pulp and paper industry (CETC 2003).

Since the U.S. pulp and paper industry relies heavily on water, pinch analyses that are aimed at optimizing both energy and water use are ideal. Several case studies of the successful application of pinch analysis by pulp and paper companies are discussed below.

At the Smurfit-Stone integrated pulp and paper mill in La Tuque, Quebec, Canada, a process integration analysis of the mill’s energy and water systems identified several heat recovery and wastewater reduction options. Pinch analysis was used to develop “hot” and “cold” composite curves for the entire mill. In addition to identifying all thermodynamically possible synergies between hot and cold systems, the pinch analysis also pinpointed inappropriate heat exchanges and ways to improve mill heat recovery. A total of 12 projects were deemed feasible from this analysis, which were estimated to lead to a 15% reduction in the mill’s total fuel use. Additional benefits included the reduction in mill effluent. The payback period of these improvements was estimated at only ten months (CETC 2002).

At a Tembec pulp mill in Skookumchuck, Canada, a process integration study identified water and energy efficiency opportunities that focused on feed water preheating measures and cooling tower hot water streams displacement. Five priority projects were identified that would reduce energy consumption while also reducing the use of fresh water by 10%.

Capital expenditures for these projects were estimated at around \$1.8 million, but the return on investment is expected to take only a little over one year (CIPEC 2008)

Georgia-Pacific has also identified significant energy savings opportunities by using pinch analysis. At the company's mill in Crossett, Arkansas, three heat recovery projects were identified that could reduce annual costs by about \$4.8 million and annual natural gas use by 1,845,000 MMBtu (U.S. DOE 2003a). The overall payback for these projects was estimated to be less than one year. At the company's paper mill in Palatka, Florida, a pinch analysis identified eight projects that could offer significant savings. It was estimated that annual steam savings of 718,972 MMBtu and annual natural gas savings of 10,483 MMBtu would be possible, with an overall payback period of around 2.75 years (U.S. DOE 2002e).

## 8 Combined Heat and Power (CHP) Systems

As discussed in Chapter 4, the U.S. pulp and paper industry is the largest self-generator of electricity in the U.S. manufacturing sector (U.S. DOE 2007a). The combination of significant and steady process steam demand, high on-site electricity demand, high annual operating hours, and on-site generated fuels (i.e., wood waste and black liquor) has made CHP an operationally and financially attractive option for many mills around the country.

The benefits of CHP are significant and well documented (see for example Shipley et al. 2008). Pulp and paper mills benefit from improved power quality and reliability, greater energy cost stability, and, possibly, increased revenues from the export of excess electrical power to the grid.<sup>19</sup> CHP systems are significantly more efficient than standard power plants, because they take advantage of waste heat that is usually lost in central power generating systems and also reduce electricity transmission losses. Thus, society also benefits from CHP in the form of reduced grid demand, reduced air pollution, and reduced GHG emissions.

CHP systems in the pulp and paper industry are typically designed with a mill's thermal energy demand in mind, as well as the supply steam temperatures and pressures that are required by key mill processes. Thus, electrical power generation is a secondary benefit. Many mills will import supplementary electricity from the grid as needed, but best practice mills may be able to meet all on-site electrical power demand through self generation (Ackel 2009). CHP systems can also be used to directly drive mechanical equipment such as pumps and air compressors.

Major industrial CHP “prime mover” technologies include steam turbines, gas turbines, reciprocating engines, and fuel cells (U.S. EPA 2008). Of these, steam and gas turbines dominate in U.S. pulp and paper mill applications. Figure 8.1 summarizes the installed CHP technologies, and their respective fuel sources, expressed by estimated share of total installed electrical power capacity as of early 2009 (EEA 2009).<sup>20</sup>

Traditional boiler and steam turbine systems are by far the most common, and account for nearly 70% of current installed CHP capacity. As shown in Figure 8.1, around half of these boiler-based systems are fired by on-site fuels (i.e., by black liquor and hog fuel) and the other half are fired by purchased fuels (i.e., by coal, natural gas, and other fuels). These systems generally produce much more steam than electricity, and as a result do not typically generate enough electricity to meet a mill's total electricity demand (NCASI 2009).

CHP systems based on natural gas-fired combustion turbines account for around 30% of the total installed CHP capacity. Roughly two-thirds of these turbine-based systems use

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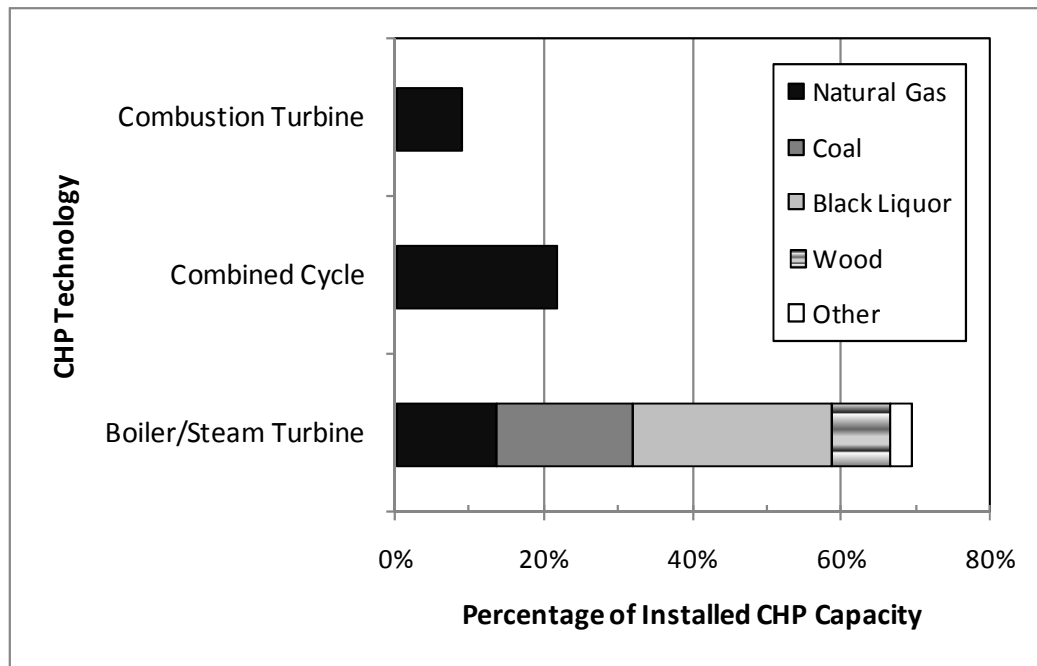
<sup>19</sup> The cost benefits of power export to the grid will depend on the regulation in the state where the mill is located. Not all states allow wheeling of power (i.e. sales of power directly to another customer using the grid for transport) while the regulations may also differ with respect to the tariff structure for power sales to the grid operator.

<sup>20</sup> Other CHP technologies made up less than 1% of installed CHP capacity in the U.S. pulp and paper industry (EEA 2009), and are therefore excluded from this figure.

combined cycles, which augment a primary gas turbine system with a secondary, steam based turbine system for improved power generation. Combustion turbine systems produce more electricity per unit of heat than boiler and steam turbine systems, and can often meet a mill's total electricity demand (NCASI 2009).

From a fuels perspective, Figure 8.1 shows that around one-third of the current CHP capacity in the U.S. pulp and paper industry is fired by biomass-based energy sources.

**Figure 8.1: Installed CHP Capacity in the U.S. Pulp and Paper Industry by CHP Technology and Fuel Source, 2009**



Source: Derived from EEA (2009)

Despite the benefits of CHP systems—and their widespread use in the U.S. pulp and paper industry—much potential for CHP remains. Recent data suggest that the current installed CHP capacity only captures between 25%-40% of the technically-feasible market for CHP in U.S. pulp and paper mills (Bryson et al. 2001; Khrushch et.al. 1999). There are a number of barriers that may account for this untapped potential. These barriers include high capital investment costs, the complexity of the CHP project development process, complexities in permitting, and knowledge barriers related to technology selection, operation, and performance characterization (see for example Bullock and Weingarden 2006).

However, there are a number of resources available to help U.S. pulp and paper mills overcome such barriers. For example, the U.S. EPA's Combined Heat and Power Partnership provides information on CHP technology basics, guidance for streamlining CHP projects, information on federal and state policies and incentives, CHP feasibility assessment tools, and a database of funding resources.<sup>21</sup> The U.S. DOE's CHP Regional Application

<sup>21</sup> For more information, visit the CHP Partnership website at: <http://www.epa.gov/chp/>.

Centers provides educational assistance and project-specific support in eight different U.S. regions, including project development and screening tools, technical assistance and training, information regarding issues related to permitting, utilities, and siting, and case studies.<sup>22</sup>

The configuration, economics, and performance of a CHP system will depend highly on site-specific conditions. However, a common goal is to choose a CHP system that will provide the greatest combined thermal and electrical energy efficiency at the lowest life-cycle cost for meeting a given thermal energy requirement. To do so, detailed, site-specific energy and cost analyses are required. Mill personnel are encouraged to elicit technical support (e.g., from the U.S. EPA and DOE resources mentioned in the previous paragraph) when conducting such analyses.

There are a variety of applications and configurations of CHP systems. As such, CHP systems represent a complex topic. In order to be concise, this chapter discusses only a few measures related to CHP system efficiency. For a comprehensive overview of CHP technologies and systems considerations, the reader is referred to Oland (2004).

**Combined cycle.** Conventional co-generation in the pulp and paper industry is based on back-pressure steam turbines fed by a mill's power and recovery boilers, as evident in Figure 8.1. An increasing number of mills are employing gas turbine-based combined cycle systems, which offer the advantages of reduced air emissions, faster start-up times, low noise, and improved electrical generation efficiency at full loads (Oland 2004; U.S. EPA 2008). Combined cycle systems utilize the waste heat from the gas turbine, which can be used to generate steam in a heat recovery steam generator (HRSG) or to preheat boiler combustion air or feed water. Steam from the HRSG or boiler is used to drive a steam turbine, thereby generating additional electrical power.

An important limitation of combined cycle systems is that part-load operation will reduce overall system efficiency. Combined cycle systems are also likely to have lower availability (77%-85%) compared to boiler and steam turbine systems (90%-95%). Further, poor maintenance and intermittent operations will negatively affect availability, reliability, and service life (Oland 2004).

In 1999, the SP Newsprint in pulp and paper mill in Newberg, Oregon initiated a project to install a gas turbine combined cycle system. A key goal of the project was to ensure the financial viability of the mill in the face of sharply rising electricity prices. Prior to the project, the mill generated 20 MW of electrical power based on two boilers fired by hog fuel, sludge, and natural gas. On average, the mill purchased 84 MW of power. At a cost of \$75 million, the mill installed a 92 MW gas-fired power plant consisting of two natural gas-fired turbines with HRSGs to provide steam for additional power and process applications. The system allowed SP Newsprint to increase the power output of its existing steam turbines, which led to a total generating capacity of 130 MW. The reported availability of the gas

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<sup>22</sup> For more information on the eight U.S. DOE CHP Regional Application Centers, visit: [http://www.eere.energy.gov/de/chp/chp\\_applications/](http://www.eere.energy.gov/de/chp/chp_applications/).



turbines was over 95%. The mill is now able to sell 20-25 MW of excess power on the wholesale market (EEA 2005).

**Replacement of pressure reducing valves.** In many steam systems, high-pressure steam produced by boilers is reduced in pressure for use by different processes. Often this pressure reduction is accomplished through a pressure reduction valve (PRV). A PRV does not recover the energy embodied in the pressure drop. However, this energy could be recovered in the form of mechanical or electrical power for beneficial use in a mill. For example, a mechanical steam drive turbine can be used in place of a PRV to replace an electric motor based drive, such as the drive for boiler feed water pumps (Kaufmann 2009).

To generate electrical power, a PRV could be replaced by a micro-scale backpressure steam turbine. Several manufacturers produce these turbine sets, such as Turbosteam (previously owned by Trigen) and Dresser-Rand. The potential for application will depend on mill-specific conditions; however, applications of this technology have been commercially demonstrated for various installations. The investments of a typical turbine set are estimated at 600 \$/kWe, with operation and maintenance costs at 0.011 \$/kWh (Neelis et al. 2008).

In an energy efficiency assessment of a 3M facility in Hutchinson, Minnesota, the installation of a steam turbine to replace a PRV was identified as a project that could save 3.1 GWh of electricity per year. Capital costs for the project were estimated at \$604,034 and avoided first year energy expenses were estimated at \$163,999 (U.S. DOE 2003b).

**Steam injected gas turbines.** Gas turbines of this type—also known as STIG or Cheng cycle turbines—boost power production and reduce NO<sub>x</sub> emissions by injecting steam into the combustion chamber of the turbine. A reported advantage of a STIG turbine is that part-load performance deteriorates at a slower rate with reduced load compared to a combined cycle (Maunsbach et al. 2001). In a combined cycle, when gas turbine efficiency drops under partial loading, more waste heat is supplied to the steam turbine. While this increases steam turbine electrical output, the overall power efficiency of the combined cycle system is reduced (Oland 2004). For mills that experience fluctuations in steam demand, a STIG turbine can improve electrical power generation during the periods of partial turbine loading.

The size of typical STIGs starts around 5 MW<sub>e</sub>, and is currently scaled up to sizes of 125 MW. STIG turbines have been installed at over 50 sites worldwide, and are found in various industries and applications, especially in Japan and Europe. Energy savings and payback period will depend on the local circumstances (e.g. thermal demand patterns and power sales conditions). No pulp and paper industry case studies could be found. For an analytical treatment, the reader is referred to Maunsbach et al. (2001) for results of a simulation of STIG versus combined cycle systems under various operating assumptions in Swedish pulp and paper mills.

**Performance and maintenance.** Like other critical mill processes, CHP systems require regular performance monitoring and maintenance to ensure that they are operating in the most energy efficient manner possible.

The efficiency of the steam turbine is determined by the inlet steam pressure and temperature as well as the outlet pressure. The higher the ratio of the steam inlet pressure to the steam exit pressure, and the higher the steam inlet temperature, the more power it will produce per unit of steam mass flow (EEA 2008). As a result, plant operators should make sure that the steam inlet temperature and pressure are as close to the optimum values for a given turbine design as possible. For example, an 18°F decrease in steam inlet temperature will reduce the efficiency of the steam turbine by 1.1% (Patel and Nath 2000). Additionally, operators should also monitor and maintain the outlet pressure of back pressure turbines, as efficiency losses will occur if this pressure gets too high. Monitoring and maintaining proper feed water and steam chemistry are also critical for avoiding corrosion and erosion problems (Oland 2004).

A key variable governing the efficiency of gas turbines is the inlet air temperature. Power and efficiency are increased at low air inlet temperatures, whereas high inlet air temperatures lead to power and efficiency reductions. Options to consider for cooling inlet air include refrigeration cooling (in which a compressor or absorption chiller cools inlet air via a heat exchanger and cooling fluid) and evaporative cooling (which uses a spray of water directly into the inlet air stream) (EEA 2008). Each cooling option has advantages and drawbacks, however, which should be explored to determine the feasibility of this measure on a site-specific basis.

Gas turbines that operate on a cyclic basis, or above rated capacity for extended periods, will require greater maintenance compared to gas turbines that are steadily operated at the rated load (Oland 2004). Reportedly, cycling every hour triples maintenance costs versus a turbine that operates for intervals of 1,000 hours or more (EEA 2008). Thus, ensuring consistency in steam demand is also an important operating consideration.

In addition to the performance optimization options above, routine maintenance is critical for reliable and efficient CHP system operations. Many of the steam system maintenance tips in Chapter 7 apply to the steam circuit of a CHP system. It must be noted that major maintenance of turbines (e.g., a turbine overhaul) should only be performed by trained turbine repair specialists. However, there are a number of routine maintenance tasks that can be performed by mill personnel to ensure that turbines are operating at peak performance. Typical measures include (EEA 2008; Oland 2004; McNamara 2006; Swagelok 2009):

- vibration measurements to detect worn bearings, rotors, and damaged blade tips;
- inspection of auxiliaries such as lubricating-oil pumps, coolers and oil strainers;
- inspection and verification of equipment alignment;
- checking safety devices such as the operation of overspeed controls;

- replacement of filter elements;
- inspection of steam piping supports to check for damage due to torque or vibration;
- for gas turbines: inspection of the combustion path for fuel nozzle cleanliness and wear, along with the integrity of other hot gas path components;
- for steam turbines: dislodging of water solid deposits by applying manual removal techniques, cracking the deposits by shutting the turbine off and allowing it to cool, and washing the turbine with water while it is running.

## 9 Motor Systems

It was shown in Chapter 4 that motor-driven systems are by far the most significant consumer of electrical energy in a typical U.S. pulp and paper mill. As of 2002, motor-driven systems accounted for around 90% of all the electricity used by the U.S. pulp and paper industry. Figure 4.3 indicated that pumps, fans, and materials processing equipment account for the majority (over 70%) of motor-driven systems electricity use in the typical U.S. mill. Other important uses of electricity in pulp and paper manufacturing include materials handling systems (e.g., conveyors) and compressed air systems.

Efficiency improvements to motor-driven systems can therefore lead to significant energy savings in most pulp and paper mills. The U.S. DOE estimates (as of 2002) that efficiency improvements to basic components of motor-driven systems in the U.S. pulp and paper industry could lead to electricity savings of 14% (U.S. DOE 2002a).

This chapter presents a number of energy efficiency measures available for motors in industrial applications.<sup>23</sup> Additional measures that are specific to pumps, fans, and compressed air systems are offered in later chapters of this Energy Guide.

When considering energy efficiency improvements to a facility's motor systems, it is important to take a "systems approach." A systems approach strives to optimize the energy efficiency of entire motor systems (i.e., motors, drives, driven equipment such as pumps, fans, and compressors, and controls), not just the energy efficiency of motors as individual components. A systems approach analyzes both the energy supply and energy demand sides of motor systems as well as how these sides interact to optimize total system performance, which includes not only energy use but also system uptime and productivity.

A systems approach typically involves the following steps. First, all applications of motors in a facility should be located and identified. Second, the conditions and specifications of each motor should be documented to provide a current systems inventory. Third, the needs and the actual use of the motor systems should be assessed to determine whether or not motors are properly sized and also how well each motor meets the needs of its driven equipment. Fourth, information on potential repairs and upgrades to the motor systems should be collected, including the economic costs and benefits of implementing repairs and upgrades to enable the energy efficiency improvement decision-making process. Finally, if upgrades are pursued, the performance of the upgraded motor systems should be monitored to determine the actual costs savings (SCE 2003).

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<sup>23</sup> The U.S. DOE's Industrial Technologies Program provides a variety of resources for improving the efficiency of industrial motor systems, which can be consulted for more detailed information on many of the measures presented in this chapter. For a collection of tips, tools, and industrial case studies on industrial motor system efficiency, visit the Industrial Technologies Program's *BestPractices* Motors, Pumps, and Fans website at: <http://www1.eere.energy.gov/industry/bestpractices/systems.html>. The Motor Decisions Matter<sup>SM</sup> Campaign also provides a number of excellent resources for improving motor system efficiency (<http://www.motorsmatter.org/>).

The motor system energy efficiency measures below reflect important aspects of this systems approach, including matching motor speeds and loads, proper motor sizing, and upgrading system components.

**Motor management plan.** A motor management plan is an essential part of a plant's energy management strategy. Having a motor management plan in place can help companies realize long-term motor system energy savings and will ensure that motor failures are handled in a quick and cost effective manner. The Motor Decisions Matter<sup>SM</sup> Campaign suggests the following key elements for a sound motor management plan (MDM 2007):

- Creation of a motor survey and tracking program.
- Development of guidelines for proactive repair/replace decisions.
- Preparation for motor failure by creating a spares inventory.
- Development of a purchasing specification.
- Development of a repair specification.
- Development and implementation of a predictive and preventive maintenance program.

The Motor Decisions Matter<sup>SM</sup> Campaign's *Motor Planning Kit* contains further details on each of these elements (MDM 2007).

**Strategic motor selection.** Several factors are important when selecting a motor, including motor speed, horsepower, enclosure type, temperature rating, efficiency level, and quality of power supply. When selecting and purchasing a motor, it is also critical to consider the life-cycle costs of that motor rather than just its initial purchase and installation costs. Up to 95% of a motor's costs can be attributed to the energy it consumes over its lifetime, while only around 5% of a motor's costs are typically attributed to its purchase, installation, and maintenance (MDM 2007). Life cycle costing (LCC) is an accounting framework that allows one to calculate the total costs of ownership for different investment options, which leads to a more sound evaluation of competing options in motor purchasing and repair or replacement decisions. A specific LCC guide has been developed for pump systems (Fenning et al. 2001), which also provides an introduction to LCC for motor systems.

The selection of energy-efficient motors can be an important strategy for reducing motor system life-cycle costs. Energy-efficient motors reduce energy losses through improved design, better materials, tighter tolerances, and improved manufacturing techniques. With proper installation, energy-efficient motors can also run cooler (which may help reduce facility heating loads) and have higher service factors, longer bearing life, longer insulation life, and less vibration.

To be considered energy efficient in the United States, a motor must meet performance criteria published by the National Electrical Manufacturers Association (NEMA). The Consortium for Energy Efficiency (CEE) has described the evolution of standards for energy-efficient motors in the United States, which is helpful for understanding "efficient" motor nomenclature (CEE 2007):

- NEMA Energy Efficient (NEMA EE) was developed in the mid-1980s to define the term “energy efficient” in the marketplace for motors. NEMA Standards Publication No. MG-1 (Revision 3), Table 12-11 defines efficiency levels for a range of different motors (NEMA 2002).
- The Energy Policy Act of 1992 (EPACT) required that many commonly used motors comply with NEMA “energy efficient” ratings if offered for sale in the United States.
- In 1996, the CEE Premium Efficiency Criteria specification was designed to promote motors with higher efficiency levels than EPACT required, for the same classes of motors covered by EPACT. The CEE efficiency levels specified were generally two NEMA efficiency bands (Table 12-10 in NEMA MG-1 Revision 3) above those required by EPACT.
- In 2001, the NEMA Premium<sup>®</sup> Efficiency Electric Motor specification was developed to address confusion with respect to what constituted the most efficient motors available in the market. This specification was developed by NEMA, CEE, and other stakeholders, and was adapted from the CEE 1996 criteria. It currently serves as the benchmark for premium energy efficient motors. NEMA Premium<sup>®</sup> also denotes a brand name for motors which meet this specification. Specifically, this specification covers motors with the following attributes:
  - Speed: 2, 4, and 6 pole
  - Size: 1-500 horsepower (hp)
  - Design: NEMA A and B
  - Enclosure type: open and closed
  - Voltage: low and medium voltage
  - Class: general, definite, and special purpose

The choice of installing a premium efficiency motor strongly depends on motor operating conditions and the life cycle costs associated with the investment. In general, premium efficiency motors are most economically attractive when replacing motors with annual operation exceeding 2,000 hours/year. However, software tools such as MotorMaster+ (see Appendix D) can help identify attractive applications of premium efficiency motors based on the specific conditions at a given plant.

Sometimes, even replacing an operating motor with a premium efficiency model may have a low payback period. According to data from the Copper Development Association, the upgrade to high-efficiency motors, as compared to motors that achieve the minimum efficiency as specified by EPACT, can have paybacks of less than 15 months for 50 hp motors (CDA 2001). Payback times will vary based on size, load factor, running time, local energy costs, and available rebates and/or incentives (see Appendix E). Given the quick payback time, it usually makes sense to buy the most efficient motor available (U.S. DOE and CAC 2003).

NEMA and other organizations have created the Motor Decisions Matter<sup>SM</sup> campaign to help industrial and commercial customers evaluate their motor repair and replacement options, promote cost-effective applications of NEMA Premium<sup>®</sup> motors and “best practice” repair, and support the development of motor management plans before motors fail.

At Mohawk Paper Mills, a manufacturer of specialty grade papers near Albany, New York, energy efficient motors were an important part of a strategy to reduce electricity costs and remain competitive. By replacing its electric motors with premium-efficiency motors, the company was able to reduce its consumption of electricity per ton of paper by 3.5% (New York Energy Smart 2008). Additionally, by taking advantage of state-sponsored energy efficiency incentives available for the purchase of premium-efficiency motors, Mohawk reduced the payback period associated with the upgrade to less than two years.

In some cases, it may be cost-effective to rewind an existing energy efficient motor, instead of purchasing a new motor. As a rule of thumb, when rewinding costs exceed 60% of the costs of a new motor, purchasing the new motor may be a better choice (MDM 2007). When rewinding a motor, it is important to choose a motor service center that follows best practice motor rewinding standards in order to minimize potential efficiency losses. An ANSI-approved recommended best practice standard has been offered by the Electric Apparatus Service Association (EASA) for the repair and rewinding of motors (EASA 2006). When best rewinding practices are implemented, efficiency losses are typically less than 0.5% to 1% (EASA 2003). However, poor quality rewinds may result in larger efficiency losses. It is therefore important to inquire whether the motor service center follows EASA best practice standards (EASA 2006).

**Maintenance.** The purposes of motor maintenance are to prolong motor life and to foresee a motor failure. Motor maintenance measures can be categorized as either preventative or predictive. Preventative measures, the purpose of which is to prevent unexpected downtime of motors, include electrical consideration, voltage imbalance minimization, load consideration, and motor ventilation, alignment, and lubrication. The purpose of predictive motor maintenance is to observe ongoing motor temperature, vibration, and other operating data to identify when it becomes necessary to overhaul or replace a motor before failure occurs (Barnish et al. 1997). The savings associated with an ongoing motor maintenance program are significant, and could range from 2% to 30% of total motor system energy use (Efficiency Partnership 2004).

**Properly sized motors.** Motors that are sized inappropriately result in unnecessary energy losses. Where peak loads on driven equipment can be reduced, motor size can also be reduced. Replacing oversized motors with properly sized motors saves, on average for U.S. industry, 1.2% of total motor system electricity consumption (U.S. DOE 2002a). Higher savings can often be realized for smaller motors and individual motor systems.

To determine the proper motor size, the following data are needed: load on the motor, operating efficiency of the motor at that load point, the full-load speed of the motor to be replaced, and the full-load speed of the replacement motor. The U.S. DOE’s BestPractices program provides a fact sheet that can assist in decisions regarding replacement of oversized

and under loaded motors (U.S. DOE 1996). Additionally, software packages such as MotorMaster+ (see Appendix D) can aid in proper motor selection.

**Adjustable speed drives (ASDs).**<sup>24</sup> Adjustable-speed drives better match speed to load requirements for motor operations, and therefore ensure that motor energy use is optimized to a given application. Adjustable-speed drive systems are offered by many suppliers and are available worldwide. Worrell et al. (1997) provide an overview of savings achieved with ASDs in a wide array of applications; typical energy savings are shown to vary between 7% and 60%. Industrial case studies from the IAC database suggest that the payback period associated with the installation of ASDs in a number of different applications ranges between roughly one and three years (IAC 2008).

The Augusta Newsprint mill (part of a joint partnership between Abitibi Consolidated and the Woodbridge Company, Ltd.) manufactures over 400,000 metric tons of standard newsprint each year from southern pine and recycled newspaper and magazines. As part of an energy efficiency review of the mill's boiler system, the company found an ideal application of an ASD to save energy and improve reliability. The boiler's re-circulation scrubber was equipped with a 1,100 rpm pump; however, this pump was being driven by a fixed-speed 1,800 rpm motor such that the operators could only adjust the flow of the pump by using an inefficient sheave. The company installed a magnetic drive ASD in this application to better match motor size with flow requirements, with the added benefit of providing operators with more efficient control over pump flow. The new motor reportedly delivered annual cost and energy savings of about \$4,000 and 114 MWh, respectively (U.S. DOE 2002f).

**Power factor correction.** Inductive loads like transformers, electric motors, and HID lighting may cause a low power factor. A low power factor may result in increased power consumption, and hence increased electricity costs. The power factor can be corrected by minimizing idling of electric motors (a motor that is turned off consumes no energy), replacing motors with premium-efficient motors (see above), and installing capacitors in the AC circuit to reduce the magnitude of reactive power in the system.

A mill's power factor can also be corrected with the use of large horsepower synchronous motors. Such motors are typically used on refiners, and on around 20% of paper machine vacuum systems. Higher speed synchronous motors (1200 and 1800 rpm) can be used to replace induction motors where gear reducers are used to bring drive speeds down to the lower speeds required for most vacuum pumps (Sweet 2009a).

**Minimizing voltage unbalances.** A voltage unbalance degrades the performance and shortens 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, which can reduce the life of a motor's winding insulation. Voltage

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<sup>24</sup> Several terms are used in practice to describe a motor system that permits a mechanical load to be driven at variable speeds, including adjustable speed drives (ASDs), variable speed drives (VSDs), adjustable frequency drives (AFDs), and variable frequency drives (VFDs). The term ASD is used throughout this Energy Guide for consistency.



unbalances may be caused by faulty 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% to 1% will result in electricity savings of 9,500 kWh or almost \$500 at an electricity rate of \$0.05/kWh (U.S. DOE 2005b).

By regularly monitoring the voltages at the motor terminal and through regular thermographic inspections of motors, voltage unbalances may be identified. It is also recommended to verify that single-phase loads are uniformly distributed and to install ground fault indicators as required. Another indicator that a voltage unbalance may be a problem is 120 Hz vibration, which should prompt an immediate check of voltage balance (U.S. DOE 2005b). The typical payback period for voltage controller installation on lightly loaded motors in the United States is 2.6 years (IAC 2008).

## 10 Pumps

As indicated in Chapter 4, pumps account for the largest share (over 30%) of motor-driven system electricity use in the U.S. pulp and paper industry. Significant amounts of energy are required in the typical mill to pressurize and circulate water, process chemicals, and pulping slurries as part of the pulp and paper making process. As a result, energy efficiency improvements to pumps can lead to significant electricity savings in the U.S. pulp and paper industry. According to the U.S. DOE, basic pump system improvements in U.S. pulp and paper mills could save over 6,300 GWh of electricity per year (U.S. DOE 2002a).

It is important to note that initial costs are only a fraction of the life cycle costs of a pump system. Energy costs, and sometimes operations and maintenance costs, are much more important in the lifetime costs of a pump system. In general, for a pump system with a lifetime of 20 years, the initial capital costs of the pump and motor make up merely 2.5% of the total costs (Best Practice Programme 1998). Depending on the pump application, energy costs may make up about 95% of the lifetime costs of the pump. Hence, the initial choice of a pump system should be highly dependent on energy cost considerations rather than on initial costs.

Optimization of the design of a new pumping system should focus on optimizing the lifecycle costs. Hodgson and Walters (2002) discuss software developed for this purpose and discuss several case studies in which they show large reductions in energy use and lifetime costs of a complete pumping system. Typically, such an approach will lead to energy savings of 10-17%.

Pumping systems consist of a pump, a driver, piping systems, and controls (such as ASDs or throttles). There are two main ways to increase pump system efficiency, aside from reducing use. These are reducing the friction in dynamic pump systems (not applicable to static or "lifting" systems) or upgrading/adjusting the system so that it draws closer to the best efficiency point on the pump curve (Hovstadius 2002). Correct sizing of pipes, surface coating or polishing and ASDs, for example, may reduce the friction loss, increasing energy efficiency. Correctly sizing the pump and choosing the most efficient pump for the applicable system will push the system closer to the best efficiency point on the pump curve. Furthermore, pump systems are part of motor systems and thus the general "systems approach" to energy efficiency described in Chapter 9 for motors applies to pump systems as well.

Some of the most significant energy efficiency measures applicable to pump system components and to pump systems as a whole are described below.<sup>25</sup>

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<sup>25</sup> The U.S. DOE's Industrial Technologies Program provides a variety of resources for improving the efficiency of industrial pumps, which can be consulted for more detailed information on many of the measures presented in this chapter. The U.S. DOE's *Improving Pumping System Performance: A Sourcebook for Industry* is a particularly helpful resource (U.S. DOE 2006e). For a collection of tips, tools, and industrial case studies on industrial pump efficiency, visit the Industrial Technologies Program's *BestPractices* Motors, Pumps, and Fans website at: <http://www1.eere.energy.gov/industry/bestpractices/systems.html>.

**Pump system maintenance.** Inadequate maintenance can lower pump system efficiency, cause pumps to wear out more quickly, and increase pumping energy costs. The implementation of a pump system maintenance program will help to avoid these problems by keeping pumps running optimally. Furthermore, improved pump system maintenance can lead to pump system energy savings of anywhere from 2% to 7% (U.S. DOE 2002a). A solid pump system maintenance program will generally include the following tasks (U.S. DOE 2006e; U.S. DOE 2002a):

- Replacement of worn impellers, especially in caustic or semi-solid applications.
- Bearing inspection and repair.
- Bearing lubrication replacement, on an annual or semiannual basis.
- Inspection and replacement of packing seals. Allowable leakage from packing seals is usually between 2 to 60 drops per minute.
- Inspection and replacement of mechanical seals. Allowable leakage is typically 1 to 4 drops per minute.
- Wear ring and impeller replacement. Pump efficiency degrades by 1% to 6% for impellers less than the maximum diameter and with increased wear ring clearances.
- Checking of pump/motor alignment.
- Inspection of motor condition, including the motor winding insulation.

**Pump system monitoring.** Monitoring in conjunction with operations and maintenance can be used to detect problems and determine solutions to create a more efficient pump system. Monitoring can determine clearances that need be adjusted, indicate blockage, impeller damage, inadequate suction, operation outside preferences, clogged or gas-filled pumps or pipes, or worn out pumps. Monitoring should include:

- Specific energy consumption, i.e. electricity use/flow rate (Hovstadius 2007)
- Wear monitoring
- Vibration analyses
- Pressure and flow monitoring
- Current or power monitoring
- Differential head and temperature rise across the pump (also known as thermodynamic monitoring)
- Distribution system inspection for scaling or contaminant build-up

**Pump demand reduction.** An important component of the systems approach is to minimize pump demand by better matching pump requirements to end use loads. Two effective strategies for reducing pump demand are the use of holding tanks and the elimination of bypass loops. Holding tanks can be used to equalize pump flows over a production cycle,

which can allow for more efficient operation of pumps at reduced speeds and lead to energy savings of 10% to 20% (U.S. DOE 2002a). Holding tanks and can also reduce the need to add pump capacity. The elimination of bypass loops and other unnecessary flows can also lead to energy savings of 10% to 20% (U.S. DOE 2002a). Other effective strategies for reducing pump demand include lowering process static pressures, minimizing elevation rises in the piping system, and lowering spray nozzle velocities.

**Controls.** Control systems can increase the energy efficiency of a pump system by shutting off pumps automatically when demand is reduced, or, alternatively, by putting pumps on standby at reduced loads until demand increases.

In 2000, Cisco Systems upgraded the controls on its fountain pumps so that pumps would be turned off automatically during periods of peak electrical system demand. A wireless control system was able to control all pumps simultaneously from one location. The project saved \$32,000 and 400,000 kWh annually, representing a savings of 61.5% in the total energy consumption of the fountain pumps (CEC 2002). With a total cost of \$29,000, the simple payback period was 11 months. In addition to energy savings, the project reduced maintenance costs and increased the pump system's equipment life.

**High-efficiency pumps.** It has been estimated that up to 16% of pumps in use in U.S. industry are more than 20 years old (U.S. DOE 2002a). Considering that a pump's efficiency may degrade by 10% to 25% over the course of its life, the replacement of aging pumps can lead to significant energy savings. The installation of newer, higher-efficiency pumps typically leads to pump system energy savings of 2% to 10% (Elliott 1994).

A number of high-efficiency pumps are available for specific pressure head and flow rate capacity requirements. Choosing the right pump often saves both operating costs and capital costs. For a given duty, selecting a pump that runs at the highest speed suitable for the application will generally result in a more efficient selection as well as the lowest initial cost (U.S. DOE 2001b).

**Properly sized pumps.** Pumps that are oversized for a particular application consume more energy than is truly necessary (see also "avoiding throttling valves" below). Replacing oversized pumps with pumps that are properly sized can often reduce the electricity use of a pumping system by 15% to 25% (U.S. DOE 2002a). Where peak loads can be reduced through improvements to pump system design or operation (e.g., via the use of holding tanks), pump size can also be reduced. If a pump is dramatically oversized, often its speed can be reduced with gear or belt drives or a slower speed motor. The typical payback period for the above strategies can be less than one year (Galitsky et al. 2005a).

At the Augusta Newsprint mill in Augusta, Georgia, a new paper machine cleaner system was installed, which required a significantly lower feed pressure than previously. The previous system was fed by a 1,250-horsepower hp primary fan pump motor. Engineers at the Augusta mill replaced this motor with an 800-hp primary fan pump motor, reducing power consumption and delivering annual electricity savings of 2,450 MWh per year. With investment costs of \$123,500, the payback period was 17 months (U.S. DOE 2002g).

**Multiple pumps for variable loads.** The use of multiple pumps installed in parallel can be a cost-effective and energy-efficient solution for pump systems with variable loads. Parallel pumps offer redundancy and increased reliability, and can often reduce pump system electricity use by 10% to 30% for highly variable loads (U.S. DOE 2002a). Parallel pump arrangements often consist of a large pump, which operates during periods of peak demand, and a small pump (or “pony” pump), which operates under normal, more steady-state conditions. Because the pony pump is sized for normal system operation, this configuration operates more efficiently than a system that relies on a large pump to handle loads far below its optimum capacity.

For example, one case study of a Finnish pulp and paper plant indicated that by installing a pony pump in parallel with an existing larger pump to circulate water from a paper machine into two tanks, electricity cost savings of \$36,500 per year were realized with a simple payback period of just 6 months (Hydraulic Institute and Europump 2001).

In another example, the bleach plant at a Boise Paper mill in Wallula, Washington, depended on a 150 hp pump to meet a variety of process requirements. However, at times of peak demand this pump could not always provide adequate capacity for production. An energy assessment recommended splitting the system by dedicating a 50 hp pump to low-head applications and using the existing pump for high-head applications. Both pumps were also upgraded with ASDs. The project resulted in annual energy savings of almost 500,000 kWh, and annual costs savings of around \$15,000 (electricity costs). Additionally, the new system also eliminated suction recirculation and cavitation problems that plagued the old system, and reduced the mill’s annual maintenance costs by \$2,500 because pump bearings and check valves didn’t have to be replaced as often. The payback period for this project was 4.2 years (U.S. DOE 2006f).

**Adjustable-speed drives (ASDs).** ASDs better match speed to load requirements for pumps where, as for motors, energy use is approximately proportional to the cube of the flow rate<sup>26</sup>. Hence, small reductions in flow rates that are proportional to pump speed may yield large energy savings for friction dominated pump systems. However, in static head dominated systems the energy use might increase when using ASDs if the speed is turned down too much. New installations may result in short payback periods. In addition, the installation of ASDs improves overall productivity, control and product quality, and reduces wear on equipment, thereby reducing future maintenance costs.

According to inventory data collected by Xenergy (1998), 82% of pumps in U.S. industry have no load modulation feature (or ASD). Similar to being able to adjust load in motor systems, including modulation features with pumps is estimated to save between 20% and

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<sup>26</sup> This equation applies to dynamic systems only. Systems that solely consist of lifting (static head systems) will accrue no benefits from (but will often actually become more inefficient) ASDs because pump efficiency usually drops when speed is reduced in such systems. A careful choice of operating points can to some extent overcome this problem. Similarly, systems with more static head will accrue fewer benefits than systems that are largely dynamic (friction) systems. More careful calculations must be performed to determine actual benefits, if any, for these systems.

50% of pump energy consumption, at relatively short payback periods, depending on application, pump size, load and load variation (Xenergy 1998; Best Practice Programme 1996a). The savings depend strongly on the system curve. As a rough rule of thumb, unless the pump curves are exceptionally flat, a 10% regulation in flow should produce pump savings of 20% and 20% regulation should produce savings of 40% (Best Practice Programme 1996).

For example, Daishowa America installed two ASDs in the effluent pumping system at its paper mill in Port Angeles, Washington due to chronic maintenance issues and rising energy costs. The project reportedly resulted in annual savings of \$32,000 in energy costs and 700,000 kilowatt-hours (kWh) in electricity. The project also eliminated problems that led to excessive maintenance costs and resulted in annual maintenance savings of \$10,000 (U.S. DOE 2002h).

In another example, Neenah Paper (Wisconsin) reduced energy use in its wastewater treatment plant by installing ASDs on the plant's aeration blowers as part of a treatment plant optimization project. The project led to annual energy savings of 1.47 GWh and annual energy cost savings of approximately \$95,000. The estimated simple payback time was under two years, after accounting for an energy efficiency financial incentive from its utility provider (Wroblewski 2009).

**Impeller trimming.** Impeller trimming refers to the process of reducing an impeller's diameter via machining, which will reduce the energy added by the pump to the system fluid. According to the U.S. DOE (2006e), one should consider trimming an impeller when any of the following conditions occur:

- Many system bypass valves are open, indicating that excess flow is available to system equipment.
- Excessive throttling is needed to control flow through the system or process.
- High levels of noise or vibration indicate excessive flow.
- A pump is operating far from its design point.

Trimming an impeller is slightly less effective than buying a smaller impeller from the pump manufacturer, but can be useful when an impeller at the next smaller available size would be too small for the given pump load. The energy savings associated with impeller trimming are dependent upon pump power, system flow, and system head, but are roughly proportional to the cube of the diameter reduction (U.S. DOE 2006e). An additional benefit of impeller trimming is a decrease in pump operating and maintenance costs. Care has to be taken when an impeller is trimmed or the speed is changed so that the new operating point does not end up in an area where the pump efficiency is low.

At the Augusta Newsprint mill in Augusta, Georgia, engineers reduced excess pressure being developed in the mill's de-inking modules by purchasing size-optimized pump impellers.

Previously, a mill-wide evaluation of inefficient pumping applications found that the impellers used in the de-inking module fan inlet pumps were not the optimum size. The impellers produced excess pressure that required hand and control valves to dissipate, leading to significant operating inefficiencies. After installation of the smaller impellers, the mill realized annual cost and electricity savings of about \$69,550, and 2,080 MWh, respectively. The total cost of the project was about \$12,000, resulting in a payback period of just two months (U.S.-DOE 2002g).

**Avoiding throttling valves.** Throttling valves and bypass loops are indications of oversized pumps as well as the inability of the pump system design to accommodate load variations efficiently, and should always be avoided (Tutterow et al. 2000). Surveys in the Finnish paper industry found that the average pumping efficiency was 40%, with 10% of the pumps running below 10% efficiency. The large inefficiencies were mainly due to throttling of pumps. In one recent mill (constructed in 2000) the average valve opening was found to be 24%, with the largest valve opening 46% (Ericsson 2008). The reasons for the throttling were generally an over-sized pump because they were designed for maximum capacity (often for the future), process variations, changed process design, safe calculations, and the “engineering factor.” Pump demand reduction, controls, impeller trimming, and multiple pump strategies (all previously discussed in this section) should always be more energy-efficient flow management strategies than throttling valves. For example, several industrial case studies from the IAC database suggest that replacement of throttling systems with ASDs will save energy with a payback period of only 0.5-1.8 years (IAC 2008).

A Swedish pulp mill discovered that at 850 kWh per ton of pulp, its energy consumption was far too high. Variable speed control of pumps, changing oversized pump motors to better match required loads, and making changes in pipe layouts reduced the pulp mill’s energy consumption to 635 kWh per ton pulp. The payback period of the investment was about 12 months. Other reported benefits were improved pulp process control and less maintenance by soft starting (ABB 2007).

**Replacement of belt drives.** Most pumps are directly driven. However, inventory data suggests 4% of pumps have V-belt drives (Xenergy 1998). Standard V-belts tend to stretch, slip, bend and compress, which lead to a loss of efficiency. Replacing standard V-belts with cog belts can save energy and money, even as a retrofit. It is even better to replace the pump by a direct driven system, resulting in increased savings of up to 8% and payback periods as short as 6 months (Studebaker 2007).

**Proper pipe sizing.** Pipes that are too small for the required flow velocity can significantly increase the amount of energy required for pumping, in much the same way that drinking a beverage through a small straw requires a greater amount of suction. Where possible, pipe diameters can be increased to reduce pumping energy requirements, but the energy savings due to increased pipe diameters must be balanced with increased costs for piping system components. A life-cycle costing approach is recommended to ensure positive economic benefits when energy savings, increased material costs, and installation costs are considered. Increasing pipe diameters will likely only be cost effective during greater pump system

retrofit projects. The U.S. DOE estimates typical industrial energy savings in the 5% to 20% range for this measure (U.S. DOE 2002a).

**Precision castings, surface coatings or polishing.** The use of castings, coatings, or polishing reduces pump surface roughness that in turn, increases energy efficiency. It may also help maintain efficiency over time. This measure is more effective on smaller pumps. One case study in the steel industry analyzed the investment in surface coating on the mill supply pumps (350 kW pumps). They determined that the additional cost of coating, \$1200, would be paid back in 5 months by energy savings of \$2700 (or 36 MWh, 2%) per year (Hydraulic Institute and Europump 2001). Energy savings for coating pump surfaces are estimated to be 2 to 3% over uncoated pumps (Best Practice Programme 1998).

**Sealings.** Seal failure accounts for up to 70% of pump failures in many applications (Hydraulic Institute and Europump 2001). The sealing arrangements on pumps will contribute to the power absorbed. Often the use of gas barrier seals, balanced seals, and non-contacting labyrinth seals decrease seal losses.

**Curtailing leakage through clearance reduction.** Internal leakage losses are a result of differential pressure across the clearance between the impeller suction and pressure sides. The larger the clearance, the greater is the internal leakage causing inefficiencies. The normal clearance in new pumps ranges from 0.35 to 1.0 mm (0.014 to 0.04 in.) (Hydraulic Institute and Europump 2001). With wider clearances, the leakage increases almost linearly with the clearance. For example, a clearance of 5 mm (0.2 in.) decreases the efficiency by 7 to 15% in closed impellers and by 10 to 22% in semi-open impellers. Abrasive liquids and slurries, even rainwater, can affect the pump efficiency. Using very hard construction materials (such as high chromium steel) can reduce the wear rate.



## 11 Fan Systems

Figure 4.3 indicated that fan systems are responsible for roughly 20% of all motor-driven system electricity consumption in the U.S. pulp and paper industry. Typical applications of fans in a pulp and paper mill include boiler and furnace applications and facility ventilation.

As in other motor applications, considerable opportunities exist to upgrade the performance and improve the energy efficiency of fan systems. For fans in particular, concern about failure or underperformance have led to many fans being oversized for their particular application (U.S. DOE 2003c). Oversized fans do not operate at optimal efficiency and therefore waste energy. However, the efficiencies of fan systems vary considerably across impeller types.

The U.S. DOE estimates that basic fan system improvements could save the U.S. pulp and paper industry around 1,100 GWh of electricity per year (U.S. DOE 2002a). A few common energy efficiency measures for industrial fans and fan systems are discussed below.<sup>27</sup> Additionally, a number of measures that are applicable to motors (Chapter 9) are also applicable to fan systems.

**Maintenance.** As for most energy using systems, a proper maintenance program for fans can improve system performance, reduce downtime, minimize repair costs, and increase system reliability. The U.S. DOE recommends establishing a regular maintenance program for fan systems, with intervals based on manufacturer recommendations and experience with fans in similar applications (U.S. DOE 2003c). Additionally, the U.S. DOE recommends the following important elements of an effective fan system maintenance program (U.S. DOE 2003c):

- *Belt inspection.* In belt-driven fans, belts are usually the most maintenance-intensive part of the fan assembly. Belts wear over time and can lose tension, which reduces their ability to transmit power efficiently. Belt inspection and tightening should be performed on a regular basis, especially for large fans because the potential size of the power loss.
- *Fan cleaning.* Many fans experience a significant loss in energy efficiency due to the buildup of contaminants on blade surfaces. Such build up can create imbalance problems that can reduce performance and contribute to premature wear of system components. Fans that operate in particulate-laden or high-moisture airstreams are particularly vulnerable and are therefore recommended to be cleaned regularly.

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<sup>27</sup> The U.S. DOE's Industrial Technologies Program provides a variety of resources for improving the efficiency of industrial fan systems, which can be consulted for more detailed information on many of the measures presented in this chapter. The U.S. DOE's *Improving Fan System Performance: A Sourcebook for Industry* is a particularly helpful resource (U.S. DOE 2003b). For a collection of tips, tools, and industrial case studies on industrial motor system efficiency, visit the Industrial Technologies Program's *BestPractices* Motors, Pumps, and Fans website at: <http://www1.eere.energy.gov/industry/bestpractices/systems.html>.

- *Leak inspection and repair.* Leakage in a fan duct system will decrease the amount of air that is delivered to the desired end use, which can significantly reduce the efficiency of the fan system. Ductwork should be inspected on a regular basis and leaks should be repaired as soon as possible. In systems with inaccessible ductwork, the use of temporary pressurization equipment can determine if the integrity of the system is adequate.
- *Bearing lubrication.* Worn bearings can lead to premature fan failure, as well as create unsatisfactory noise levels. Fan bearings should be monitored and lubricated frequently based on manufacturer recommendations.
- *Motor replacement.* Eventually, all fan motors will wear and will require repair or replacement. The decision to repair or replace a fan motor should be based on a life cycle costs analysis, as described in Chapter 9.

**Properly sized fans.** Conservative engineering practices often result in the installation of fans that exceed system requirements. Such oversized fans lead to higher capital costs, higher maintenance costs, and higher energy costs than fans that are properly sized for the job (U.S. DOE 2003c). However, other options may be more cost effective than replacing an oversized fan with a smaller fan (U.S. DOE 2002a). Other options include (U.S. DOE 2003c):

- Decreasing fan speed using different motor and fan sheave sizes (may require downsizing the motor)
- Installing an ASD or multiple-speed motor (see below)
- Using an axial fan with controllable pitch blades

At a Louisiana Pacific Corporation board mill in Tomahawk, Wisconsin, a fan system optimization project was pursued to resize and replace fans to better meet airflow and pressure requirements. The previous system was originally relocated from Colorado, where thinner high elevation air required greater fan speed. This system had to be modified with dampers on the combustion air, dryer, and scrubber fans when it was installed in Wisconsin. The new fan system led to electricity savings of about 2.5 million kWh per year, with annual cost savings of around \$85,000. With investment costs of \$44,000, the payback period was only around 6 months (U.S. DOE 1999b).

**Adjustable speed drives (ASDs) and improved controls.** Significant energy savings can be achieved by installing adjustable speed drives on fans. Savings may vary between 14% and 49% when retrofitting fans with ASDs (U.S. DOE 2002a).

In an example from the chemicals industry, an energy-efficiency assessment of the Anaheim, California site of Neville Chemical Company (U.S. DOE 2003d) found that fan motors in a cooling tower ran continuously throughout the year despite the variable heat load resulting from the batch operations on the site. Installing variable speed drives on these fan motors (costs \$9,103) could save 69.7 MWh of electricity per year with a payback time of 1.7 year.

A similar project at the Knoxville, Tennessee, plant of Rohm and Haas would reduce the electric load of the cooling tower by approximately 50% (U.S. DOE 2003e).

Adjustable speed drives can also help to reduce energy consumption in combustion air fans in steam boilers. At a fertilizer plant of PCS Nitrogen Inc. in Augusta, Georgia, the installation of a variable speed fan eliminated the generation of excess steam during low load periods, resulting in annual energy savings of 76,400 MMBtu annually (cost savings of \$420,000) with a payback time of only 2 months (U.S. DOE 2005c).

**High efficiency belts (cog belts).** Belts make up a variable, but significant portion of the fan system in many plants. It is estimated that about half of the fan systems use standard V-belts, and about two-thirds of these could be replaced by more efficient cog belts (U.S. DOE 2002a). Standard V-belts tend to stretch, slip, bend and compress, which lead to a loss of efficiency. Replacing standard V-belts with cog belts can save energy and money, even as a retrofit. Cog belts run cooler, last longer, require less maintenance and have an efficiency that is about 2% higher than standard V-belts. Typical payback periods will vary from less than one year to three years.

**Duct leakage repair.** Duct leakage can waste significant amounts of energy in fan and ventilation systems. Measures for reducing duct leakage include installing duct insulation and performing regular duct inspection and maintenance, including ongoing leak detection and repair. For example, according to studies by Lawrence Berkeley National Laboratory, repairing duct leaks in industrial and commercial spaces could reduce HVAC energy consumption by up to 30% (Galitsky et al. 2005a).

Because system leakage can have a significant impact on fan system operating costs, the U.S. DOE recommends considering the type of duct, the tightness and quality of the fittings, joints assembly techniques, and the sealing requirements for duct installation as part of the fan system design process as proactive leak prevention measures (U.S. DOE 2003c).

## 12 Compressed Air Systems

Compressed air generally represents one of the most inefficient uses of energy in U.S. industry due to poor system efficiency. Typically, the efficiency of a compressed air system—from compressed air generation to end use—is only around 10% (U.S. DOE and CAC 2003). Because of this inefficiency, if compressed air is used, it should be of minimum quantity for the shortest possible time; it should also be constantly monitored and weighed against potential alternatives.

Many opportunities to reduce energy consumption in compressed air systems are not prohibitively expensive; payback periods for some options can be extremely short. Energy savings from compressed air system improvements can range from 20% to 50% of total system electricity consumption (McKane et al. 1999). A properly managed compressed air system can also reduce maintenance, decrease downtime, increase production throughput, and improve product quality.

Compressed air systems consist of a supply side, which includes compressors and air treatment, and a demand side, which includes distribution and storage systems and end-use equipment. According to the U.S. DOE, a properly managed supply side will result in clean, dry, stable air being delivered at the appropriate pressure in a dependable, cost-effective manner. A properly managed demand side minimizes waste air and uses compressed air for appropriate applications (U.S. DOE 2003c).

Common energy efficiency measures for industrial compressed air systems are discussed below.<sup>28</sup> Additionally, a number of measures that are applicable to motors (Chapter 9) are also applicable to compressed air systems.

**System improvements.** Adding additional compressors should be considered only after a complete system evaluation. In many cases, compressed air system efficiency can be managed and reconfigured to operate more efficiently without purchasing additional compressors. System improvements utilize many of the energy efficiency measures for compressors discussed below. Compressed air system service providers offer integrated services both for system assessments and for ongoing system maintenance needs, alleviating the need to contact several separate firms. The Compressed Air Challenge<sup>®</sup> (<http://www.compressedairchallenge.org>) offers extensive training on the systems approach, technical publications, and free web-based guidance for selecting the right integrated service provider. Also provided are guidelines for walk-through evaluations, system assessments, and fully instrumented system audits (CAC 2002).

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<sup>28</sup> The U.S. DOE's Industrial Technologies Program provides a variety of resources for improving the efficiency of industrial compressed air systems, which can be consulted for more detailed information on many of the measures presented in this chapter. The U.S. DOE's *Improving Compressed Air System Performance: A Sourcebook for Industry* is a particularly helpful resource (U.S. DOE 2003e). For a collection of tips, tools, and industrial case studies on industrial pump efficiency, visit the Industrial Technologies Program's *BestPractices* Compressed Air website at: [http://www1.eere.energy.gov/industry/bestpractices/compressed\\_air.html](http://www1.eere.energy.gov/industry/bestpractices/compressed_air.html).

In an example of a successful system evaluation project, Weyerhaeuser implemented a project that increased the efficiency of the compressed air system at its Coburg, Oregon sawmill in 2000. In addition to improving the performance of the compressed air system, the U.S. DOE reports that this project yielded important energy savings and enabled the mill to increase production without reconfiguring or adding production equipment. The systems evaluation included preparing schematics to profile the system, and taking baseline measurements of flow rate, power usage, and pressure levels to assess the system's performance. The evaluation discovered a number of opportunities for improvement, including leaks in excess of 25% of the compressed air load, ineffective condensate traps, inefficient compressor controls, and a defective timing board in the dryer. A number of opportunities were pursued, including the installation of a new multiple compressor network control system. The project saved the mill \$55,000 in annual energy costs and 1.3 million kWh in annual electricity use (U.S. DOE 2004b). Moreover, using the Coburg's facility as a model, Weyerhaeuser commissioned similar evaluations and improvements of compressed air systems at six other company plants and mills. The aggregate savings in electricity and energy costs resulting from these additional projects were 6.8 million kWh and \$250,000, respectively (U.S. DOE 2004b).

**Maintenance.** Inadequate maintenance can lower compression efficiency and increase air leakage or pressure variability, as well as lead to increased operating temperatures, poor moisture control, and excessive contamination. Improved maintenance will reduce these problems and save energy. Proper maintenance includes the following (U.S. DOE and CAC 2003; Scales and McCulloch 2007):

- *Ongoing filter inspection and maintenance.* Blocked filters increase the pressure drop across the filter, which wastes system energy. By inspecting and periodically cleaning filters, filter pressure drops may be minimized. Fixing improperly operating filters will also prevent contaminants from entering into equipment, which can cause premature wear. Generally, when pressure drops exceed 2 psi to 3 psi, particulate and lubricant removal elements should be replaced. Regular filter cleaning and replacement has been projected to reduce compressed air system energy consumption by around 2% (Radgen and Blaustein 2001).
- *Keeping compressor motors properly lubricated and cleaned.* Poor motor cooling can increase motor temperature and winding resistance, shortening motor life and increasing energy consumption. Compressor lubricant should be changed every 2 to 18 months and periodically checked to make sure that it is at the proper level. In addition, proper compressor motor lubrication will reduce corrosion and degradation of the system.
- *Inspection of fans and water pumps* for peak performance.
- *Inspection of drain traps* to ensure that they are not stuck in either the open or closed position and are clean. Some users leave automatic condensate traps partially open at all times to allow for constant draining. This practice wastes substantial energy and should never be undertaken. Instead, simple pressure driven valves should be

employed. Malfunctioning traps should be cleaned and repaired instead of left open. Some auto drains, such as float switch or electronic drains, do not waste air. Inspecting and maintaining drains typically has a payback of less than two years (U.S. DOE 2004c).

- *Maintaining the coolers* on the compressor to ensure that the dryer gets the lowest possible inlet temperature (U.S. DOE and CAC 2003).
- *Compressor belt inspection.* Where belt-driven compressors are used, belts should be checked regularly for wear and adjusted. A good rule of thumb is to adjust them after every 400 hours of operation.
- *Replacing air lubricant separators* according to specifications or sooner. Rotary screw compressors generally start with their air lubricant separators having a 2 psi to 3 psi pressure drop at full load. When the pressure drop increases to 10 psi, the separator should be changed (U.S. DOE and CAC 2003).
- *Checking water-cooling systems* regularly for water quality (pH and total dissolved solids), flow, and temperature. Water-cooling system filters and heat exchangers should be cleaned and replaced per the manufacturer's specifications.
- *Minimizing compressed air leak throughout the systems.*
- Applications requiring compressed air should be *checked for excessive pressure, duration, or volume.* Applications not requiring maximum system pressure should be regulated, either by production line sectioning or by pressure regulators on the equipment itself. Using more pressure than required wastes energy and can also result in shorter equipment life and higher maintenance costs. Case studies have demonstrated that the payback period for this measure can be shorter than half a year (IAC 2008).

**Monitoring.** In addition to proper maintenance, a continuous monitoring system can save significant energy and operating costs in compressed air systems. Effective monitoring systems typically include the following (CADET 1997):

- Pressure gauges on each receiver or main branch line and differential gauges across dryers, filters, etc.
- Temperature gauges across the compressor and its cooling system to detect fouling and blockages.
- Flow meters to measure the quantity of air used.
- Dew point temperature gauges to monitor the effectiveness of air dryers.
- Kilowatt-hour meters and hours run meters on the compressor drive.

- Checking of compressed air distribution systems after equipment has been reconfigured to be sure that no air is flowing to unused equipment or to obsolete parts of the compressed air distribution system.
- Checking for flow restrictions of any type in a system, such as an obstruction or roughness, which can unnecessarily raise system operating pressures. As a rule of thumb, every 2 psi pressure rise resulting from resistance to flow can increase compressor energy use by 1% (U.S. DOE and CAC 2003). The highest pressure drops are usually found at the points of use, including undersized or leaking hoses, tubes, disconnects, filters, regulators, valves, nozzles and lubricators (demand side), as well as air/lubricant separators, after-coolers, moisture separators, dryers and filters.
- Checking for compressed air use outside production hours.

**Leak reduction.** Air leaks can be a significant source of wasted energy. A typical industrial facility that has not been well maintained will likely have a leak rate ranging from 20% to 30% of total compressed air production capacity (U.S. DOE and CAC 2003). Overall, a 20% reduction of annual energy consumption in compressed air systems is projected for fixing leaks (Radgen and Blaustein 2001).

The magnitude of the energy loss associated with a leak varies with the size of the hole in the pipes or equipment. A compressor operating 2,500 hours per year at 87 psi with a leak diameter of 0.02 inches (½ mm) is estimated to lose 250 kWh per year; 0.04 inches (1 mm) to lose 1,100 kWh per year; 0.08 inches (2 mm) to lose 4,500 kWh per year; and 0.16 in. (4 mm) to lose 11,250 kWh per year (CADDET 1997). Several pulp and paper industry case studies suggest that the payback period for leak reduction efforts is generally shorter than seven months (IAC 2008).

In addition to increased energy consumption, leaks can make air-powered equipment less efficient, shorten equipment life, and lead to additional maintenance costs and increased unscheduled downtime. Leaks also cause an increase in compressor energy and maintenance costs.

The most common areas for leaks are couplings, hoses, tubes, fittings, pressure regulators, open condensate traps and shut-off valves, pipe joints, disconnects, and thread sealants. The best way to detect leaks is to use an ultrasonic acoustic detector, which can recognize the high frequency hissing sounds associated with air leaks. Leak detection and repair programs should be ongoing efforts.

In early 2001, the Augusta Newsprint Company consolidated two compressed air systems at its facility in Augusta, Georgia. The project resulted in a more streamlined system, added storage capacity, backflow prevention, and the elimination of unused equipment. Additionally, a number of leaks were discovered and fixed. The project resulted in energy savings of more than 1.8 million kWh per year. Leak elimination contributed to more than 40% of the expected savings in energy costs (U.S. DOE 2002i).

**Turning off unnecessary compressed air.** Equipment that is no longer using compressed air should have the air turned off completely. This can be done using a simple solenoid valve. Compressed air distribution systems should be checked when equipment has been reconfigured to ensure that no air is flowing to unused equipment or to obsolete parts of the compressed air distribution system.

**Modification of system in lieu of increased pressure.** For individual applications that require a higher pressure, instead of raising the operating pressure of the whole system, special equipment modifications should be considered, such as employing a booster, increasing a cylinder bore, changing gear ratios, or changing operation to off peak hours.

**Replacement of compressed air by alternative sources.** Many operations can be accomplished more economically and efficiently using energy sources other than compressed air (U.S. DOE 2004d, 2004e). Various options exist to replace compressed air use, including:

- Cooling electrical cabinets: air conditioning fans should be used instead of using compressed air vortex tubes.
- Flowing high-pressure air past an orifice to create a vacuum: a vacuum pump system should be applied instead of compressed air venturi methods.
- Cooling, aspirating, agitating, mixing, or package inflating: use blowers instead of compressed air.
- Cleaning parts or removing debris: brushes, blowers, or vacuum pump systems should be used instead of compressed air.
- Moving parts: blowers, electric actuators, or hydraulics should be used instead of compressed air.
- Tools or actuators: electric motors should be considered because they are more efficient than using compressed air (Howe and Scales 1995). However, it has been reported that motors can have less precision, shorter lives, and lack safety compared to compressed air. In these cases, using compressed air may be a better choice.

Based on numerous industrial case studies, the average payback period for replacing compressed air with other applications is estimated at 11 months (IAC 2008).

**Improved load management.** Because of the large amount of energy consumed by compressors, whether in full operation or not, partial load operation should be avoided. For example, unloaded rotary screw compressors still consume 15% to 35% of full-load power while delivering no useful work (U.S. DOE and CAC 2003).

Air receivers can be employed near high demand areas to provide a supply buffer to meet short-term demand spikes that can exceed normal compressor capacity. In this way, the



number of required online compressors may be reduced. Multi-stage compressors theoretically operate more efficiently than single-stage compressors. Multi-stage compressors save energy by cooling the air between stages, reducing the volume and work required to compress the air. Replacing single-stage compressors with two-stage compressors typically provides a payback period of two years or less (Ingersoll-Rand 2001). Using multiple smaller compressors instead of one large compressor can save energy as well. Large compressors consume more electricity when they are unloaded than do multiple smaller compressors with similar overall capacity. An analysis of U.S. case studies shows an average payback period for optimally sizing compressors of about 1.2 years (IAC 2008).

In June 2004, the Canandaigua Wine Company upgraded the compressed air system at its winery in Lodi, California. Before the project began, the winery was served by two 125 hp rotary screw compressors that operated at full load only during the 3-month fall grape crushing season. During the rest of the year, however, the compressors were operated at part-load, which wasted energy. The company opted to install a 75 hp variable-speed compressor, which could be used to satisfy facility demand during the off-season while also providing supplemental power to the two 125 hp units during the fall crush season. Additionally, the company installed a new compressor control system, additional storage, and started a leak reduction campaign. The total energy savings attributable to the upgrade were estimated at 218,000 kWh per year, saving the company \$27,000 annually (U.S. DOE 2005d). The simple payback period was estimated at 1.2 years.

**Pressure drop minimization.** An excessive pressure drop will result in poor system performance and excessive energy consumption. Flow restrictions of any type in a system, such as an obstruction or roughness, results in higher operating pressures than is truly needed. Resistance to flow increases the drive energy on positive displacement compressors by 1% of connected power for each 2 psi of differential (U.S. DOE and CAC 2003). The highest pressure drops are usually found at the points of use, including undersized or leaking hoses, tubes, disconnects, filters, regulators, valves, nozzles, and lubricators (demand side), as well as air/lubricant separators on lubricated rotary compressors and after-coolers, moisture separators, dryers, and filters (supply side).

Minimizing pressure drop requires a systems approach in design and maintenance. Air treatment components should be selected with the lowest possible pressure drop at specified maximum operating conditions and best performance. Manufacturers' recommendations for maintenance should be followed, particularly in air filtering and drying equipment, which can have damaging moisture effects like pipe corrosion. Finally, the distance the air travels through the distribution system should be minimized. Audits of U.S. pulp and paper mills found that the payback period is typically shorter than one year for this measure (IAC 2008).

**Inlet air temperature reduction.** If airflow is kept constant, reducing the inlet air temperature reduces the energy used by the compressor. In many plants, it is possible to reduce the inlet air temperature to the compressor by taking suction from outside the building. As a rule of thumb, each temperature reduction of 5°F (3°C) will save 1% compressor energy (CADDET 1997; Parekh 2000). A payback period of two to five years has been reported for importing fresh air (CADDET 1997). In addition to energy savings,

compressor capacity is increased when cold air from outside is used. Industrial case studies have found an average payback period for importing outside air of less than 1.7 years (IAC 2008), but costs can vary significantly depending on facility layout.

**Controls.** The primary objectives of compressor control strategies are to shut off unneeded compressors and to delay bringing on additional compressors until needed. Energy savings for sophisticated compressor controls have been reported at around 12% annually (Radgen and Blaustein 2001). An excellent review of compressor controls can be found in Compressed Air Challenge® *Best Practices for Compressed Air Systems* (Second Edition) (Scales and McCulloch 2007). Common control strategies for compressed air systems include:

- *Start/stop (on/off) controls*, in which the compressor motor is turned on or off in response to the discharge pressure of the machine. Start/stop controls can be used for applications with very low duty cycles and are applicable to reciprocating or rotary screw compressors. The typical payback for start/stop controls is one to two years (CADDET 1997).
- *Load/unload controls*, or constant speed controls, which allow the motor to run continuously but unloads the compressor when the discharge pressure is adequate. In most cases, unloaded rotary screw compressors still consume 15% to 35% of full-load power while delivering no useful work (U.S. DOE and CAC 2003). Hence, load/unload controls can be inefficient.
- *Modulating or throttling controls*, which allow the output of a compressor to be varied to meet flow requirements by closing down the inlet valve and restricting inlet air to the compressor. Throttling controls are applied to centrifugal and rotary screw compressors.
- *Single master sequencing system controls*, which take individual compressor capacities on-line and off-line in response to monitored system pressure demand and shut down any compressors running unnecessarily. System controls for multiple compressors typically offer a higher efficiency than individual compressor controls.
- *Multi-master controls*, which are the latest technology in compressed air system control. Multi-master controls are capable of handling four or more compressors and provide both individual compressor control and system regulation by means of a network of individual controllers (Martin et al. 2000). The controllers share information, allowing the system to respond more quickly and accurately to demand changes. One controller acts as the lead, regulating the whole operation. This strategy allows each compressor to function at a level that produces the most efficient overall operation. The result is a highly controlled system pressure that can be reduced close to the minimum level required (U.S. DOE and CAC 2003). According to Nadel et al. (2002), such advanced compressor controls are expected to deliver energy savings of about 3.5% where applied.

In addition to energy savings, the application of controls can sometimes eliminate the need for some existing compressors, allowing extra compressors to be sold or kept for backup. Alternatively, capacity can be expanded without the purchase of additional compressors. Reduced operating pressures will also help reduce system maintenance requirements (U.S. DOE and CAC 2003).

**Properly sized pipe diameters.** Increasing pipe diameters to the greatest size that is feasible and economical for a compressed air system can help to minimize pressure losses and leaks, which reduces system operating pressures and leads to energy savings. Increasing pipe diameters typically reduces compressed air system energy consumption by 3% (Radgen and Blaustein 2001). Further savings can be realized by ensuring other system components (e.g., filters, fittings, and hoses) are properly sized.

**Heat recovery.** As much as 90% of the electrical energy used by an industrial air compressor is converted into heat. In many cases, a heat recovery unit can recover 50% to 90% of this available thermal energy and apply it to space heating, process heating, water heating, make-up air heating, boiler make-up water preheating, and heat pump applications (Parekh 2000). It has been estimated that approximately 50,000 Btu/hour of recoverable heat is available for each 100 cfm of compressor capacity (U.S. DOE and CAC 2003).

Payback periods are typically less than one year (Galitsky et al. 2005a). For example, a plant-wide assessment at an Appleton Paper mill in West Carrollton, Ohio, estimated that investments to reclaim heat from air compressors would have a payback period of only 0.8 year (U.S. DOE 2002c).

Heat recovery for space heating is not as common with water-cooled compressors because an extra stage of heat exchange is required and the temperature of the available heat is somewhat low. However, with large water-cooled compressors, recovery efficiencies of 50% to 60% are typical (U.S. DOE and CAC 2003).

**Natural gas engine-driven air compressors.** Gas engine-driven air compressors can replace electric compressors with some advantages and disadvantages. Gas engine-driven compressors are more expensive and can have higher maintenance costs, but may have lower overall operating costs depending on the relative costs of electricity and gas. Variable-speed capability is standard for gas-fired compressors, offering a high efficiency over a wide range of loads. Heat can be recovered from the engine jacket and exhaust system. However, gas engine-driven compressors have some drawbacks: they need more maintenance, have a shorter useful life, and sustain a greater likelihood of downtime. According to Galitsky et al. (2005a), gas engine-driven compressors currently account for less than 1% of the total air compressor market.

Ultra Creative Corporation, a U.S. manufacturer of specialty plastic bags, installed gas engine-driven compressors in its plant in Brooklyn, New York. The initial costs were \$85,000 each for two 220 hp units and \$65,000 for one 95 hp unit. The company reported savings of \$9,000 in monthly utilities (averaging \$108,000 annually) (Audin 1996).

Similarly, Nestlé Canada found that its gas engine-driven air compressor system was a cost effective option when it was operated properly. The company's projected payback period was estimated as low as 2.6 years with a 75% efficient heat recovery system, and as high as 4.2 years without heat recovery (Audin 1996).

## 13 Lighting

Facility lighting accounted for around 4% of the total electricity use by the U.S. pulp and paper industry in 2002 (U.S. DOE 2007a). Although lighting is often a small component of mill energy use, efficiency improvements to lighting systems are often easy changes that offer quick payback periods. Thus, lighting efficiency improvements are often an attractive area of “low hanging fruit” within many industrial energy management programs.

The lighting efficiency measures discussed below are applicable to most workspaces within a typical pulp and paper facility, including manufacturing areas, offices, laboratory spaces, and warehouses.

**Turning off lights in unoccupied areas.** An easy and effective measure is to encourage personnel to turn off lights in unoccupied building spaces. An energy management program that aims to improve the awareness of personnel with regard to energy use can help staff get in the habit of switching off lights and other equipment when not in use.

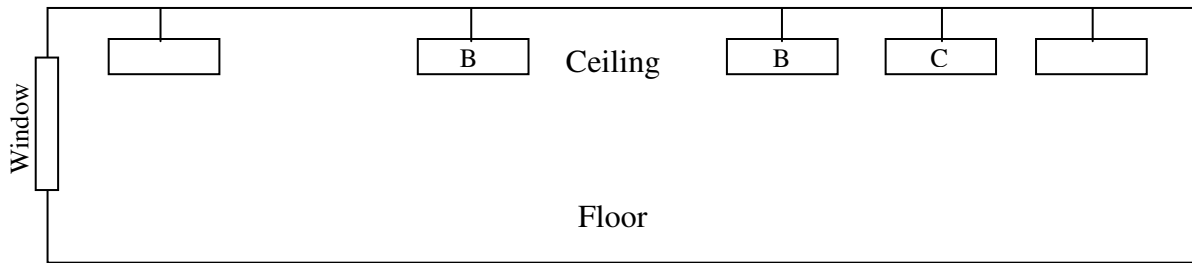
**Lighting controls.** Lights can be shut off during non-working hours by automatic controls, such as occupancy sensors that turn off lights when a space becomes unoccupied. Occupancy sensors can save up to 10% to 20% of facility lighting energy use (Galitsky et al. 2005a). Numerous case studies throughout the United States suggest that the average payback period for occupancy sensors is approximately 1 year (IAC 2008).

In a case study from the pharmaceutical industry, at the Merck office and storage building in Rahway, New Jersey, lighting panels were programmed to turn off automatically during expected periods of building non-use (override switches in entrance hallways allowed lights to be turned on manually during these times, if needed). Annual savings amounted to 1,310 MMBtu per year, which corresponded to avoided energy-related carbon dioxide (CO<sub>2</sub>) emissions of nearly 260 tons per year (Merck 2005).

Manual controls can be used in conjunction with automatic controls to save additional energy in smaller areas. One of the easiest measures is to install switches to allow occupants to control lights. Other lighting controls include daylight controls for indoor and outdoor lights, which adjust the intensity of electrical lighting based on the availability of daylight.

An example of energy efficient lighting control is illustrated by Figure 12.1, which depicts five rows of overhead lights in a workspace. During the brightest part of the day, ample daylight is provided by the window and thus only row C would need to be turned on. At times when daylight levels drop, all B rows would be turned on and row C would be turned off. Only at night or on very dark days would it be necessary to have both rows A and B turned on (Cayless and Marsden 1983). These methods can also be used as a control strategy on a retrofit by adapting the luminaries already present. (For example, turning on the lighting in rows farthest away from the windows during the brightest parts of the day, then turning on additional rows as needed later.)

**Figure 12.1 Lighting placement and controls.**



**Exit signs.** Energy costs can be reduced by switching from incandescent lamps to light emitting diodes (LEDs) or radium strips in exit sign lighting. An incandescent exit sign uses about 40 W, while LED signs may use only about 4W to 8 W, reducing electricity use by 80% to 90%. A 1998 Lighting Research Center survey found that about 80% of exit signs being sold use LEDs (LRC 2001). The lifetime of an LED exit sign is about 10 years, compared to 1 year for incandescent signs, which can reduce exit sign maintenance costs considerably. In addition to exit signs, LEDs are increasingly being used for path marking and emergency way finding systems. Their long life and cool operation allows them to be embedded in plastic materials, which makes them well suited for such applications (LRC 2001).

New LED exit signs are inexpensive, with prices typically starting at around \$20. The U.S. EPA's ENERGY STAR program website (<http://www.energystar.gov>) provides a list of suppliers of LED exit signs.

Tritium exit signs are an alternative to LED exit signs. Tritium signs are self-luminous and thus do not require an external power supply. The advertised lifetime of these signs is around 10 years and prices typically start at around \$150 per sign.

**Electronic ballasts.** A ballast regulates the amount of electricity required to start a lighting fixture and maintain a steady output of light. Electronic ballasts can require 12% to 30% less power than their magnetic predecessors (Cook 1998; Galitsky et al. 2005a). New electronic ballasts have smooth and silent dimming capabilities, in addition to longer lives (up to 50% longer), faster run-up times, and cooler operation than magnetic ballasts (Eley et al. 1993; Cook 1998). New electronic ballasts also have automatic switch-off capabilities for faulty or end-of-life lamps.

**Replacement of T-12 tubes with T-8 tubes.** In many industrial facilities, it is common to find T-12 lighting tubes in use. T-12 lighting tubes are 12/8 inches in diameter (the "T-" designation refers to a tube's diameter in terms of 1/8 inch increments). T-12 tubes consume significant amounts of electricity, and also have extremely poor efficacy, lamp life, lumen depreciation, and color rendering index. Because of this, the maintenance and energy costs of T-12 tubes are high. T-8 lighting tubes have around twice the efficacy of T-12 tubes, and can

last up to 60% longer, which leads to savings in maintenance costs. Typical energy savings from the replacement of a T-12 lamp by a T-8 lamp are around 30% (Galitsky et al. 2005a).

**Replacement of mercury lights.** Where color rendition is critical, metal halide lamps can replace mercury or fluorescent lamps with energy savings of up to 50%. Where color rendition is not critical, high-pressure sodium lamps offer energy savings of 50% to 60% compared to mercury lamps (Price and Ross 1989).

**High-intensity discharge (HID) voltage reduction.** Reducing lighting system voltage can also save energy. A Toyota production facility installed reduced-voltage HID lights and realized a 30% reduction in lighting energy consumption (Galitsky et al. 2005a). Commercial products are available that attach to a central panel switch (controllable by computer) and constrict the flow of electricity to lighting fixtures, thereby reducing voltage and saving energy, with an imperceptible loss of light. Voltage controllers work with both HID and fluorescent lighting systems and are available from multiple vendors.

**High-intensity fluorescent lights.** Traditional HID lighting can be replaced with high-intensity fluorescent lighting systems, which incorporate high-efficiency fluorescent lamps, electronic ballasts, and high-efficacy fixtures that maximize output to work areas. These systems have lower energy consumption, lower lumen depreciation over the lifetime of the lamp, better dimming options, faster startup and re-strike capabilities, better color rendition, higher pupil lumens ratings, and less glare than traditional HID systems (Martin et al. 2000).

**Daylighting.** Daylighting involves the efficient use of natural light in order to minimize the need for artificial lighting in buildings. Increasing levels of daylight within rooms can reduce electrical lighting loads by up to 70% (CADDET 2001; IEA 2000). Unlike conventional skylights, an efficient daylighting system may provide evenly dispersed light without creating heat gains, which can reduce the need for cooling compared to skylights. Daylighting differs from other energy efficiency measures because its features are integral to the architecture of a building; therefore, it is applied primarily to new buildings and incorporated at the design stage. However, existing buildings can sometimes be cost-effectively refitted with daylighting systems.

Daylighting can be combined with lighting controls to maximize its benefits. Because of its variability, daylighting is almost always combined with artificial lighting to provide the necessary illumination on cloudy days or after dark (see also Figure 11.1). Daylighting technologies include properly placed and shaded windows, atria, clerestories, light shelves, and light ducts. Clerestories, light shelves, and light ducts can accommodate various angles of the sun and redirect daylight using walls or reflectors.

More information on daylighting can be found at the website of the Daylighting Collaborative led by the Energy Center of Wisconsin (<http://www.daylighting.org/>).

## 14 Energy Efficiency Measures for Raw Material Preparation

The processes associated with raw materials preparation are estimated to consume roughly 10% of the electricity use and 3% of the steam use in U.S. pulp manufacturing operations (see Figure 4.4) (Jacobs and IPST 2006). This chapter presents some possible measures for reducing this energy use.

**Cradle debarker.** The cradle debarker is designed to remove bark from de-limbed logs in a manner that reduces debarking energy use by up to 33% (U.S. DOE 2002j). According to the U.S. DOE, a cradle debarker works in the following manner: Logs are loaded into a long trough that contains a series of horizontal and vertical conveyor chains, which are oriented at a slight angle to the path of the logs. The chains lift and drop the logs as they move along the trough; this action loosens and removes bark via compressive and shear forces that are generated between the logs in the trough (U.S. DOE 2002j). Additional reported benefits include less damage to logs leading to a greater wood recovery rate, decreased transportation costs through elimination of off-site debarking, and greater process control. The U.S. DOE reports that the cradle debarker can save a mill \$30 per ton of wood in debarking costs (U.S. DOE 2007b).

**Replace pneumatic chip conveyors with belt conveyors.** Two common methods of transporting wood chips within a mill are pneumatic conveyors and mechanical (belt) conveyors. Of these, belt conveyors are typically far more energy efficient (Martin et al. 2000). An analysis by the National Council for Air and Steam Improvement (NCASI 2001) illustrates the possible savings of replacing pneumatic conveyors with belt conveyors at a typical mill. For a mill operating at 1,000 tons per day, it was assumed that an 18.2 kWh/ton pneumatic conveyor from the chip pile to screening could be replaced by a 1 kWh/ton belt conveyor. The resulting energy savings were estimated at 17,200 kWh per day, or \$210,000 per year in electricity costs (NCASI 2001). Belt conveyors can also reduce fine and chip pin losses, which can improve yield by about 1.6% (Martin et al. 2000). However, installation and maintenance costs associated with belt conveyors can be significant.

**Use secondary heat instead of steam in debarking.** In some parts of the country, logs can freeze during the winter season and require defrosting prior to debarking operations. Defrosting is commonly done by steam thawing, hot water sprinklers, or hot ponds (NCASI 2001). When feasible, hot water and/or steam for use in defrosting can be generated from waste heat recovered from other sources in the mill. According to an analysis by NCASI (2001), the typical steam use associated with defrosting (northern conditions) is around 0.5 MMBtu per air dried ton (ADT) of pulp. Replacing this steam use by recovered heat was estimated to save over \$150,000 per year in energy costs (NCASI 2001), although energy savings will vary based on boiler fuel type and costs. Capital investments were estimated at \$110,000, primarily for piping.

**Automatic chip handling and thickness screening.** Automated chip handling is based on the “first in, first out” inventory principle to maintain more consistent wood chip aging. Improved screening processes that allow for a more even size distribution of wood chips entering the digester will reduce steam consumption in both the digester and the evaporator



in chemical pulping (Elahi and Lowitt 1988). Combined, automated chip handling and thickness screening can result in reduced cooking energy, higher pulp yields, higher by-product yields, and less chip damage due to handling. Published estimates suggest that digester yield can be increased by around 5% to 10% (which is offset somewhat by raw material screened out as undersized), which can reduce raw materials input (which also reduced raw materials transportation requirements) and save hundreds of thousands of dollars in energy costs per year (Focus on Energy 2006a). It is estimated that the return on investment is about 15% to 20% for this measure.

**Bar-type chip screens.** The design of a bar screen is different from the majority of the installed disc and V-type screens in the United States. Due to the design, the life-time of a bar-screen is longer than that of conventional screens. Maintenance costs in bar screens are lower, and working energy consumed is minimal (Strakes 1995). Martin et al. (2000) estimate energy savings from bar-type screen installations at 0.33 MMBtu/ton chemical pulp, due to about 2% increase in yield. Operation and maintenance cost savings due to improved yield are estimated at \$0.70/ton pulp (Kincaid 1998). Capital costs required for new bar-type screens are approximately the same as for other screening equipment (EPA 1993).

**Chip conditioning.** Chip conditioners prepare chips for efficient delignification by making cracks along their grains, unlike chip slicers that fractionate chips (Henry, Strakes 1993). According to Martin et al. (2000), chip conditioning generates fewer fines, achieves an average reduction of 1.2% in rejects, and requires less maintenance than slicing equipment. Energy savings from replacing chip slicers with chip conditioners have been estimated at 0.19 MMBtu/ton chemical pulp, and savings in operations and maintenance costs from improved yield have been estimated at \$0.40/t chemical pulp (Kincaid 1998; Martin et al. 2000).

## 15 Energy Efficiency Measures for Chemical Pulping

As discussed in Chapter 3, the vast majority (85%) of U.S. wood pulp is produced by chemical pulping processes. Similarly, Chapter 4 showed that chemical (i.e., Kraft) pulping and its associated chemical recovery account for the vast majority of steam, electricity, and direct fuel used by the industry in the manufacture of pulp. Efficiency improvements to the chemical pulping process can therefore lead to significant energy savings across the industry. This chapter briefly discusses some of the most significant energy saving measures for Kraft pulping, bleaching, and chemical recovery.

### 15.1 Kraft Pulping

**Use of pulping aids to increase yields.** Advanced chemical pulping aids can be added to the pulping process to increase liquor penetration and promote more even cooking. This can increase pulp yields and lead to reduced energy consumption per ton of pulp, reduced raw material inputs, and improved productivity. The financial viability of this measure is typically determined by comparing the costs of chemicals to the projected fiber savings; some studies have suggested savings of around \$20 per ton of bleached pulp after the cost of chemicals have been considered (Focus on Energy 2006a). Anthraquinone compounds are commonly used as chemical pulping aids, but new alternatives are emerging.

For example, with help of U.S. DOE the application of the chemical ChemStone OAE-11 was investigated. Reportedly, this chemical can be applied at both hardwood and softwood pulps and also protects fine fibers from over processing (U.S. DOE 2008d). It was estimated that the reduction of cooking time can lead to energy savings of 125,000 Btu per ton of processed wood chips. Other reported benefits included an increase in yield of 2-5% per ton of wood, reductions in rejected pulp, less use of bleaching chemicals, and reductions of sulfur-based emissions. (U.S. DOE 2008d; Ronneberg and Jennings 2007).

Phosphonate is another emerging chemical pulping aid. Preliminary results of a U.S. DOE project suggested that adding phosphonate to Kraft cooking liquor increases lignin removal, improves yield and bleached brightness, and conserves pulp viscosity (U.S. DOE 2006g). Energy savings of phosphonate addition were estimated at 8-10%, and yield increases were estimated at 4-6% (U.S. DOE 2006f). Additional reported benefits were an expected reduction in pulping chemical use and a corresponding reduction in effluent.

**Optimize the dilution factor control.** Organic solids and spent cooking chemicals can be washed from the pulp with brownstock, resulting in a higher level of chemical recovery while minimizing dilution of black liquor. According to NCASI, optimizing the dilution factor control will lower the average amount of water that must be evaporated from weak black liquor, thereby reducing steam consumption in the evaporators (NCASI 2001). The dilution factor can be optimized by controlling shower water flow on the last washing stage to an optimum level that can be determined by considering the cost of steam, the cost of bleaching chemicals, the impact on effluent quality, and other process variables (NCASI 2001).

At an assessment of a Weyerhaeuser pulp and paper mill in Longview, Washington, a project was identified to improve digester washing and to reduce the dilution factor. It was estimated that these improvements would save 200 gallons of water per minute, and 310,000 MMBtu of natural gas annually (U.S. DOE 2004e). The projected annual cost savings associated with these measures was \$580,000.

**Continuous digester control systems.** Improving digester performance can significantly reduce production losses, operating costs, and negative environmental effects while increasing paper quantity and quality (U.S. DOE 2008d, 2007c). Control systems can optimize the process based on key mechanical, chemical, and thermal process parameters. For example, a computer model sponsored by the U.S. DOE allows for material, energy balance, and diffusion simulations to be calculated as various-origin chips pass through a continuous digester, which can help identify process improvements. The model's first commercial application in a Texas mill allowed the temperature to be reduced in part of the pulping process, thereby saving 1% of the process energy (U.S. DOE 2008d, 2007c).

**Batch digester modification.** For smaller mills, it may not be operationally efficient to switch to larger batch digesters in the digesting operation. Additionally, specialty mills or mills that need to be able to produce a variety of pulp types are less suited for continuous digesters. There are several approaches to reduce energy consumption in batch digesters, such as the use of indirect heating and cold blow (Martin et al. 2000).

In indirect heating, cooking liquor is withdrawn from the digester through a center pipe, pumped through an external heat exchanger, and returned into the digester at two separate locations in the vessel, thereby reducing direct steam loads (Martin et al. 2000). Energy savings are estimated to amount to 3 MMBtu/ton; however, there are some additional maintenance costs with this system including maintaining the heat exchangers (Elahi and Lowitt 1988).

In cold blow systems, hot spent pulping liquor is displaced from the digester contents using brownstock washer filtrate at the end of the cooking cycle. Heat is thereby recovered from the spent liquor for heating subsequent cooks, leading to reduced steam requirements for heating the digester contents (NCASI 2001). Recovered black liquor can be used for preheating and impregnating incoming wood chips or for the heating of other process inputs, such as white liquor or process water. An analysis by NCASI estimated that for a typical 1,000 ton per day mill, annual energy savings would be around \$2 million (NCASI 2001). However, capital costs for additional equipment (i.e., additional pumps and accumulators for the recovered black liquor) are quite high for this measure.

**Digester blow/flash heat recovery.** In the Kraft chemical pulping process, steam is produced when hot pulp and cooking liquor is reduced to atmospheric pressure at the end of the cooking cycle. In batch digesters, steam is typically stored as hot water in an accumulator tank. In continuous digesters, extracted black liquor flows to a tank where it is flashed (NCASI 2001). Recovered heat from these processes can be used in other facility applications, such as chip pre-steaming, facility water heating, or black liquor evaporation (NCASI 2001; Focus on Energy 2006a).

For black liquor evaporation, flash steam from batch digester blow (created by flashing from the hot water accumulator) or black liquor flash from a continuous digester can be used for thermal energy in a multi-stage evaporator. This thermal energy will offset the need for steam generated by a boiler for black liquor evaporation (NCASI 2001).

In chip steaming, the black liquor that is flashed in stages from continuous digesters can be used in two ways. Flash vapor from the first stage is normally used to heat the chips in the steaming vessel, while the flash vapor of the second stage can be used instead of live steam in the chip bin (NCASI 2001). Reportedly, the use of flash steam in the chip bin has been proven out at several North American mills; however, U.S. regulations state that the vent from the chip bin has to be collected and treated if flash steam is used for chip preheating (NCASI 2001).

A plant-wide energy audit of Georgia-Pacific's mill in Crossett, Arkansas, recommended improving blow heat recovery from the mill's two parallel batch digester lines. At the time of the audit, a cooling tower was used to remove excess heat from the blow steam accumulator and a steam heater was used to generate hot water for the bleach plant (U.S. DOE 2003a). The audit team recommended installing new heat exchangers and rerouting water lines such that the cooling tower and steam heater could be shut down. It was estimated that this project would save 940,000 MMBtu of fuel, 705,000 MMBtu of natural gas, and \$2,350,000 in costs each year with a payback period of around one year (U.S. DOE 2003a).

At the Weyerhaeuser pulp and paper mill in Longview, Washington, the proposed addition of a digester heat recovery system was expected to result in annual natural gas savings of 130,000 MMBtu, leading to \$280,000 per year in cost savings (U.S. DOE 2004f).

## 15.2 Bleaching

**Heat recovery from bleach plant effluents.** Bleach plant effluents can contain a large amount of heat, which will be wasted if the effluents are discharged without heat recovery. Heat exchangers can be installed to recover some of this heat for other beneficial uses around the mill, including hot water heating.

At Georgia-Pacific's mill in Crossett, Arkansas, an audit uncovered an opportunity for installing heat exchangers to recover heat from bleach plant effluent for the generation of hot water for the mill's paper machine. Estimated energy savings were 890,000 MMBtu per year, with annual cost savings of around \$2.4 million (U.S. DOE 2003a). With an estimated capital investment of \$1.6 million, the expected payback period was only 0.7 years (U.S. DOE 2003a).

**Improved brownstock washing.** Conventional brownstock washing technology consists of a series of three to four drum washers where a fiber mat under vacuum pressure is sprayed with water to dissolve solids. State-of-the-art washing systems replace the vacuum pressure

units with pressure diffusion or wash presses. These systems reportedly remove solids more efficiently; require less electric power and/or steam and less bleaching chemicals (Martin et al. 2000). In particular, wash presses have demonstrated improved efficiency and their adoption is becoming widespread in the industry. Published estimates suggest steam savings associated with state-of-the-art washing systems of around 9,500 Btu per ton of production, and electricity savings of around 12 kWh per ton of production (Martin et al. 2000).

**Chlorine dioxide (ClO<sub>2</sub>) heat exchange.** Solutions of ClO<sub>2</sub> are normally chilled to maximize ClO<sub>2</sub> concentration prior to use in the bleach plant. However, preheating of ClO<sub>2</sub> before it enters the mixer will reduce steam demand in the bleach plant, and is therefore an important energy conservation measure (NCASI 2001). Pre-heating can be accomplished using secondary heat sources by installing heat exchangers in the ClO<sub>2</sub> feed circuit.

For example, at a Georgia-Pacific mill in Crossett, Arkansas, a U.S. DOE sponsored audit identified an opportunity to pre-heat ClO<sub>2</sub> using chiller feed water. The mill operates two chillers to provide cold water for the ClO<sub>2</sub> plant; each chiller takes well water at 70F and chills it down to 45F. A proposed prechiller would utilize 50F ClO<sub>2</sub> solution from the bleach plant to cool the incoming well water while simultaneously preheating the ClO<sub>2</sub> solution, thereby reducing bleach plant steam demand. Annual savings in fuel, electricity, and steam were estimated at \$61,000, while capital costs were estimated at \$124,000 (U.S. DOE 2003a). The payback period of this measure was therefore around 2 years, which is similar to estimated payback periods elsewhere in the literature (NCASI 2001).

### 15.3 Chemical Recovery

**Lime kiln oxygen enrichment.** Oxygen enrichment is an established technology for increasing the efficiency of combustion, and has been adopted in various forms by a number of industries with high-temperature combustion processes (e.g., glass manufacturing). Oxygen enrichment of lime kilns can reduce fuel requirements by around 7-12% (Focus on Energy 2006a). Reportedly, capital investments for oxygen enrichment are low, with only feed piping, an injection lance, and controls required (McCubbin 1996). Payback periods have been estimated between roughly one and three years (Focus on Energy 2006a).

**Lime kiln modification.** Several modifications are possible to reduce energy consumption in lime kilns. High efficiency filters can be installed to reduce the water content of the kiln inputs, thereby reducing evaporation energy. Higher efficiency refractory insulation brick can be installed to decrease radiation heat losses from the kiln. For example, one published estimate suggests that newer high-performance refractory can lead to lime kiln energy savings of up to 5% (Focus on Energy 2006a). Heat can also be captured from the lime and from kiln exhaust gases to pre-heat incoming lime and combustion air. Martin et al. (2000) estimate that the energy savings achievable through the combined application of the above measures is around 0.47 MMBtu per ton of production. Furthermore, such improvements may also improve the rate of recovery of lime from green liquor, thus reducing a mill's requirement for additional purchased lime (Martin et al. 2000)

**Lime kiln electrostatic precipitators.** Electrostatic precipitators can replace wet scrubbers on lime kilns and lead to energy and water savings. Electrostatic precipitators can collect kiln dust as a dry material, and return it directly to the kiln feed without unnecessarily loading the lime mud filter (NCASI 2001). In contrast, wet scrubbers require effluent recycling via the lime mud filter and are significant consumers of water (Focus on Energy 2006a). One published estimate suggests that for every 1% reduction in lime mud feed moisture content (through the addition of dry dust), lime kiln energy consumption is reduced by around 46 MMBtu (Focus on Energy 2006a). An analysis by NCASI suggested increasing mud dryness from 70% to 75% would reduce fuel consumption by 0.4 MMBtu per ton of lime (NCASI 2001).

**Black liquor solids concentration.** Black liquor concentrators are designed to increase the solids content of black liquor prior to combustion in a recovery boiler. Increased solids content means less water must be evaporated in the recovery boiler, which can increase the efficiency of steam generation substantially. There are two primary types in use today: submerged tube concentrators and falling film concentrators.

In a submerged tube concentrator, black liquor is circulated in submerged tubes where it is heated but not evaporated; the liquor is then flashed to the concentrator vapor space, causing evaporation (NCASI 2001). An analysis by NCASI suggests that for a 1,000 ton per day pulp plant, increasing the solid content in black liquor from 66% to 80% would lead to fuel savings of 30 MMBtu/hour, or roughly \$550,000 (NCASI 2001). Capital costs of the high solids concentrator will include concentrator bodies, piping for liquor and steam supplies, and pumps (NCASI 2001).

A tube type falling film evaporator effect operates almost exactly the same way as a more traditional rising film effect, except that the black liquor flow is reversed. The falling film effect is more resistant to fouling because the liquor is flowing faster and the bubbles flow in the opposite direction of the liquor. This resistance to fouling allows the evaporator to produce black liquor with considerably higher solids content (up to 70% solids rather than the traditional 50%), thus eliminating the need for a final concentrator (Nilsson et al. 1995). Martin et al. (2000) estimate a steam savings of 0.76 MMBtu per ton of pulp (Elaahi and Lowitt 1988).

A U.S. pulp and paper mill with 900 ton paper production per day installed a liquor concentrator to increase its solids content from 73% to 80%. This increase results in annual energy savings of about 110,000 MMBtu. Costs saving were about \$900,000/year, leading to an estimated period of payback of 4 years (Anonymous 2008)

**Improved composite tubes for recovery boilers.** Recovery boilers consist of tubes that circulate pressurized water to permit steam generation. These tubes are normally made out of carbon steel, but severe corrosion thinning and occasional tube failure has led to the search for more advanced tube alloys. Research sponsored by the U.S. DOE led to the development of new weld overlay and co-extruded tubing alloys. These advanced alloys make it possible to use black liquor with higher dry solids content, leading to an increase in boiler thermal efficiency, as well as to a decrease in the number of shutdowns. Improved composite tubes

have been installed in more than 18 Kraft recovery boilers in the United States, leading to a cumulative energy savings of 4.6 TBtu since their commercialization in 1996 (U.S. DOE 2007c).

**Recovery boiler deposition monitoring.** Better control of deposits on heat transfer surfaces in recovery boilers can lead to higher operating efficiencies, reduced downtime (due to avoidance of plugging), and more predictable shutdown schedules. A handheld infrared inspection system has been developed that can provide early detection of defective fixtures (tube leaks or damaged soot blower) and slag formation, preventing impact damage and enabling cleaning before deposits harden (U.S. DOE 2007c). The system can reportedly provide clear images in highly particle-laden boiler interiors, and enable inspection anywhere in the combustion chamber. As of 2005, 69 units were in use in the United States, generating 1.4 TBtu in energy savings since their introduction in 2002 (energy savings are attributable to reduced soot blower steam use) (U.S. DOE 2007c).

**Quaternary air injection.** According to Focus on Energy (2006a), most recovery boilers in the United States have three stages of air injection, but utilize the third stage in a limited fashion. By fully utilizing the third stage and adding a fourth air injection port, carry over and tube fouling can be reduced. This can reduce the frequency of recovery boiler washing, which will lead to energy savings because boiler shut downs and reheat can be reduced. Focus on Energy (2006a) estimates that each boiler reheat cycle will consume around 10 MMBtu at a cost of around \$50,000. Capital costs for this measure are estimated at \$300,000 to \$500,000 (Focus on Energy 2006a).

## 16 Energy Efficiency Measures for Mechanical Pulping

Although less common than chemical pulping, mechanical pulping operations still account for around 8% of wood pulp production in the United States. Mechanical pulping is also the primary method used in the manufacture of pulp from recycled and secondary fibers. This chapter discusses some key energy saving measures for various aspects of mechanical pulping operations.

**Refiner improvements.** Several improvements are possible within the refiner section of a mill, which can reduce electricity consumption in mechanical pulping. For example, a newsprint mill in Quebec, Canada implemented a refiner control strategy to minimize variations in the freeness of ultra-high-yield sulfite pulps and saved 51.3 kWh per ton of production due to reduced motor load (Tessier et al. 1997). Another option in refining is the switch to conical refiners rather than disk refiners. By decreasing the consistency of pulping to about 30% from 50%, a 7-15% electricity savings are possible in TMP and RMP processes (Alami 1997). Martin et al. (2000) estimated an electricity savings potential of 11% due to such mechanical refining improvements, at a capital cost of around \$7.7 per ton of pulp production.

**Refiner optimization for overall energy use.** Fibers (either from waste paper or virgin pulp) are refined to optimize fiber properties. However, refining also leads to higher water retention in the fiber, which leads to lower dewatering on the wire and hence increased steam consumption in the dryer. The increased water retention can potentially lead to additional energy costs of \$30-\$40 per ton of paper (Westenbroek and Dekker 2006). Hence, in refiner operation it is important to include water retention in the optimization strategy. Alternatively, it is important to optimize the refiner effect on steam consumption by improved pulp selection.

**Pressurized groundwood.** Pressurized groundwood pulping was first developed in Scandinavia in the 1970s. In a pressurized groundwood system, grinding takes place under compressed air pressure where water temperature is high (more than 95 °C), thereby allowing for higher grinding temperatures without steam flashing (Martin et al. 2000). The higher temperature promotes softening of the lignin, which improves fiber separation and reduces specific energy consumption (NCASI 2001). The technical literature claims around 20-36% saving in electricity compared with atmospheric mechanical pulping processes (Martin et al. 2000; NCASI 2001). So-called super pressurized groundwood technology—which operates at higher temperatures and pressures than pressurized groundwood technology—provides better smoothness and opacity of paper (EPA 1993).

**Continuous repulping.** The repulping process for purchased market pulp involves blending the dried pulp feedstock with water in a large tank to produce a fibrous slurry. Typically this is done as a batch process, but converting to a continuous process can lead to energy savings due to improved process efficiency. Focus on Energy (2006a) estimates that energy savings of up to 40% are possible, in the form of reduced pulping motor power requirements. If the existing repulper can be retrofitted, capital costs are estimated around \$100,000 (Focus on Energy 2006a).



**Efficient repulping rotors.** Newer repulper rotor designs have been optimized for power consumption using computational fluid dynamics simulations to study the interaction of rotors with pulping slurries. Reportedly, replacing an existing rotor with a new rotor that is optimized for efficiency can reduce rotor motor consumption by anywhere from 10% to 30% (Focus on Energy 2006a). Payback periods for this measure have been estimated at one to two years (Focus on Energy 2005a).

Wausau Paper installed and tested a new 500 hp high efficiency repulper rotor in its mill in Rhinelander, Wisconsin. Reportedly, the high efficiency rotor reduced repulping electricity consumption by 23%, while producing a pulp furnish with similar defibering time and fiber quality as their conventional repulper rotor (Focus on Energy 2005b).

In another example, Canfor's Northwood Kraft Pulp Mill in Prince George, British Columbia tested a new high capacity, aerodynamic, variable speed pulping rotor. The design of the rotor allows operation at low speeds while still effectively cleaning the pulper screen apertures (BC Hydro 2006). Reportedly, the new rotor reduced electricity consumption by more than 50%, while producing the same or higher tonnage with similar shive removal efficiency. Projected annual energy savings amounted to around 3.6 GWh, or about \$193,000 in electricity costs (BC Hydro 2006).

**Drum pulpers.** Drum pulpers are applicable to mills that generate pulp from recovered paper and paperboard products. A drum pulper is essentially a rotating, inclined drum with baffles that is used to mix recovered fiber sources, water, and (in de-inking applications) de-inking chemicals. The more gentle mechanical action of drum depulpers allows contaminants to remain intact while the paper is defibered (Focus on Energy 2006a; NCASI 2001). Drum pulpers have lower energy requirements than conventional mechanical pulpers, can use less water, and reduce fiber shortening (Focus on Energy 2006a; APPW 2004). However, when drum pulpers are used in brown fiber applications, the rapid wetting of furnish and the incomplete removal of bailing wire can reportedly cause problems (APPW 2004). An analysis by NCASI suggests that replacing a vat type batch pulper with a continuous drum pulper in de-inking operations can reduce specific pulping energy by over 25% (NCASI 2001).

**Increased use of recycled pulp.** The production of recycled pulps consumes, on average, significantly less energy than that required to produce mechanical or chemical wood pulps. According to the AF&PA, nearly 200 U.S. mills rely exclusively on recovered paper for pulp production, and roughly 80% of U.S. mills use recovered paper in some fashion (U.S EPA 2002). In its collaborative research work with the U.S. DOE, the U.S. pulp and paper industry is pursuing an increased use of recycled pulp to further reduce energy use associated with virgin pulping processes (Martin et al. 2000). Martin et al. (2000) estimate that costs for the construction of recycled pulp processing capacity in the United States is around \$485 per ton of pulp; however, depending on the price of waste paper versus virgin pulp this may result in up to \$73.9 per ton of pulp in operations and maintenance cost savings (O'Brien 1996). However, recycled pulp produces sludge that can present a disposal difficulty.

**Heat recovery from de-inking effluent.** De-inking effluents are often discharged at elevated temperatures and represent a possible source of low-grade heat recovery in a typical recycled fiber pulping mill. The installation of heat exchangers in the effluent circuit can recover some of this heat for other beneficial uses, such as facility water heating.

For example, a U.S. DOE sponsored energy assessment (U.S. DOE 2004g) at the Blue Heron Paper Company mill in Oregon City, Oregon, revealed a cost-effective opportunity for effluent heat recovery. The mill produces newsprint and specialty paper products on three paper machines, using about 60% recycled fiber from old newsprint and magazines in its furnish. The mill's combined effluent streams were at approximately 120°F with a flow rate of 600 gallons per minute. A proposed heat exchanger would generate warm filtered shower water for the mill's paper machines, which would offset some of the mill's steam demand. Annual boiler fuel savings of 37,000 MMBtu were estimated, which would lead to annual cost savings of \$125,000 (U.S. DOE 2004g). Capital costs were estimated at \$375,000; the resulting payback period would be around 3 years.

**Fractionation of recycled fiber.** Andritz (Austria) has tested the potential of separating the long fibers and short fibers in a deinking line. This enables a simplification of the deinking line (with a capital reduction of 13-22% compared to traditional DIP-lines), and a reduction in electricity by 11-13% and thermal energy of 40% (Hertl 2008). This setup is now being implemented and tested at the newsprint mill of Perlen Papier in Switzerland.

**Thermopulping.** Thermopulping is a variation of the TMP process whereby pulp from the primary stage refiner is subjected to a high temperature treatment for a short time in a thermo-mixer and in the subsequent secondary refiner. Temperatures in the primary stage are below the lignin softening temperature. The higher operating pressures in the secondary refiner reduce the volumetric flow of generated steam. An advantage is that in contrast with other energy savings technologies this process can be turned on and off as desired by mill personnel. A drawback is a small brightness loss and a slight reduction in the tear index (Martin et al. 2000; Miotti 2001). Published estimates suggest that thermopulping can reduce specific energy consumption compared to TMP by up to 20% (Miotti 2001; Ola et al 1998).

**RTS pulping.** RTS stands for short residence time, elevated temperature, high speed pulping. In the RTS process, energy consumption is reduced by increasing the rotational speed of the primary refiner. This leads to reduced residence time, smaller plate gaps, and higher refining intensity. Chips are subjected to elevated temperatures for a short residence time prior to high speed primary stage refining. (Martin et al. 2000). Temperatures of approximately 165 °C are used, resulting in a reduction in specific energy consumption with no loss of pulp quality and a one-point brightness improvement (Cannell 1999; Fergusson 1997; Patrick 1999). Published estimates for the energy savings achievable with RTS pulping vary. Martin et al. (2000) estimate that RTS pulp can be produced with approximately 15% lower specific energy requirements than pulp produced with a traditional refining system. Data from Miotti (2001) suggest that the specific energy of RTS pulping is around 20% lower than TMP processes. Focus on Energy (2006a) estimates that the effect of increasing rotational speed on TMP refiners will reduce energy use by anywhere from 15-

30%, depending on plate type and refiner mode. Reportedly, RTS pulp has slightly higher strength properties and comparable optical properties to TMP pulps.

**Heat recovery in TMP.** A vast amount of steam is produced as by-product of thermo mechanical pulping. This low-pressure steam is often contaminated, but most of the energy can be reclaimed for use in other mill processes through heat recovery equipment. Heat recovery options include: (1) mechanical vapor recompression (Tistad and Asklund 1989; Martin et al 2000) for integrated mills, where the clean steam generated can be used in the paper machine dryer section (Martin et al. 2000), (2) direct contact heat exchangers for generating hot water for use in paper machines and as boiler makeup water and clean process steam (Focus on Energy 2006a), (3) reboilers for producing clean process steam (NCASI 2001), and (4) other devices such as thermo vapor recompression and cyclotherm plus heat pump systems (Martin et al. 2000; Klass 1999). According to NCASI (2001), TMP heat recovery is applicable to any mill that uses pressurized refining and currently does not use heat recovery (which usually means older mills, because most modern TMP mills are designed with heat recovery systems). Focus on Energy (2006a) estimates that typical heat recovery systems for pressurized refiners can generate 1.1 to 1.9 tons of clean steam at dryer can pressure per ton of pulp. Payback periods vary widely depending on capital costs, but can be as low as a few months (Focus on Energy 2006a; NCASI 2001; Martin et al. 2000). Martin et al. (2000) estimate average installation costs of \$21 per ton of pulp with significant increases in operations and maintenance costs. Jaccard et al. (1996) report a wide range of installation costs.

## 17 Energy Efficiency Measures for Papermaking

Chapter 4 showed that the papermaking process accounts for about half of the total steam, electricity, and direct fuel used by the U.S. pulp and paper industry. In particular, the drying stage of the paper machine accounts for the vast majority of thermal energy use in papermaking. Most energy saving opportunities for papermaking are therefore related to improving the efficiency of the drying process and recovering its waste heat for beneficial use. This chapter discusses several key energy saving measures that can help reduce the energy use of papermaking.<sup>29</sup> Combined, such measures for improving the efficiency of papermaking can add up to big energy and cost savings.

For example, one two-machine mill reduced annual energy costs by \$ 1 million by implementing several paper machine efficiency improvements. These improvements included adjusting dryer differential pressures to reduce steam venting to the condenser, reducing rewet after the last press, lowering whitewater temperatures, modifying the dry end pulper so one agitator could be shut down when the sheet was on the reel, lowering pocket ventilation supply air temperatures, and upgrading paper machine clothing designs. The costs of implementation amounted to less than US\$100,000 (Reese 2008).<sup>30</sup>

In another example, Procter & Gamble won a Wisconsin Governor's 2008 Pulp and Paper Energy Efficiency Award for the development of a new energy efficient tissue paper machine at their Green Bay location (Wroblewski 2009). The new paper machine uses 19% less natural gas and electricity than the most recent similar machine installed in 2004 that makes a similar paper grade (normalized for production schedule differences). The machine design is customized, and has a blend of commonly accepted design practices, including efficient lighting, premium efficiency motors, and low-NOx burners, as well as uncommon features such as cascade heat uses. Reportedly, the new paper machine will save 20,000 metric tons of CO<sub>2</sub> per year, while reducing other air emissions.

**Advanced dryer controls.** Control systems are a well-known way to optimize process variables and thereby reduce energy consumption, increase productivity, and improve the quality of industrial processes. One example of a control system for dryers is Dryer Management System<sup>TM</sup> control software, which reportedly offers advanced control of dryer system set points and process parameters to reduce steam use and improve productivity (Focus on Energy 2006a, 2006b, 2006c; Reese 2005). Several case studies of this technology are available in the literature.

Focus on Energy (2006b) describes a pilot of the Dryer Management System software at a Stora Enso mill in Steven's Point, Wisconsin. The mill's paper machine was metered to

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<sup>29</sup> TAPPI (2003)—entitled “TAPPI TIP #0404-63: Paper Machine Energy Conservation”—provides further recommendations for assessing and optimizing the energy use of paper machines, as well as references to other TAPPI publications on energy conservation in the pulp and paper industry.

<sup>30</sup> These energy savings were identified using a paper machine energy scorecard system that was developed under funding by the U.S. DOE. The scorecard system provides a comparison to the energy performance of paper machines producing similar grades, and helps identify opportunities to reduce energy consumption (Reese 2008). Further information on the paper machine energy scorecard can be found in Appendix D.

determine energy savings, which were deemed quite significant: 4,500 pounds of steam per hour, which were estimated to lead to \$360,000 in annual energy cost savings (Focus on Energy 2006b). Additionally, the company reportedly experienced significant improvement with product quality and throughput. The payback period was estimated at under 3 years based on energy savings alone (i.e., no consideration of productivity benefits).

Reese (2005) describes results from another Stora Enso installation of Dryer Management System software, this time on a Voith lightweight coated machine with two on-machine coaters. Reportedly, annual savings of \$263,000 were observed due to reduced energy consumption, lower maintenance cost, and higher production. The reported payback period was seven months.

**Control of dew point.** The water vapor dew point (in the dryer hood) determines the heat exchange efficiency, but is affected by the setting of ventilation fans. The dew point levels in paper drying hoods should be measured and controlled to optimize the drying process (Mulder 2008). Optimizing the operation of the dryer hood provides greater quality control, which leads to a more consistent product.

**Optimization of water removal in forming and pressing.** Water is removed in three successive steps in a paper machine in the wire, press, and dryer sections. A rule of thumb is that five times as much energy is required to remove a pound of water in the press section compared to removing a pound of water in the forming section, and that up to 25 times as much energy is required to remove a pound of water in the dryer section compared to removing a pound of water in the forming section (Sweet 2009a). Thus, the energy benefits of removing as much water prior to the dryer section are self-evident.

Many paper machines operate with less than ideal water removal in the forming section. There are many reasons for this, including equipment limitations, and inadequate and/or poorly maintained instrumentation and controls in the low and high vacuum dewatering elements. On older paper machines, there is often an excessive quantity of high vacuum elements which add to the vacuum system operating power as well as increasing the forming fabric drag load and associated drive power (Sweet 2009a).

An issue is the potential for rewetting of the paper after the wire and press sections, which increases the energy use in the drying section. Research has demonstrated that it is important to use the right felt for the paper grade produced to reduce the amount of rewetting taking place (Vomhoff 2008). As grades change on a paper machine, it is hence important to optimize the choice of felt. It is also important to optimize the geometry of the web path and the felt paths such that the two are separated as early as possible to minimize rewetting (Rollinson 2008). The “double doctor” approach may be an effective option for couch rolls and suction rolls to reduce rewetting when leaving the Fourdrinier and press nips.

As with the forming section, press optimization can help to improve water removal prior to the dryer section. Press water balances will provide valuable information which points to where the sheet water is extracted within the press. However, many paper machines lack the proper equipment required to make water measurement possible from uhle boxes and press

nips. There are many variables to pressing and there is not a single set of parameters to set up the press for maximum water removal on all grades. Press nip loadings need to be maximized within design limits. Also, analysis of roll coverings (soft to hard) and surface patterns (drilled, grooved, and hybrids of these) should be part of the entire press section study. Additionally, felt design changes should be considered and will require some trial and error as each step in the optimization process is taken. Typically, sheet temperature is reduced as it passes through the press, so efforts should be made to maintain, or even increase the sheet temperature as it exits the press. An 18°F increase in sheet temperature leaving the press provides a 4% decrease in dryer steam. Additionally, higher pressing temperatures can improve water extraction from the sheet which further reduces dryer steam requirements. Increasing sheet temperature can be achieved with significantly increasing press shower water temperature (over 130° F) and/or adding steam showers at the uhle boxes, where the steam is pulled into the felt at the vacuum slot. Finally, sheet rewetting within the press should be addressed to be sure it does not exist, or is minimized (Sweet 2009a).

**Reduction of blowthrough losses.** Modern high speed paper machines use stationary siphons. The amount of blow through steam depends upon the siphon differential pressure required for efficient evacuation. The lower the differential pressure, the lower the blow through steam use. At initial commissioning these were set at reasonable values. However, during operation these setpoints may have increased and were not re-set to the original values but are only needed in exceptional circumstances. This results in increased blowthrough steam use, which can be reduced by sticking to the original setpoints (Duller 2008).

**Reduced air requirements.** Air to air heat recovery systems on existing machines recover only about 15% of the energy contained in the hood exhaust air (Martin et al. 2000). This percentage could be increased to 60-70% for most installations with proper maintenance and extensions of the systems (Maltais –ABB Industrial drying, in Martin et al. 2000). Paper machines with enclosed hoods require about one-half the amount of air per ton of water evaporated compared to paper machines with a canopy hoods. Enclosing the paper machine reduces thermal energy demands since a smaller volume of air is heated. Electricity requirements in the exhaust fan are also reduced (Elaahi and Lowitt 1988). Published estimates suggest steam savings of 0.72 MMBtu per ton of paper and electricity savings of 6.3 kWh per ton of paper by installing a closed hood and an optimized ventilation system. Investment costs and operations and maintenances costs have been reported at \$9.5/ton paper and \$0.07/ton paper, respectively (Martin et al. 2000).

**Optimizing pocket ventilation temperature.** Mill operators often monitor the operating air temperature of pocket ventilation systems, but when such systems operate at greater air temperatures than the minimum required for proper operation, energy can be wasted. Focus on Energy (2006a) estimates that when the temperature of the pocket ventilation system can be decreased to between 180-195F, the overall use of steam can also be decreased by about 1,000 to 2,000 lb per hour in a typical mill. Paybacks are immediate since this measure involves improved operations and control rather than capital investments.

**Waste heat recovery.** In the paper drying process, several opportunities exist to recover thermal energy from steam and waste heat. One mill replaced the dryers with stationary siphons in their paper machine and was able to achieve energy savings of 0.85 MMBtu/ton

due to improved drying efficiency, with an operation cost savings of \$25,000 (\$0.045/ton) (Morris 1998). A second system used mechanical vapor recompression in a pilot facility to reuse superheated steam into the drying process (Van Deventer 1997). Steam savings for this approach were up to 4.7 MMBtu/ton (50%) with additional electricity consumption of 160 kWh/ton (Van Deventer 1997). A third system noted in the literature was the use of heat pump systems to recover waste heat in the drying section (Abrahamsson et al. 1997). Martin et al. (2000) estimates steam energy savings of around 0.4 MMBtu/ton of paper are achievable through paper machine heat recovery, with installation costs of around \$18 per ton of paper. However, the installation of heat recovery systems will lead to more maintenance since heat exchangers require periodic cleaning.

Heat can also be recovered from the ventilation air of the drying section and used for heating of the facilities (de Beer et al. 1994). For example, a mill-wide energy assessment Appleton Paper's mill in West Carrollton, Ohio, found that the recovery of paper machine vent heat could be used for heating the plant in winter months. It was recommended that cross-flow heat exchangers be installed to generate hot air for plant heating from recovered heat in the paper machine vent exhaust gas. The estimated annual cost savings were about \$1,000,000. With investment costs of about \$1,500,000, the payback period was estimated at only 1.5 years (U.S. DOE 2002c)

For direct-fired air dryer hoods, which are mainly used on tissue and toweling machines, several opportunities for waste heat recovery exist (Marin 2008). Hood exhaust air can be recovered and used to preheat the air entering the combustion chamber, thereby reducing hood fuel demand. A cascade system can be employed, which uses the hood exhaust air to feed the supply fan of the wet section, which will reduce the fuel demand for wet section burners. Lastly, an economizer can be installed to reclaim heat from hood exhaust air and use it to heat fresh water for high pressure showers of the paper machine felt and wires.

**Shoe (extended nip) press.** After paper is formed, it is pressed to remove as much water as possible. Normally, pressing occurs between two felt liners pressed between two rotating cylinders. Extended nip presses use a large concave shoe instead of one of the rotating cylinders (Martin et al. 2000). The additional pressing area adds dwell time in the nip and allows for greater water extraction (about 5-7% more water removal) to a level of 35-50% dryness (Elaahi and Lowitt 1988; Miller Freeman 1998; Lange and Radtke 1996; Sweet 2009a). Greater water extraction leads to decreased energy requirements in the dryer, which leads to reductions in steam demand. Furthermore, reduced dryer loads allow plants to increase capacity up to 25% in cases where production is dryer limited (Martin et al. 2000). Extended nip pressing also increases wet tensile strength (Lange and Radtke 1996). Published estimates for the steam savings achievable through the installation of extended nip presses range from 2% to around 15%, depending on product and plant configuration (Martin et al. 2000; Focus on Energy 2006a). The application of the X-NIP T shoe press in tissue plants is estimated to reduce drying energy use by 15% (Baubock and Anzel 2007). Capital costs have been estimated at \$38 per ton of paper and additional maintenance costs have been estimated at \$2.24 per ton of paper (deBeer et al. 1994).

**Paper machine vacuum system optimization.** Vacuum pumps and a vacuum system exist on every paper machine. There is approximately the same horsepower associated with the vacuum system as is used to drive the entire paper machine (Sweet 2009a). However, inefficiencies within the vacuum system increase the electrical and/or steam energy requirements of water removal, and therefore represent an important energy efficiency improvement opportunity.

For example, following an audit of 14 paper machines owned by a Canadian manufacturer, a potential of 3.5 MW of electrical power demand could be saved following system modifications, operational changes, and even removal of some vacuum pumps. The 14 paper machines had a total of 50,000 horsepower connected to the vacuum pump systems and were operating with a combined demand of 45,000 horsepower by the drive motors. Cost to achieve the first MW of savings was considered negligible with minor piping or operational changes. Total annual cost savings was approximately \$400,000 per year (Sweet 2009a).

The situation of excess vacuum capacity sometimes exists because significant operational changes have occurred since the system was new, which can impact the performance and requirements of the vacuum system. Over time, changes in furnish, chemistry, headbox consistency, retention, and forming and press fabrics can have an effect on the needs and performance of the vacuum system. In one recent example, a survey of a newly rebuilt paper machine with a new press found many problems with improper vacuum control and excess vacuum capacity. Furthermore, there was a total potential of removing 700+ hp from the vacuum system by removing or slowing down some of the vacuum pumps (Sweet 2009b).

**Gap forming.** Gap formers are an alternative to the Fourdrinier paper machine. They can be categorized as blade formers, roll formers, and roll-blade formers (Kincaid et al. 1998; Buehler and Guggemos 1995). Gap formers receive furnish which is injected into the head box through a gap of air onto a twin wire unit. As the furnish passes between the wires, moisture is removed from the fibers through the wires forming a paper web between the wires from the pulp (Martin et al. 2000). Rolls, blades, or vacuums facilitate the removal of excess water from the web, known as dewatering (Kincaid et al. 1998). The forming sections are very short and the formation takes place in a fraction of the time it takes for a Fourdrinier machine (Martin et al. 2000). The gap former produces a paper of equal and uniform quality at a higher rate of speed. Coupling the former with a press section rebuild or an improvement in the drying capacity increases production capacity by as much as 30% (Kincaid et al. 1998; Paulapuro 1993; Elenz and Schaible 1995). Nevertheless, retrofitting a gap former may increase retention losses. Energy savings from gap formers come from reduced electricity consumption (Kline 1991). The technology also may improve quality. Published estimates for electricity savings are around 40 kWh/ton of paper (Jaccard & Willis 1996). Based on (AF&PA 1999b) installation costs including the head box for a gap former amount to approximately \$75,750 per inch of width, as opposed to \$30,750 for a Fourdrinier with head box.

**CondeBelt drying.** The first commercial CondeBelt dryers were installed in Finland in 1996, and in Korea 1999 (Martin et al. 2000). In CondeBelt drying the paper is dried in a drying chamber by contact with a continuous hot steel band, heated by either steam or hot gas. The water from the paper is evaporated by the heat from this metal band. (De Beer et al.



1998) This drying technique has the potential to completely replace the drying section of a conventional paper machine, with a drying rate 5-15 times higher than conventional steam drying (Lehtinen 1993 in Martin et al. 2000). However, CondeBelt drying is not suited for high basis weight papers (Martin et al. 2000) and has seen limited application in the United States to date (although it is operating in mills in Europe and Korea) (Jacobs and IPST 2006). Capital costs are considered to be high, although the size of the drying area can be reduced. Martin et al. (2000) estimated savings of 15% in steam consumption (1.5 MMBtu/ton of paper) and a slight reduction in electricity consumption (20 kWh/ton of paper), with investment costs of \$28/ton paper for retrofit installations (De Beer 1998).

**Air impingement drying.** Air impingement drying involves blowing hot air (at 300C) in gas burners at high velocity against the wet paper sheet. Air impingement drying leads to less steam use and slightly higher electricity use (Martin et al. 2000). This technology is mostly applicable to coating drying, but is also gaining acceptance for general paper drying in place of traditional steam cylinders (Focus on Energy 2006a). Published estimates suggest that impingement drying can lead to steam savings of 10-40% compared to conventional gas-fired or infrared drying technologies, but with an increased electricity use of up to 5% (Martin et al. 2000; Focus on Energy 2006a). Given that this measure involves a tradeoff between thermal and electrical energy use, and the extent of this tradeoff may vary by installation, it is important that net energy savings be verified on a facility by facility basis.

## 18 Emerging Energy Efficiency Technologies

Chapters 6 through 17 of this Energy Guide discussed a wide range of energy efficiency opportunities and practices based on commercially available technologies. In addition to these opportunities, there are also a number of emerging technologies that hold promise for improving energy efficiency in the U.S. pulp and paper industry. (An emerging technology is defined as a technology that was recently developed or commercialized with little or no market penetration at the time of this writing.)

New and improved technologies for pulp and paper mills are being developed and evaluated continuously. Many of these technologies can provide not only energy savings, but also water savings, increased reliability, reduced emissions to water and air, higher paper quality, and improved productivity.

In this chapter, several promising emerging technologies are discussed briefly. Where possible, information on potential energy savings compared to existing technologies and other technology benefits are provided. However, for many emerging technologies, such information is scarce or nonexistent in the literature. Thus, the energy savings and other benefits discussed in this chapter are preliminary estimates. Actual performance will depend on the facility, the application of the technology, and the existing production equipment with which the new technology is integrated.

Moreover, only time will tell if these technologies will prove successful and be adopted on a wide scale in the U.S. pulp and paper industry. However, given their promise with respect to energy savings, it may be worthwhile to monitor the development and adoption of these technologies for future consideration.

**Black liquor gasification.** As shown in Chapter 4, black liquor accounts for a significant fraction of the fuel consumed by the U.S. pulp and paper industry. Kraft mills combust black liquor in so-called Tomlinson recovery boilers to recover chemicals and generate process steam and on-site electricity (via a steam turbine). The efficiency of such boilers is typically low, around 65-70% (U.S. DOE 2005a; Jacobs and IPST 2006). Black liquor gasification refers to the process of creating a clean synthesis gas (syngas) from black liquor by converting its biomass content into a gaseous energy carrier. The syngas can be used in boilers or in combined cycle processes to generate on-site electricity and process steam.

Black liquor gasifiers may be applied as an incremental addition in chemical recovery capacity in situations where the recovery boiler is a process bottleneck (Martin et al. 2000). There is also increasing interest in using gasifiers in combined cycle power systems as replacements for Tomlinson recovery boiler systems (Larson et al. 2003), to provide fuel for lime kilns, and even for transport fuels such as Fischer-Tropsch liquids or hydrogen (Nilsson et al. 1995; Lienhard and Bierbach 1991).

The two main types of gasification are low temperature/solid phase and high temperature/smelt phase. The gasification produces a fuel gas that needs to be cleaned to remove undesired impurities for the power system and to recover pulping chemicals.

Low temperature gasification is based on a fluidized bed at atmospheric pressure and a temperature 1290°F (700°C) or lower, below the melting point of inorganic salts that comprise most of the char from black liquor (Martin et al 2000b). Sodium carbonate is used as the bed material and is precipitated out and reused (Worrell, Bode, and de Beer 1997).

High temperature gasification occurs at 360 lbs/in<sup>2</sup> (2.5 MPa) and above the melting point of the inorganic salts 1740°F (950°C) or higher, and chemicals are recovered in a smelt. Higher temperatures lead to higher carbon conversion rates but also may lead to more corrosion in the reactor vessel (Worrell, Bode, and de Beer 1997). The synthesis gas is water quenched (producing low-pressure steam) and cleaned before being fired in the turbine. The first fully commercial high temperature air-blown black liquor gasifier plant was installed in 1997 at Weyerhaeuser in New Bern, North Carolina (Erikson and Brown 1999).

The potential advantages of black liquor gasification are the greater end use flexibility offered by a gaseous fuel, reduced air pollutant content, and higher electricity-to-heat ratios in combined cycle systems than standard recovery boiler steam turbine systems (U.S. DOE 2005a). Potential disadvantages of gasification combined cycle systems include the energy investments required for achieving sufficient black liquor solids concentration (Kaufmann 2009) and higher lime kiln and causticizer loads (and associated fuel inputs) compared to Tomlinson systems (Larson et al. 2003). Additionally, since combined cycle systems generate electrical power more efficiently than steam turbine based systems, more fuel is required in the gasification combined cycle system than in the Tomlinson boiler system to meet the same level of facility steam demand (Larson et al. 2003). However, this additional fuel use also results in more available electricity for facility use or export to the grid.

At least one study has comprehensively analyzed the potential for black liquor gasification accompanied by combined cycle electricity generation at pulp and paper mills in the United States. Larson et al. (2003) analyzed the various tradeoffs of different gasification and Tomlinson boiler co-generation systems under different assumptions. The study results suggest that on a thermodynamic basis, high-efficiency Tomlinson boiler systems would be more efficient at generating steam and power than low-temperature, mill-scale gasification systems. However, the study results also suggested that high-temperature, mill-scale gasification systems would be more efficient than high-efficiency Tomlinson boiler systems.

Black liquor gasification technologies and applications are in continuous states of research and development. The potential benefits and costs of black liquor gasification – both environmental and economic – are likely to depend highly on the characteristics of individual installations and will be better understood as the technologies and applications are demonstrated and evaluated over time.

**Magnetically-coupled adjustable-speed drives.** Magnetically-coupled adjustable-speed drives (MC-ASDs) are a new type of ASD, in which the physical connection between the motor and the driven load is replaced with a gap of air. Torque is generated by the interaction of rare-earth magnets on one side of the drive with induced magnetic fields on the other side (NEEA 2008). The amount of torque transferred is controlled by varying the air gap distance between the rotating plates in the assembly. According to Worrell et al. (2004), compared to existing ASDs, MC-ASDs have several advantages, including:

- A greater tolerance for motor misalignment.
- Little impact on power quality.
- The ability to be used with regular duty motors (instead of inverters).
- Expected lower long term maintenance costs.
- Extended motor and equipment lives, due to elimination of vibration and wear on equipment.

One commercially-available model, the MagnaDrive, is currently installed in pump, fan, and blower installations in the pulp and paper, mining, food processing, and raw materials processing industries, as well as in irrigation, power generation, water treatment, and HVAC systems (Worrell et al. 2004).

Ponderay Newsprint, in Usk, Washington opted to install a MagnaDrive coupling to reduce wasted energy in the pumping of TMP whitewater to its pulping process and de-inking system. According to NEEA (2002a), the constant-speed pump ran at full capacity during normal operations, which resulted in cavitation and excessive vibration leading to maintenance problems. Further, a bypass valve was used to maintain constant pressure in the system when there was no demand for TMP whitewater, which led to significant energy waste. A MagnaDrive coupling was installed in this application instead of an ASD due to its lower installation and infrastructure costs. The coupling allowed Ponderay Newsprint to vary the speed of its pump motor to maintain the required pressure but with an energy demand that was around 60% lower than the former constant-speed, bypass-valve based system. Annual energy costs were reduced by around \$19,000, cavitation was eliminated, and pump vibration was dramatically reduced (NEEA 2002a).

In a similar case study, the MagnaDrive was installed in a pumping application at a Daishowa America mill in Port Angeles, Washington. The mill had 100 HP 1175 RPM motors operated in parallel running vertical shaft pumps to move wastewater from the main pump station to a clarifier (NEEA 2002b). These two pumps ran constantly to meet a maximum flow rate of 7,000 gallons per minute; however, the average demand was only 4,800 gallons per minute, which meant that 2,200 gallons per minute was passed through an energy wasting bypass valve. MagnaDrive couplings were installed on the two pumps as a lower-cost alternative compared to ASDs. The MagnaDrive couplings allowed the mill to maintain its 4,800 gallons per minute flow while reducing electricity demand from 142 to 62

kW, a savings of 56%. Reportedly, the couplings also eliminated damaging vibration and water hammer, resulting in equipment and maintenance cost savings of approximately \$15,000 per year (NEEA 2002b).

**Laser-ultrasonic web stiffness sensor.** A new laser-ultrasonic sensor has been developed by researchers at Lawrence Berkeley National Laboratory, which measures a paper's bending stiffness and shear strength — two hallmarks of paper quality — as it speeds through a production web. Conventionally, a few samples of each finished roll are analyzed for their mechanical properties by observing how they bend. If the samples don't meet certain specifications, the entire roll is recycled into pulp or sold as an inferior grade. Thus, manufacturers often over-engineer paper and use more pulp than necessary to ensure product quality (LBNL 2005).

The new laser-ultrasonic sensor measures these important mechanical properties in real time, which can allow paper manufacturers to optimize the amount of raw material used to make paper by running closer to specifications. Reportedly, this could save the United States approximately \$200 million in energy costs and \$330 million in fiber costs each year (LBNL 2005).

The technology has been proven in a full-scale mill trial, and is currently being evaluated in a larger pilot study. At the mill scale, it is estimated that implementation of this technology could lead to a 2% decrease in basis weight due to the ability of run closer to specification. Furthermore, the portion of off-grade paper that must be recycled could be reduced by 1% (which avoids the additional energy necessary to reprocess the recycled fiber in the mill). In total, mill-scale energy savings of 3% have been estimated (Ridgeway 2008).

In general, any sensor that can provide real-time quality data can help to reduce energy costs through improved product monitoring and reduced product rejection.

**Steam cycle washer for unbleached pulp.** According to the U.S. DOE, current U.S. pulp washing equipment has an average age of 45 years (U.S. DOE 2006h). Thus, significant energy saving opportunities may exist with the development and adoption of new, more efficient pulp washing technologies. The U.S. DOE is sponsoring the development of a new steam cycle washer that is designed to de-water and wash wood pulp using counter-current washing, steam, and high-differential pressure. Reportedly, the technology uses 70-75% less water than conventional washers because it allows the pulp mat to be washed at a high consistency of 28-32% (U.S. DOE 2006h). This results in less energy consumption—up to a 21% decrease in electrical power consumption and up to a 40% decrease in fuel use for unbleached pulp production (U.S. DOE 2006h). This technology is currently undergoing demonstration and commercialization.

**Microwaving logs.** By microwaving logs, the lignin in the wood can be softened leading to lower energy requirements in the TMP process. Test results from Scott et al. (2002) suggested that high-power microwave cooking of commercial black spruce for TMP could lead to energy savings of 15%, with the added benefit of improved pulp quality. A tradeoff is that with microwaving more bleaching may be required to receive the desired paper

quality; however, increased bleaching costs may be justified by the energy and quality improvements (Scott et al. 2002). Initial estimates of capital costs for 20-kW and 50-kW systems range from \$7.5 to \$12.5 million (Scott et al. 2002).

**Gas-fired paper dryer.** In partnership with the U.S. DOE, the Gas Technology Institute (GTI) is developing new approach to drying paper that may significantly increase efficiency. The gas-fired dryer system uses small dimples or cavities for combustion in a cylinder dryer, which can replace current steam dryers whose productivity is limited by drying capacity (U.S. DOE 2006h). The new technology significantly raises drum temperatures (to over 600°F), thereby increasing drying rates, which can reportedly reduce energy use and increase the throughput of the paper machine by an estimated 10-20% (U.S. DOE 2008d; Chudnovsky et al. 2004; GTI 2004). A key contributor to increased efficiency is the fact that diffusion firing allows high levels of heat recovery to preheat combustion air (U.S. DOE 2006h).

**Advanced fibrous fillers.** Mineral fillers are commonly used to replace wood fibers in the production of paper products, but filler loading is currently limited to roughly 15-20% due to paper strength and quality requirements (U.S. DOE 2006i). New inorganic fibrous fillers have been developed that could raise the filler loading limit to up to 50%, while maintaining paper strength and quality in many products. Reportedly, the use of fillers could reduce energy consumption by 25% and costs by \$10 to \$50 per ton of paper produced (U.S. DOE 2006i). Energy savings are attributable to avoided wood pulp production and reduced drying energy due to an increase in the percentage of press solids in the sheet (Mathur 2006). Mill-scale production trials of this technology are underway.

**Biotreatment.** The treatment of wood chips with a fungus or enzymes can soften the bonds in wood, resulting in less energy use in pulping processes. Swaney et al. (2003) showed the results of a pilot project in which the biopulping process for treating wood chips prior to mechanical pulping was scaled up to a 50 ton, semi-commercial scale. The economic advantages of biomechanical pulping derived from several effects, including significantly improved strength properties and significantly reduced refiner energy requirements (about 33% less energy use for refining) (Swaney et al. 2003).

The physical process begins after the pulpwood has been chipped and screened for oversize chips. At this point the chips are briefly heated to 100 °C to kill off anything that might compete with the lignin-degrading fungus. The chips are then air-cooled and the fungus and the nutrients are added. The treated chips are placed in a pile for the next 1 to 4 weeks: climatic and seasonal factors are very important for the effectiveness of the treatment (Martin et al. 2000; USDA 1998). The fact that up to 4 weeks worth of chips must be stored may be a problem for mill sites with space constraints (Martin et al. 2000). This technology is reportedly ready for commercial deployment (Swaney et al. 2003; Scott 2001), but no data could be found on the extent to which this technology has been adopted by U.S. pulp and paper mills.

**Electrohydraulic contaminant removal.** Adhesive materials (often called “stickies”) on secondary fiber feedstock can significantly degrade the quality of recycled paper products. A demonstration project sponsored by the U.S. DOE indicated that a new contaminant removal

technology that is based on the principle of electrohydraulic discharge may remove such contaminants effectively and in an energy efficient manner. The technology uses the discharge of sparks in cleaning and screening processes to enhance the removal efficiency of stickies in screening and cleaning and to increase the efficiency of flotation deinking (Banerjee 2005). Trials have been run at several mills owned by Appleton Papers, Graphics Packaging, Stora Enso, and Jackson Paper. Banerjee (2005) reports that improved stickies removal, flotation, and clarification were observed that could lead to direct energy use reductions of 10-15% in contaminant removal and cleaning equipment.

**Lateral corrugator.** The lateral corrugator holds promise for reducing the fiber use and energy consumption associated with the manufacture of corrugated boxes. The technology is being developed and piloted by the Institute of Paper Science and Technology at Georgia Tech University (IPST 2008). The lateral corrugator is designed to increase the compression strength of corrugated containers by aligning the corrugated flutes with the orientation of the linerboard fibers (i.e., the paper machine direction). This change reportedly increases the compressive strength of corrugated boxes by up to 30% and may allow manufacturers to use 15% less fiber to produce boxes with the same strength (U.S. DOE 2006j and Schaepe 2008). Significant energy savings should be possible due to the reductions in raw materials preparation, pulping, and paperboard making energy attributable to reduced fiber input.

**Multiport dryer.** A new multi-port cylinder dryer has been developed by Argonne National Laboratory that can reportedly increase paper production rates by 50% relative to conventional dryers and by 20% relative to dryers fitted with so-called “spoiler bars” (ANL 2006). Conventional steam-filled drying cylinders develop condensate on the inside of the drum, which is a major thermal barrier. The new multi-port cylinder dryer uses smaller-sized ports located in close proximity to the inside surface of the cylinder dryer, which improves heat transfer by significantly minimizing the condensate layer thickness and increasing the surface temperature of the dryer shell (U.S. DOE 2006k). This technology is reportedly being designed for retrofit applications, and is projected to cost only 20% as much as the installation of a new dryer cylinder (ANL 2006). The multi-port dryer is currently undergoing pilot demonstration (U.S. DOE 2007d).

**Directed green liquor utilization pulping.** This technology is based on the use of green liquor for pretreatment of wood chips prior to pulping. Green liquor is naturally rich in hydrosulfide ions, which can accelerate pulping. The use of green liquor in this manner has been demonstrated in pulp mills in Finland and can reportedly increase pulp yields, produce higher fiber strength, reduce digester alkali demand by as much as 50 percent, offload the lime kiln by up to 30 percent, provide higher pulp bleachability, and reduce energy use by up to 25 percent (U.S. DOE 2007e; Lucia 2005). As of 2006, this technology was being demonstrated at Evergreen Pulp, in Samoa, California and was expected to be commercialized shortly (Lucia 2008).

**Impulse drying.** Impulse drying may lower the moisture content of the paper web entering the drying section by up to 38%, thereby significantly lowering the energy required in the paper machine’s drying stage (U.S. DOE 1999c). Impulse drying involves pressing the paper between one very hot rotating roll (150-500°C) and a static concave press with a very short

contact time. The pressure is about 10 times higher than that in press and CondeBelt drying (De Beer 1998; Boerner and Orloff 1994). Potentially, energy savings can be significant. De Beer (1998) estimates potential savings in drying steam consumption of 50-75%. Another description of impulse drying claims energy savings of about 18-20% or 2 MMBtu per ton of paper (Lockie 1998). Electricity requirements do increase however, by 5-10%. (De Beer 1998). Other reported benefits of this technology include reduced capital costs, increased machine productivity, improved strength, reduced fiber use, and increased recycled fiber content allowed for any given paper strength (Martin et al. 2000; U.S. DOE 1999c). However, current results from pilot operations show limited energy efficiency improvements when compared to state-of-the-art efficient paper machines. Hence, further research is needed to realize the promises of impulse drying.



## **19 Water Efficiency Opportunities in the U.S. Pulp and Paper Industry**

The pulp and paper industry is among the largest industrial process water users in the United States (U.S. DOC 2000). Water is used in significant quantities in all major process stages of pulp and paper manufacture, from raw materials preparation (e.g., wood chip washing) to pulp washing and screening to the paper machine (e.g., fabric showers). Large amounts of water are also used to generate steam for use in processes and on-site power generation, for process cooling, for materials transport, for equipment cleaning, and for general facilities operations. Water is therefore a resource that is as critical as energy in the pulp and paper making process, and one that accounts for considerable operating costs.

Water efficiency is an important strategy for reducing the use of water and its associated costs. Although the U.S. pulp and paper industry has significantly reduced its water use—from an average of 26,700 gallons per ton of product in 1975 to an estimated 16,000 gallons per ton of product in 1995 (Bryant et al. 1996)—opportunities still exist to reduce the use of water in the typical U.S. mill. For example, Gleick et al. (2003) estimate that California's pulp and paper mills could reduce water use by around 40% through process improvements.

Water use is also closely tied to energy use in pulp and paper mills. Energy is required to pressurize, circulate, filter, heat, and treat water throughout the mill. Thus, in addition to reducing water use, many water efficiency improvements can have the added benefit of reducing energy consumption and related fuel costs. Improved water efficiency can also lead to reduced wastewater discharges and reduced water treatment costs, as well as reduced demands on local freshwater sources and wastewater treatment plants.

However, it is important for individual mills to evaluate water efficiency projects holistically, to ensure that other operational variables (e.g., energy use, product quality, water treatment considerations, and operating costs) are not negatively affected by reductions in water use.

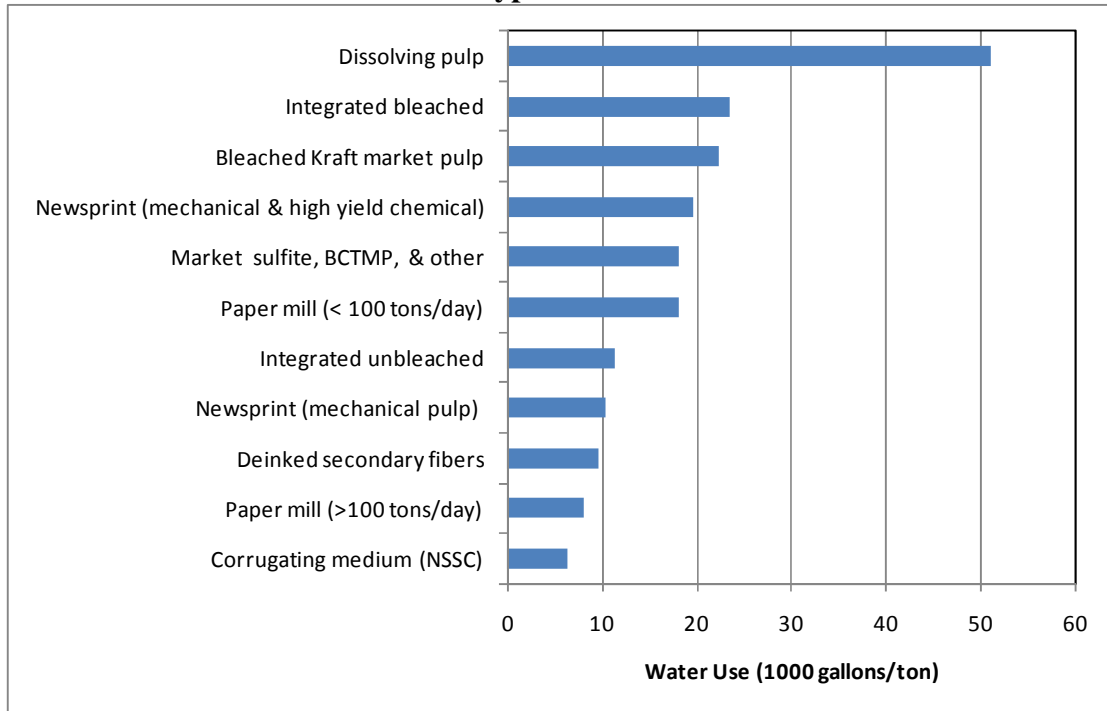
This chapter starts with an overview of the water use and major water end uses of the U.S. pulp and paper industry. Next, select opportunities for water efficiency in a typical pulp and paper mill are discussed. Wherever possible, references to literature and online resources are provided for further information on individual measures and on the topic of industrial water efficiency in general.

### **19.1 Water Use in Pulp and Paper Manufacturing**

As of 1995, the North American pulp and paper industry is estimated to use around 16,000 gallons of freshwater per ton of product produced (Bryant et al. 1996). However, the water use of an individual mill is highly dependent upon the processes it employs (e.g., recycled fiber versus Kraft pulping), the products it produces (e.g., bleached versus unbleached products), its installed equipment, and its water and energy efficiency practices. Figure 17.1 summarizes data from a comprehensive analysis of North American pulp and paper mill

water use (as of 1995), which show that water use intensity varies widely based on mill process and product characteristics.<sup>31</sup>

**Figure 17.1: Mean water use intensity of the North American pulp and paper mills by type of mill**



Source: Bryant et al. (1996)

The vast majority of water in a typical mill is used in process applications such as pulping, bleaching, and paper machine operations. Published estimates suggest that process applications account for around 90% of water use in a typical mill, while boiler water use accounts for around 5% and cooling and other uses account for the remainder (Gleick et al.

<sup>31</sup> More recent data are available from several published information sources. However, these data are limited in their scope and detail compared to the 1995 data from Bryant et al. (1996), which are based on 600+ U.S. and Canadian mills and cover 11 different product categories. For example, recent sustainability reports of paper companies suggest a range of between 7,000 to 15,000 gallons per ton of production, but these data are limited to a small subset of companies (Weyerhaeuser, 2007, StoraEnso, 2007 and Georgia-Pacific, 2007). Gleick et al. (2003) estimate the total water use of pulp mills, paper mills, and paperboard mills in California in 2000, but these data are not disaggregated by product/process type and are not normalized to production output. Several sources (U.S. DOE 2005a; Simko 2004) report estimates of water use intensities for specific processes (e.g., debarking, mechanical pulping, and chemical pulping) but not at the mill level. Several sources provide recent estimates of mill and process water use in Europe, but the extent to which these data are applicable to U.S. mills is not clear. For example, Carpentier (2001) estimates an overall water use intensity of around 9,200 gallons/ton for European operations. Envirowise (2002) reports water use intensities ranging from around 2,000 to over 30,000 gallons per ton for six different product categories, but these data are for U.K. pulp and paper mills. Lastly, a European Commission (2001) report provides benchmark water use rates for various unit processes. However, given their applicability to U.S. mills, the Bryant et al. (1996) data were used here as the most comprehensive estimates of overall water use differences between mill types, with the caveats that they are over a decade old at the time of this writing and should be interpreted as illustrative of differences between mill types.

2003; Bryant et al. 1996). Table 17.1 provides a brief summary of water use by major process step in the manufacture of pulp and paper. The values of water intensity listed in Table 17.1 are estimates based on available data; however, these values can vary widely from mill to mill. Bryant et al. (1996) note that the age of installed equipment has a significant influence on the water efficiency of a mill. Mills that have newer or recently upgraded equipment are generally the most water efficient, while mills with older, more water intensive equipment are typically the least water efficient (Bryant et al. 1996).

**Table 17.1: Main uses of water by pulp and paper process stage**

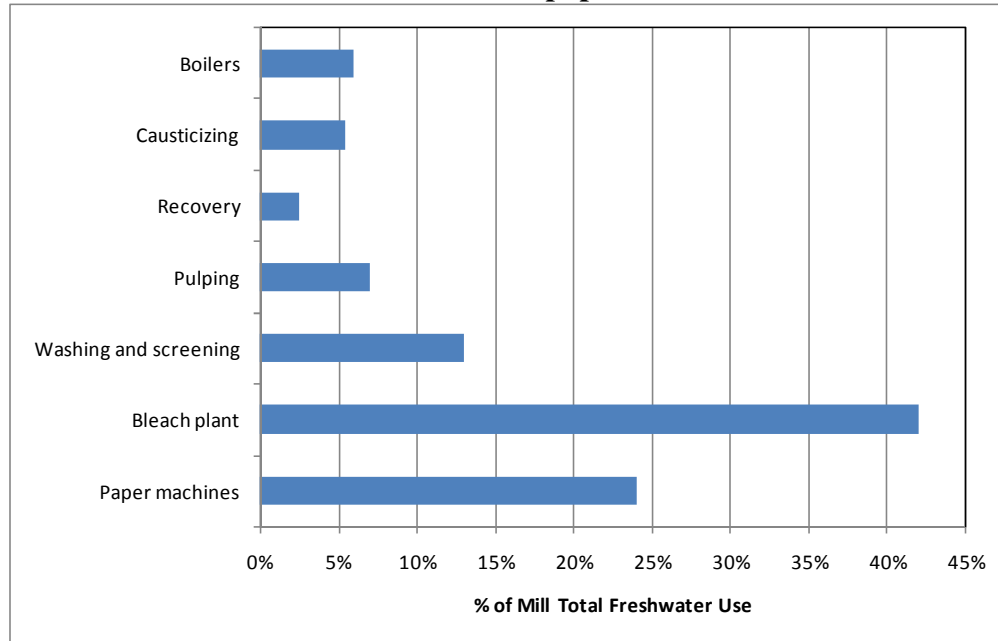
<b>Process Stage</b>	<b>Main Uses of Water</b>
Raw materials preparation	Water is used in deicing, washing, debarking, and fluming operations. Deicing and/or washing can consume around 100-300 gallons per ton of wood debarked. Wet drum and hydraulic debarking methods are most water intensive, but are being phased out of use in the United States as the industry moves toward dry processing techniques. Wet drum debarkers often use reclaimed process water, while hydraulic debarkers typically use fresh water. The estimated water intensity of hydraulic debarkers ranges from 2,500-6,000 gallons per ton of wood debarked.
Pulping	Water is used in large quantities in both mechanical and chemical pulping operations. Chemical pulping is typically more water intensive than mechanical pulping. The water intensity of mechanical pulping has been estimated at 5,000-7,000 gallons per ton of pulp. Water is used in mechanical pulping to aid in fiber separation, to produce the pulp slurry, and to aid in contaminant removal in recycled pulp production. Estimates for the water intensity of chemical pulping are as high as around 30,000 gallons per ton of pulp, due primarily to large amounts of water used in pulp washing (to remove cooking chemicals and lignin byproducts) and pulp screening operations. The water intensity of pulp washing depends heavily on the washing technology employed.
Chemical recovery	Water is primarily used in lime mud washing, in the washing of dregs from green liquor clarification, and in the dissolving of lime and green liquor.
Bleaching	The bleach plant is typically by far the largest user of water in the manufacture of bleached paper products (see Figure 17.2). The water use of bleach plants varies widely based on bleaching techniques and water efficiency practices, but can be as high as around 28,000 gallons per air dry ton and as low as around 2,500 gallons per air dry ton (for ozone bleaching processes). The major uses of water in a typical bleach plant are washer showers (to remove dissolved solids between bleaching stages), hydraulic doctors and wire showers (to aid in pulp discharge and drainage), brownstock dilution, chemical makeup, and direct steam injection.
Papermaking	Water is used in the paper machine to produce the low consistency pulp (~1% pulp) slurry that comprises the initial paper web, for showers that clean and condition machine fabrics and rolls, and for vacuum pump sealing applications. U.S. paper machines have been estimated to use roughly 3,000-8,000 gallons of freshwater per ton.

Sources: Adapted from U.S. EPA (2002), U.S. DOE (2005a), Biermann (1996), Bryant et al. (1996), Stora Enso (2004), and P2Pays (2008)

Figure 17.2 provides a breakdown of water use by process area for a typical integrated Kraft bleached paper mill. It can be seen in Figure 17.2 that the bleach plant represents the most significant use of water, followed by water use in the paper machine. Together, these two

process areas account for around two-thirds of water use in the typical integrated Kraft bleached paper mill. The next largest users of water are Kraft pulping and its associated pulp washing and screening processes. Water efficiency improvements to these high water intensity process areas can thus lead to significant savings.

**Figure 17.2: Water use by process area in a typical integrated Kraft bleached paper mill**



Source: Bryant et al. (1996)

Surface waters are by far the most significant source of freshwater for North American pulp and paper mills. Rivers and lakes account for around three-quarters of freshwater withdrawals, with wells, municipal sources, and mixed supply (i.e., water use from multiple sources not further specified) accounting for the remainder (Bryant et al. 1996).

## 19.2 Pulp and Paper Manufacturing Water Efficiency Measures

The water efficiency measures discussed in this chapter are grouped into two major categories, depending on their general area of applicability: (1) general and facilities water management practices, and (2) process strategies. While there are many opportunities for water efficiency in the typical pulp and paper mill, this chapter focuses primarily on measures drawn from publicly-available sources. Water efficiency audits at individual mills are recommended and may discover additional opportunities. Wherever possible, references to literature and online resources are provided for further information on individual measures and on the topic of industrial water efficiency in general.

### 19.2.1 General and Facilities Water Efficiency

**Strategic water management program.** Similar to a strategic energy management program (discussed in Chapter 6), a strategic, organization-wide water management program can be one of the most successful and cost-effective ways to bring about sustainable water efficiency improvements. Strategic water management programs help to ensure that water efficiency improvements do not just happen on a one-time basis, but rather are continuously identified and implemented in an ongoing process of continuous improvement. In addition to reducing water use and its related costs, other benefits of strategic water management can include improvements in security of mill water supply (which can be a significant issue for mills in drought-affected areas), and better relationships with regulators, employees, and members of the public through the demonstration of sustainable mill water use policies.

Establishing and maintaining a successful industrial water management program generally involves the following key steps (NCDENR 1998; NHDES 2001; CDWR 1994; Envirowise 1998, 2002; Farlow 1996):

- 1) *Establish commitment and goals.* Goals for water savings should be qualitative and included in statements of commitment and company environmental policies. These goals should be communicated to all key stakeholders. A commitment of staff, budget, and resources should be established at the outset of the water management program to ensure success.
- 2) *Line up support and resources.* Internal and external staff and resources should be identified and secured, including a water program manager, with buy in from senior level management. Many of the recommendations for establishing an Energy Team (see Chapter 6) are applicable at this stage. Responsibilities should be clearly defined and communicated so that water management accountability is clear. Water management goals should be fully integrated into existing energy and environmental management systems. Additionally, adequate training should be provided and continuously evaluated to that ensure that good practices are reinforced.
- 3) *Conduct a water audit.* A facility water audit should be performed to identify and document all sources and end uses of water, daily or hourly water consumption rates for all end uses, and water efficiency practices already in place. Performance indicators (e.g., specific water consumption) should be developed and tracked to identify trends in water use and to measure progress over time. Performance indicators should be communicated to all stakeholders via staff meetings, noticeboards, newsletters, annual reports, and other media. The installation of sub-meters to monitor the end uses of water can greatly aid in the accuracy of water audits and subsequent performance monitoring.<sup>32</sup>

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<sup>32</sup> Although sub-metering can greatly aid a mill's auditing and performance tracking programs, the use of sub-meters is still fairly limited across the global pulp and paper industry. For example, a survey of sub-metering in mills in the UK found that only 37% of mills metered water use for production processes and 48% did not know how much water was used in production (Envirowise 2002). This survey further found that the worst metering penetration was for washdown, which is process for which water use can vary dramatically.

- 4) *Identify water management opportunities.* Based on the results of the audit, opportunities for the elimination, reduction, and reuse of water applicable to each end use should be identified. This process should include an assessment of potential recycled water use (e.g., minimum quality, water volume, and flow rate requirements) by end use throughout the mill to identify opportunities for water reuse (e.g., white water reuse). The identification and pursuit of water management opportunities should occur regularly such that a culture of continuous water efficiency improvement is institutionalized. Where appropriate, modeling techniques (e.g., mill water balance simulation) can be used to set targets and evaluate specific opportunities before implementation. Furthermore, to reduce risk mills can also consider running trials before making full-scale changes to mill operations.
- 5) *Prepare an action plan and implementation schedule.* Cost-benefit analyses on all identified opportunities can be performed to determine the most practical ways for meeting the established goals for water efficiency. An action plan with specific goals, timelines, and staff responsibilities for water efficiency updates should be established to implement all feasible opportunities.
- 6) *Track results and publicize successes.* Progress toward established water efficiency goals should be tracked and publicized as a means of highlighting successes and educating personnel on water efficiency. Successes should be acknowledged and awarded on a regular basis.

**Good housekeeping.** A general housekeeping program for facility water systems can ensure that water supplies and end uses continue to operate at optimal efficiency and that potential maintenance issues are identified and addressed promptly. In general, good housekeeping for water efficiency involves the following actions (Envirowise 1998, 2002; NCDNER 1998):

- Inspection of all water connections, piping, hoses, valves, and meters regularly for leaks, with prompt repair of leaks when found.
- Inspection and replacement of faulty valves and fittings.
- Switching off water sprays and hoses when not in use.
- Measuring and optimizing process flow rates.
- Keeping spray nozzles free of dirt and scale.
- Installing water meters on equipment to better enable monitoring and reduction of water consumption.
- Implementing process controls, shielding, and protocols to reduce spills of fibers and chemicals, which can require significant amounts of water for cleanup.

- Disconnecting or removing redundant pipework.

A case study of Weyerhaeuser's Flint River mill, in Oglethorpe, Georgia, demonstrates the water and cost savings benefits of aggressive water management. According to the Georgia Department of Natural Resources (2007), mill personnel placed a high priority on reducing water use and launched a comprehensive initiative to improve water efficiency. Actions included forming a water reduction team to raise awareness, installing flow measurement devices and control valves, resizing and replacing shower nozzles, installing reclamation and reuse systems for cooling water, installing automating shutoff valves in wood yard applications, and instituting a leak repair program (GADNR 2007). During the first six months of this initiative, the use of fresh water was reportedly lowered by about 500,000 gallon per day. It was further estimated that if all water conservation projects identified by the team were completed, future mill water usage will be lowered by about 33% from its previous level (from 11.5 million gallons per day to 7.5 million gallons per day) (Business Wire 2001 and GADNR 2007)

Results of two case studies from the United Kingdom further demonstrate the significant water use and cost savings achievable through improved water management and good housekeeping practices.

The Inveresk Caldwells Mill in Fife, Scotland, produces graphic papers, including security papers which use significant quantities of fresh water. Greater attention to reducing carbon emissions led the mill to more closely monitor all utilities, including water use. A detailed assessment of water metering data revealed to mill staff that water use had increased significantly over a recent two-year period, which led to the discovery of an underground leak in one of the mill's water mains. The leak was estimated to be wasting roughly 300,000 cubic meters of water per year (79 million gallons) at a cost of around £140,000 per year (\$210,000 in 2002 dollars). Since identifying the leak, the mill has continued to save money through monitoring projects and launched work with a local water company to test a water metering system that monitors water consumption continuously (Envirowise 2002).

At a BPB Paperboard Davidson Mill in Aberdeen, Scotland, an environmental management system (EMS) was implemented in 1998 that included the explicit goal of wastewater reduction. The mill produces around 250,000 tons per year using mostly recycled fiber. Mill wastewater reduction targets associated with the EMS resulted in a number of water reduction projects, including a gravity strainer to clarify and recycle wet end water for use in paper machine showers, recycling of starch emulsifier and starch cooking waters, a water pressure control system for paper machine pumps to optimize seal water use, and improved spray nozzle maintenance. In total, such measures reduced specific water use by 16%, from around 1,350 gallons per air dry ton to around 1,130 gallons per air dry ton (Envirowise 2002).

**Cooling towers.** Once-through cooling systems can be replaced by cooling towers, which continuously recycle cooling water and lead to significant water savings. The U.S. DOE (2006m) estimates that to remove the same heat load, once-through cooling systems can use as much as 40 times more water than a cooling tower (operated at 5 cycles of concentration). In a cooling tower, circulating warm water is put into contact with an air flow, which

evaporates some of the water. The heat lost by evaporation cools the remaining water, which can then be recirculated as a cooling medium.

The U.S. DOE (2006n) offers the following guidelines for operating cooling towers at optimal water efficiency:

- Consider using acid treatment (e.g., sulfuric or ascorbic acid), where appropriate. Acids can improve water efficiency by controlling scale buildup created from mineral deposits.
- Install a sidestream filtration system that is composed of a rapid sand filter or high-efficiency cartridge filter to cleanse the water. These systems enable the cooling tower to operate more efficiently with less water and chemicals.
- Consider alternative water treatment options such as ozonation or ionization, to reduce water and chemical usage.
- Install automated chemical feed systems on large cooling tower systems (over 100 tons). The automated feed system should control bleed-off by conductivity and add chemicals based on makeup water flow. Automated chemical feed systems minimize water and chemical use while optimizing control against scale, corrosion and biological growth.

**Reducing cooling tower bleed-off.** Cooling tower “bleed-off” refers to water that is periodically drained from the cooling tower basin to prevent the accumulation of solids. Bleed-off volumes can often be reduced by allowing higher concentrations of suspended and dissolved solids in the circulating water, which saves water. The challenge is to find the optimal balance between bleed-off and makeup water concentrations (i.e., the concentration ratio) without forming scales. The water savings associated with this measure can be as high as 20% (Galitsky et al. 2005b).

In an example from the food industry, Ventura Coastal Plant, a manufacturer of citrus oils and frozen citrus juice concentrates in Ventura County, California, was able to increase the concentration ratios of its cooling towers and evaporative coolers such that bleed-off water volumes were reduced by 50%. The water savings amounted to almost 5,200 gallons per day, saving the company \$6,940 per year in water costs (CDWR 1994). With capital costs of \$5,000, the simple payback period was estimated at around seven months.

**Once-through cooling water reuse.** In applications where once-through cooling replacement isn’t feasible, it may be possible to collect cooling water in storage tanks for reuse in process applications (such as shower water). This measure involves the installation of additional pipes, pumps, and tanks to the extent dictated by where cooling water is used in a mill in relation to its suitable process applications. Additionally, the higher temperature of used cooling water can be an advantage in some shower applications (Envirowise 1998).



**Minimizing hose water use.** When hoses are used for cleaning and rinsing applications within the mill, proper management can lead to significant water savings. All applications of hoses should be assessed, and, where feasible, the smallest possible diameter hoses should be installed. Small diameter hoses provide a low flow, high pressure condition, which can reduce the volume of water required for a given task (Lom and Associates 1998). Additional strategies for minimizing hose water use in pulp and paper mills include fitting all hoses with triggers to ensure that they cannot be left running or leaking when unattended; installing high-pressure, low-volume systems; and reviewing the need for hoses in individual locations (Envirowise 1998).

**Use of water efficient building fixtures.** For building fixtures such as toilets, showers, and faucets, water efficient designs can be installed that lead to significant water savings. For example, low-flow toilets typically require only 1.6 gallons per flush, compared to 3.5 gallons per flush required for standard toilets (Galitsky et al. 2005b). Additional options include low-flow shower heads, aerating faucets, self-closing faucets, and proximity sensing faucets that turn on and off automatically.<sup>33</sup> Although the water savings achievable through such measures will be much smaller than the savings that might be realized through process improvements, these measures are highly visible to plant personnel and can help reinforce a corporate culture of continuous water management and a commitment to water efficiency improvement.

## 19.2.2 Process-Related Water Efficiency Measures

**Dry debarking.** Many mills are moving away from wet debarking methods (i.e., wet drum debarkers or hydraulic debarkers), which require large amounts of water to remove bark from logs and can result in high effluent generation. In contrast, in dry debarking process water is used only for log washing and de-icing (as needed), and it is recirculated with minimum generation of wastewater and water pollutants (European Commission 2001). Additionally, dry debarking generates bark with lower water content, which means that less water must be evaporated when it is combusted as hog fuel. According to a study by the European Commission (2001), wet debarkers generate between 800 and 2,600 gallons of wastewater per ton of pulp, while dry debarkers will only generate between 130 and 660 gallons of wastewater per ton of pulp. When a wet debarking system is converted to a dry system, the costs of equipment and installation (as of 1999) have been estimated at \$4-6 million (European Commission 2001).

**Optimizing shower water use.** Paper machine showers represent one of the largest end uses of freshwater in a typical paper mill. It has been estimated that even well designed showers can require 2,600 gallons of water per ton of product (Envirowise 1998). The UK's Environmental Technology Best Practice Programme estimates that, for shower systems that haven't been designed to optimize water use, the use of shower water can be reduced by an order of magnitude (Envirowise 1998). Actions they recommend to optimize shower water use include the following:

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<sup>33</sup> For additional information on water-saving fixtures and appliances, visit the U.S. EPA's WaterSense website at <http://www.epa.gov/owm/water-efficiency/> and the U.S. DOE's Federal Energy Management Program Water Efficiency website at [http://www.eere.energy.gov/femp/technologies/water\\_efficiency.cfm](http://www.eere.energy.gov/femp/technologies/water_efficiency.cfm).

- adjusting the total number of shower nozzles, their positions, jet angles, and the distance between nozzles and the paper machine felt/wire to minimize water use;
- varying water temperatures and pressures to determine whether effective cleaning can be achieved at lower temperatures and flow rates;
- using different types of nozzles that use less water, such as flat or needle jet;
- using sprays intermittently (e.g., for 10 minutes/hour);
- using steam condenser cooling water in showers.

**Water efficient bleaching.** “Closed cycle bleaching” has been a visionary goal of the industry for decades; the term refers to bleaching processes with the recovery and recycling of all pulping and bleaching process wastewater (CEC 2007). In the late 1970s, Great Lakes Forest Products' Kraft mill in Thunder Bay, Canada, was the first to implement a closed-cycle bleaching process, but this mill was reportedly forced to abandon closed-cycle operations in 1988 due to poor economics and operational problems (Bryant et al. 1996). While closed cycle bleaching operations may not yet be practical, it is possible for bleach plants that use advanced technologies to operate in a very water efficient, near closed-cycle fashion, with low freshwater use and wastewater discharges.

One example of such a system is an ozone system employed by International Paper (formerly Union Camp) at its mill in Franklin, Virginia. The system reuses ozone and caustic extraction stage filtrates in a counter current fashion to its post-oxygen delignification washers (Bryant et al. 1996). Reportedly, this is possible because ozone-stage filtrate does not contain the chlorides found in conventional chlorine-based bleach-stage filtrates. The mill's last bleach stage uses  $\text{ClO}_2$  with filtrate sent to the sewer; also, a small purge of the acid-wash stage prior to the ozone stage is reportedly required to control calcium scaling. The Franklin mill has a bleach effluent flow of only 2,500 gallons/ton, which (in 1995) was one of the lowest bleach plant water use or discharge rates in the United States.

**Improving white water quality.** The clarification of white water can lead to significant benefits, including the recovery of fiber for reuse, reduced suspended solids loads, and the possibility of re-using clarified water in other facility applications to reduce mill freshwater demand (see for example the measure “use clarified water as vacuum pump seal water”) (Envirowise 1998). Proven clarification technologies include disc and drum filters, inclined screens, dissolved air flotation, and gravity sedimentation (European Commission 2001; Envirowise 1998). The reuse of clarified white water for paper machine showers requires a high level of clarification and proper shower design to prevent nozzle plugging and/or sheet defects (Bryant et al. 1996).<sup>34</sup>

Envirowise (1998) describes two case studies from the United Kingdom that highlight the savings achievable through white water clarification. First, a fine paper mill installed stock

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<sup>34</sup> Envirowise (1998) offers a table of examples of where white water can typically be used in paper machine showers, as well as guidelines published by one equipment manufacturer for the limiting solids contents for shower duties in paper machines. Such guidelines should be consulted before considering the use of clarified water in shower applications.

thickeners on a number of machines, which, along with improvements to the broke and white water systems, produced cost savings in recovered fiber of more than \$1.28 million per year (in 1995 dollars). Additionally, fresh water consumption reportedly fell by 20%. Second, a tissue mill installed three dissolved air flotation units to recycle fiber and water from paper machines and a de-inking plant. The capital cost of the system was approximately \$3 million (in 1998 dollars), but the resulting fiber and water recovery resulted in a payback period of only two years. Additionally, effluent suspended solids concentration was significantly reduced and helped to improve compliance with effluent discharge limits.

An energy and water systems pinch analysis of the Weyerhaeuser mill in Longview, Washington, identified plant-wide opportunities for reusing white water that could amount to water savings of 1,250 gallons per minute, natural gas savings of 100,000 MMBtu per year, and cost savings of \$220,000 per year (U.S. DOE 2004f).

**Vacuum pump seal water conservation.** The use of a fresh water supply for vacuum pump seal water can be minimized by several proven methods. Since a vacuum system with a once-through water system can use from 0.5 to 2.0 million gallons of water per day it is important to minimize this water consumption. Many systems are consuming excess water, up to 25% more, because supply pressures are not well controlled, or necessary valve, orifices and spray nozzles have been removed or are not maintained. Once the seal water is better controlled, there are options for reducing the flow by 50 to 95% (Sweet 2009a).

Water reduction of at least 50% can be possible by cascading water from high vacuum pumps to lower vacuum pumps in the system. Reductions of 90 to 95% are possible with a closed-loop system that is controlled for temperature, solids buildup, and biological growth. Often a cooling tower is used for maintaining temperature in closed loop systems. However, this introduces an added process for the paper mill. Well designed systems will have good pre-separation systems to minimize whitewater carryover from the paper machine. Also, filters are used to remove fiber and scale. Water treatment can include biocides and corrosion inhibitors. Some mills have had success with allowing the vacuum system to heat incoming water with the seal water system, with special attention to air/water separators. Some mills have permitted the vacuum pump seal water system as a non-contact cooling system where water quality is closely monitored. Discharged seal water is then pumped to the mill's effluent outfall without treatment (Sweet 2009a).

For a more comprehensive treatment of seal water treatment and conservation, the reader is referred to Blake and Sweet (2001).

On recent example of a seal water conservation opportunity relates to a U.S. DOE sponsored energy assessment (U.S. DOE 2004g) at the Blue Heron Paper Company mill in Oregon City, Oregon. The audit revealed an opportunity to recycle 75% of the vacuum pump seal water from the mill's #4 paper machine. An audit team recommended to first route this flow through the mill's #1 paper machine for use as vacuum pump seal water, then route the water to the de-ink process water clarifier showers to reduce filtered water usage as well as the net amount of steam required in the paper mill. Furthermore, the re-circulated vacuum pump seal water for each paper machine would be used to heat water required for the paper machine. It

was estimated that these improvements would reduce effluent flow by around 1.6 million gallons per day, with the added benefits of reduced heat load discharge and energy cost reductions (U.S. DOE 2004g).

**Direct white water reuse.** Where water quality (e.g., microbial counts and solids content) is acceptable, white water may be used in general floor cleaning applications or to lubricate low-vacuum boxes on the paper machine (Envirowise 1998). However, this measure depends highly on the minimum water quality necessary for the intended end use, which should be verified before application of this measure.

**Mechanical pump seals.** Where feasible, liquid ring seals can be replaced by mechanical face seals and lip seals to eliminate the use of seal water. However, replacing water seals with mechanical seals can increase pump energy use due to increased friction (P2PAYS 2008). An International Paper (formerly Union Camp) mill in Savannah, Georgia, reportedly replaced water lubricated seals with mechanical seals with a 95% success rate, and claimed reduced water usage, reduced equipment damage, reduced water contamination, and reduced maintenance time (P2PAYS 2008). In another example, the introduction of mechanical seals on 70 pumps in a UK tissue mill reduced water consumption by 66,000 gallons per day, which was an amount equivalent to 1,320 gallons per ton of product (Envirowise 1998).

**Chemi (belt) washer.** As discussed in Table 17.1, pulp washing is one of the largest end uses of water in a typical Kraft pulp and paper mill. A Chemi or belt washer can be employed to minimize the water usage associated with pulp washing, without sacrificing cleaning ability. This process employs a counter current washing approach, in which pulp is washed on a belt with a series of showers using progressively cleaner water. Used wash water is collected and reapplied to the dirty pulp entering the washing unit for several cycles until the wash water is saturated with liquor (P2PAYS 2008). The saturated wash water is then sent to a recovery process. At least two mills in Georgia are known to use Chemi washers (P2PAYS 2008). An analysis by the U.S. EPA suggests that capital costs (for the Chemi washer and supporting systems) are around \$10-\$12 million (in 1993 dollars), with annual operating cost savings (including water and energy savings) of around \$4.67 per ton of pulp and an average payback period of around 4.5 years (U.S. EPA 1993).

**Carbon dioxide brownstock washing.** The injection of CO<sub>2</sub> into the wash water of brownstock washers reportedly improves pulp drainage, which can enhance washing efficiency and lead to improved throughput and reduced water usage. One published estimate suggests that CO<sub>2</sub> injection in brownstock washing could lead to a 10% reduction in wash water use (Focus on Energy 2006a).

## 20 Summary and Conclusions

The U.S. pulp and paper industry spent roughly \$7.5 billion on purchased fuels and electricity in 2006, making energy use a significant cost driver for the industry. Energy efficiency improvement is an important way to reduce these costs and to increase predictable earnings in the face of ongoing energy price volatility. Many companies in the U.S. pulp and paper producing industry have already accepted the challenge to improve their energy efficiency and have begun to reap the rewards of energy efficiency investments.

This Energy Guide has summarized a number of energy-efficient technologies and practices that are cost-effective and available for implementation today. Energy efficiency improvement opportunities have been discussed that are applicable at the component, process, facility, and organizational levels. Preliminary estimates of savings in energy and energy-related costs have been provided for many energy efficiency measures, based on case study data from real-world industrial applications. Additionally, typical investment payback periods and references to further information in the technical literature have been provided, when available.

A key first step in any energy improvement initiative is to establish a focused and strategic energy management program, as depicted in Figure 6.1. An energy management program will help companies identify and implement energy efficiency measures and practices across and organization and ensure continuous improvement.

Tables 5.1 to 5.3 summarized the energy efficiency measures presented in this Energy Guide. While the expected savings associated with some of the individual measures in Tables 5.1 to 5.3 may be relatively small, the cumulative effect of these measures across an entire plant may potentially be quite large. Many of the measures in Tables 5.1 to 5.3 have relatively short payback periods and are therefore attractive economic investments on their own merit. The degree of implementation of these measures will vary by plant and end use; continuous evaluation of these measures will help to identify further cost savings in ongoing energy management programs.

In recognition of the importance of water as a resource in the U.S. pulp and paper industry, as well as its rising costs, this Energy Guide also provided information on basic measures for improving plant-level water efficiency. These measures were summarized in Table 5.4.

For all energy and water efficiency measures presented in this Energy Guide, individual plants should pursue further research on the economics of the measures, as well as on the applicability of different measures to their own unique production practices, in order to assess the feasibility of measure implementation.

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## **Appendix A: Basic Energy Efficiency Actions for Plant Personnel**

Personnel at all levels should be aware of energy use and organizational goals for energy efficiency. Staff should be trained in both skills and general approaches to energy efficiency in day-to-day practices. In addition, performance results should be regularly evaluated and communicated to all personnel, recognizing high achievement. Some examples of simple tasks employees can do are outlined below (Caffal 1995).

- Eliminate unnecessary energy consumption by equipment. Switch off motors, fans, and machines when they are not being used, especially at the end of the working day or shift, and during breaks, when it does not affect production, quality, or safety. Similarly, turn on equipment no earlier than needed to reach the correct settings (temperature, pressure) at the start time.
- Switch off unnecessary lights; rely on daylighting whenever possible.
- Use weekend and night setbacks on HVAC in offices or conditioned buildings.
- Report leaks of water (both process water and dripping taps), steam, and compressed air. Ensure they are repaired quickly. The best time to check for leaks is a quiet time like the weekend.
- Look for unoccupied areas being heated or cooled, and switch off heating or cooling.
- Check that heating controls are not set too high or cooling controls set too low. In this situation, windows and doors are often left open to lower temperatures instead of lowering the heating.
- Check to make sure the pressure and temperature of equipment is not set too high.
- Prevent drafts from badly fitting seals, windows and doors, and hence, leakage of cool or warm air.
- Carry out regular maintenance of energy-consuming equipment.
- Ensure that the insulation on process heating equipment is effective.

## Appendix B: Guidelines for Energy Management Assessment Matrix



### Introduction

The U.S. EPA has developed guidelines for establishing and conducting an effective energy management program based on the successful practices of ENERGY STAR partners.

These guidelines, illustrated in the graphic, are structured on seven fundamental management elements that encompass specific activities.

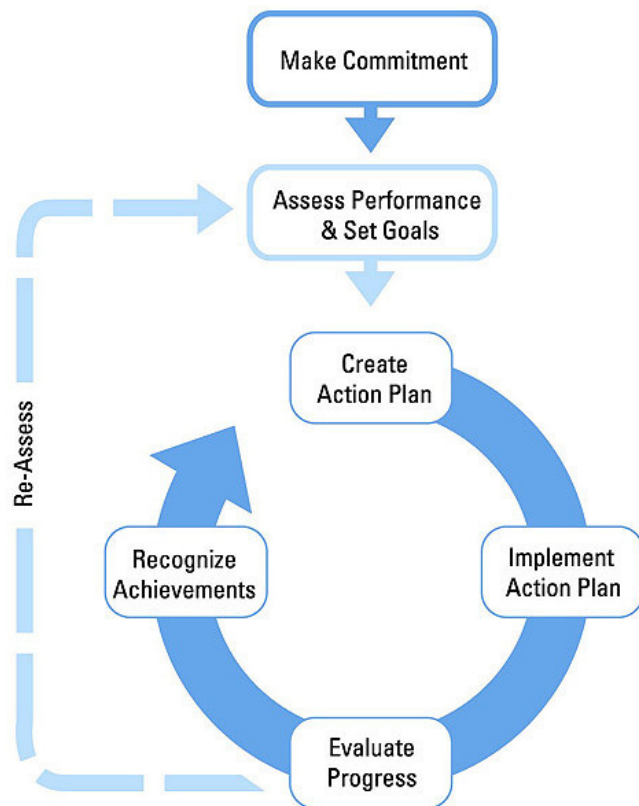
This assessment matrix is designed to help organizations and energy managers compare their energy management practices to those outlined in the Guidelines. The full Guidelines can be viewed on the ENERGY STAR web site – <http://www.energystar.gov/>.

### How To Use The Assessment Matrix

The matrix outlines the key activities identified in the ENERGY STAR Guidelines for Energy Management and three levels of implementation:

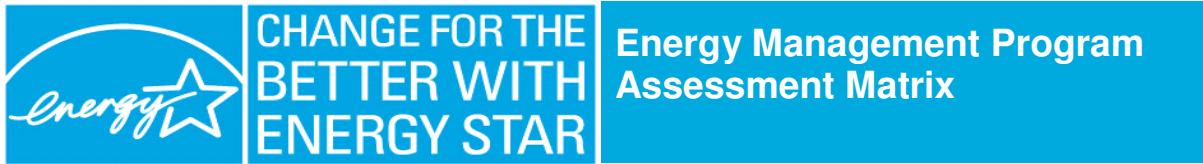
- No evidence
- Most elements
- Fully Implemented

1. Print the assessment matrix.
2. Compare your program to the Guidelines by identifying the degree of implementation that most closely matches your organization's program.
3. Use a highlighter to fill in the cell that best characterizes the level of implementation of your program. You will now have a visual comparison of your program to the elements of the ENERGY STAR Guidelines for Energy Management.
4. Identify the steps needed to fully implement the energy management elements and record these in the Next Steps column.



<b>Energy Management Program Assessment Matrix</b>				
	<b>Little or no evidence</b>	<b>Some elements</b>	<b>Fully implemented</b>	<b>Next Steps</b>
<b>Make Commitment to Continuous Improvement</b>				
<b>Energy Director</b>	No central corporate resource Decentralized management	Corporate or organizational resource not empowered	Empowered corporate leader with senior management support	
<b>Energy Team</b>	No company energy network	Informal organization	Active cross-functional team guiding energy program	
<b>Energy Policy</b>	No formal policy	Referenced in environmental or other policies	Formal stand-alone EE policy endorsed by senior mgmt.	
<b>Assess Performance and Opportunities</b>				
<b>Gather and Track Data</b>	Little metering/no tracking	Local or partial metering/tracking/reporting	All facilities report for central consolidation/analysis	
<b>Normalize</b>	Not addressed	Some unit measures or weather adjustments	All meaningful adjustments for corporate analysis	
<b>Establish baselines</b>	No baselines	Various facility-established	Standardized corporate base year and metric established	
<b>Benchmark</b>	Not addressed or only same site historical comparisons	Some internal comparisons among company sites	Regular internal & external comparisons & analyses	
<b>Analyze</b>	Not addressed	Some attempt to identify and correct spikes	Profiles identifying trends, peaks, valleys & causes	
<b>Technical assessments and audits</b>	Not addressed	Internal facility reviews	Reviews by multi-functional team of professionals	
<b>Set Performance Goals</b>				
<b>Determine scope</b>	No quantifiable goals	Short term facility goals or nominal corporate goals	Short & long term facility and corporate goals	
<b>Estimate potential for improvement</b>	No process in place	Specific projects based on limited vendor projections	Facility & corporate defined based on experience	
<b>Establish goals</b>	Not addressed	Loosely defined or sporadically applied	Specific & quantifiable at various organizational levels	
<b>Create Action Plan</b>				
<b>Define technical steps and targets</b>	Not addressed	Facility-level consideration as opportunities occur	Detailed multi-level targets with timelines to close gaps	
<b>Determine roles and resources</b>	Not addressed or done on ad hoc basis	Informal interested person competes for funding	Internal/external roles defined & funding identified	

<b>Energy Management Program Assessment Matrix</b>				
	<b>Little or no evidence</b>	<b>Some elements</b>	<b>Fully implemented</b>	<b>Next Steps</b>
<b>Implement Action Plan</b>				
<b>Create a communication plan</b>	Not addressed	Tools targeted for some groups used occasionally	All stakeholders are addressed on regular basis	
<b>Raise awareness</b>	No promotion of energy efficiency	Periodic references to energy initiatives	All levels of organization support energy goals	
<b>Build capacity</b>	Indirect training only	Some training for key individuals	Broad training/certification in technology & best practices	
<b>Motivate</b>	No or occasional contact with energy users and staff	Threats for non-performance or periodic reminders	Recognition, financial & performance incentives	
<b>Track and monitor</b>	No system for monitoring progress	Annual reviews by facilities	Regular reviews & updates of centralized system	
<b>Evaluate Progress</b>				
<b>Measure results</b>	No reviews	Historical comparisons	Compare usage & costs vs. goals, plans, competitors	
<b>Review action plan</b>	No reviews	Informal check on progress	Revise plan based on results, feedback & business factors	
<b>Recognize Achievements</b>				
<b>Provide internal recognition</b>	Not addressed	Identify successful projects	Acknowledge contributions of individuals, teams, facilities	
<b>Get external recognition</b>	Not sought	Incidental or vendor acknowledgement	Government/third party highlighting achievements	



### **Interpreting Your Results**

Comparing your program to the level of implementation identified in the Matrix should help you identify the strengths and weaknesses of your program.

The U.S. EPA has observed that organizations fully implementing the practices outlined in the Guidelines achieve the greatest results. Organizations are encouraged to implement the Guidelines as fully as possible.

By highlighting the cells of the matrix, you now can easily tell how well balanced your energy program is across the management elements of the Guidelines. Use this illustration of your energy management program for discussion with staff and management.

Use the "Next Steps" column of the Matrix to develop a plan of action for improving your energy management practices.

### **Resources and Help**

ENERGY STAR offers a variety tools and resources to help organizations strengthen their energy management programs.

Here are some next steps you can take with ENERGY STAR:

1. Read the Guidelines sections for the areas of your program that are not fully implemented.
2. Become an ENERGY STAR Partner, if you are not already.
3. Review ENERGY STAR Tools and Resources.
4. Find more sector-specific energy management information at <http://www.energystar.gov/industry>.
5. Contact ENERGY STAR for additional resources.

## Appendix C: Teaming Up to Save Energy Checklist

The following checklist can be used as a handy reference to key tasks for establishing and sustaining an effective energy team. For more detailed information on energy teams, consult the U.S. EPA's *Teaming Up to Save Energy* guide (U.S. EPA 2006), which is available at <http://www.energystar.gov/>.

<b>ORGANIZE YOUR ENERGY TEAM</b>		(
<b>Energy Director</b>	<b>Able to work with all staff levels from maintenance to engineers to financial officers. Senior-level person empowered by top management support</b>	
<b>Senior Management</b>	<b>Energy director reports to senior executive or to a senior management council. Senior champion or council provides guidance and support</b>	
<b>Energy Team</b>	<b>Members from business units, operations/engineering, facilities, and regions. Energy networks formed. Support services (PR, IT, HR).</b>	
<b>Facility Involvement</b>	<b>Facility managers, electrical personnel. Two-way information flow on goals and opportunities. Facility-based energy teams with technical person as site champion.</b>	
<b>Partner Involvement</b>	<b>Consultants, vendors, customers, and joint venture partners. Energy savings passed on through lower prices.</b>	
<b>Energy Team Structure</b>	<b>Separate division and/or centralized leadership. Integrated into organization's structure and networks established.</b>	
<b>Resources &amp; Responsibilities</b>	<b>Energy projects incorporated into normal budget cycle as line item. Energy director is empowered to make decisions on projects affecting energy use. Energy team members have dedicated time for the energy program.</b>	
<b>STARTING YOUR ENERGY TEAM</b>		(
<b>Management Briefing</b>	<b>Senior management briefed on benefits, proposed approach, and potential energy team members.</b>	
<b>Planning</b>	<b>Energy team met initially to prepare for official launch.</b>	
<b>Strategy</b>	<b>Energy team met initially to prepare for official launch.</b>	
<b>Program Launch</b>	<b>Organizational kickoff announced energy network, introduced energy director, unveiled energy policy, and showcased real-world proof.</b>	
<b>Energy Team Plans</b>	<b>Work plans, responsibilities, and annual action plan established.</b>	
<b>Facility Engagement</b>	<b>Facility audits and reports conducted. Energy efficiency opportunities identified.</b>	



<b>BUILDING CAPACITY</b>		√
Tracking and Monitoring	Systems established for tracking energy performance and best practices implementation.	
Transferring Knowledge	Events for informal knowledge transfer, such as energy summits and energy fairs, implemented.	
Raising Awareness	Awareness of energy efficiency created through posters, intranet, surveys, and competitions.	
Formal Training	Participants identified, needs determined, training held. Involvement in ENERGY STAR Web conferences and meetings encouraged. Professional development objectives for key team members.	
Outsourcing	Use of outside help has been evaluated and policies established.	
Cross-Company Networking	Outside company successes sought and internal successes shared. Information exchanged to learn from experiences of others.	
<b>SUSTAINING THE TEAM</b>		√
Effective Communications	Awareness of energy efficiency created throughout company. Energy performance information is published in company reports and communications.	
Recognition and Rewards	Internal awards created and implemented. Senior management is involved in providing recognition.	
External Recognition	Credibility for your organization's energy program achieved. Awards from other organizations have added to your company's competitive advantage.	
<b>MAINTAINING MOMENTUM</b>		√
Succession	Built-in plan for continuity established. Energy efficiency integrated into organizational culture.	
Measures of Success	Sustainability of program and personnel achieved. Continuous improvement of your organization's energy performance attained.	

## **Appendix D: Support Programs for Industrial Energy Efficiency Improvement**

This appendix provides a list of energy efficiency support available to industry. A brief description of the program or tool is given, as well as information on its target audience and the URL for the program. Included are federal and state programs. Use the URL to obtain more information from each of these sources. An attempt was made to provide as complete a list as possible; however, information in this listing may change with the passage of time.

### **Tools for Self-Assessment**

#### **Paper Machine Energy Scorecard**

Description: The U.S. DOE funded scorecard system has Excel spreadsheets with a series of energy-related questions that provides benchmarking and helps identify opportunities for reducing energy consumption. Energy performance targets for 10 different paper grades are included.

Target Group: Pulp and paper mills

Format: MS Excel, available by email at no charge

Contact: Dick Reese and Associates, (771) 448-8002

#### **Steam System Assessment Tool**

Description: Software package to evaluate energy efficiency improvement projects for steam systems. It includes an economic analysis capability.

Target Group: Any industry operating a steam system

Format: Downloadable software package (13.6 MB)

Contact: U.S. Department of Energy

URL: <http://www1.eere.energy.gov/industry/bestpractices/software.html>

#### **Steam System Scoping Tool**

Description: Spreadsheet tool for plant managers to identify energy efficiency opportunities in industrial steam systems.

Target Group: Any industrial steam system operator

Format: Downloadable software (Excel)

Contact: U.S. Department of Energy

URL: <http://www1.eere.energy.gov/industry/bestpractices/software.html>

#### **3E Plus: Optimization of Insulation of Boiler Steam Lines**

Description: Downloadable software to determine whether boiler systems can be optimized through the insulation of boiler steam lines. The program calculates the most economical thickness of industrial insulation for a variety of operating conditions. It makes calculations using thermal performance relationships of generic insulation materials included in the software.

Target Group: Energy and plant managers

Format: Downloadable software

Contact: U.S. Department of Energy

URL: <http://www1.eere.energy.gov/industry/bestpractices/software.html>

**MotorMaster+**

Description: Energy-efficient motor selection and management tool, including a catalog of over 20,000 AC motors. It contains motor inventory management tools, maintenance log tracking, efficiency analysis, savings evaluation, energy accounting, and environmental reporting capabilities.

Target Group: Any industry

Format: Downloadable software (can also be ordered on CD)

Contact: U.S. Department of Energy

URL: <http://www1.eere.energy.gov/industry/bestpractices/software.html>

**The 1-2-3 Approach to Motor Management**

Description: A step-by-step motor management guide and spreadsheet tool that can help motor service centers, vendors, utilities, energy-efficiency organizations, and others convey the financial benefits of sound motor management.

Target Group: Any industry

Format: Downloadable Microsoft Excel spreadsheet

Contact: Consortium for Energy Efficiency (CEE), (617) 589-3949

URL: <http://www.motorsmatter.org/tools/123approach.html>

**AirMaster+: Compressed Air System Assessment and Analysis Software**

Description: Modeling tool that maximizes the efficiency and performance of compressed air systems through improved operations and maintenance practices

Target Group: Any industry operating a compressed air system

Format: Downloadable software

Contact: U.S. Department of Energy

URL: <http://www1.eere.energy.gov/industry/bestpractices/software.html>

**Fan System Assessment Tool (FSAT)**

Description: The Fan System Assessment Tool (FSAT) helps to quantify the potential benefits of optimizing a fan system. FSAT calculates the amount of energy used by a fan system, determines system efficiency, and quantifies the savings potential of an upgraded system.

Target Group: Any user of fans

Format: Downloadable software

Contact: U.S. Department of Energy

URL: <http://www1.eere.energy.gov/industry/bestpractices/software.html>

### **Combined Heat and Power Application tool (CHP)**

Description: The Combined Heat and Power Application Tool (CHP) helps industrial users evaluate the feasibility of CHP for heating systems such as fuel-fired furnaces, boilers, ovens, heaters, and heat exchangers.

Target Group: Any industrial heat and electricity user

Format: Downloadable software

Contact: U.S. Department of Energy

URL: <http://www1.eere.energy.gov/industry/bestpractices/software.html>

### **Pump System Assessment Tool 2004 (PSAT)**

Description: The tool helps industrial users assess the efficiency of pumping system operations. PSAT uses achievable pump performance data from Hydraulic Institute standards and motor performance data from the MotorMaster+ database to calculate potential energy and associated cost savings.

Target Group: Any industrial pump user

Format: Downloadable software

Contact: U.S. Department of Energy

URL: <http://www1.eere.energy.gov/industry/bestpractices/software.html>

### **Quick Plant Energy Profiler**

Description: The Quick Plant Energy Profiler, or Quick PEP, is an online software tool provided by the U.S. Department of Energy to help industrial plant managers in the United States identify how energy is being purchased and consumed at their plant and also identify potential energy and cost savings. Quick PEP is designed so that the user can complete a plant profile in about an hour. The Quick PEP online tutorial explains what plant information is needed to complete a Quick PEP case.

Target Group: Any industrial plant

Format: Online software tool

Contact: U.S. Department of Energy

URL: <http://www1.eere.energy.gov/industry/bestpractices/software.html>

### **ENERGY STAR Portfolio Manager**

Description: Online software tool helps to assess the energy performance of buildings by providing a 1-100 ranking of a building's energy performance relative to the national building market. Measured energy consumption forms the basis of the ranking of performance.

Target Group: Any building user or owner

Format: Online software tool

Contact: U.S. Environmental Protection Agency

URL: [http://www.energystar.gov/index.cfm?c=evaluate\\_performance.bus\\_portfoliomanager](http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager)

## **Assessment and Technical Assistance**

### **Industrial Assessment Centers**

Description: Small- to medium-sized manufacturing facilities can obtain a free energy and waste assessment. The audit is performed by a team of engineering faculty and students from 30 participating universities in the U.S. and assesses the plant's performance and recommends ways to improve efficiency.

Target Group: Small- to medium-sized manufacturing facilities with gross annual sales below \$75 million and fewer than 500 employees at the plant site.

Format: A team of engineering faculty and students visits the plant and prepares a written report with energy efficiency, waste reduction and productivity recommendations.

Contact: U.S. Department of Energy

URL: <http://www1.eere.energy.gov/industry/bestpractices/iacs.html>

### **Save Energy Now Assessments**

Description: The U.S. DOE conducts plant energy assessments to help manufacturing facilities across the nation identify immediate opportunities to save energy and money, primarily by focusing on energy-intensive systems, including process heating, steam, pumps, fans, and compressed air.

Target Group: Large plants

Format: Online request

Contact: U.S. Department of Energy

URL: <http://www1.eere.energy.gov/industry/saveenergynow/>

### **Manufacturing Extension Partnership (MEP)**

Description: MEP is a nationwide network of not-for-profit centers in over 400 locations providing small- and medium-sized manufacturers with technical assistance. A center provides expertise and services tailored to the plant, including a focus on clean production and energy-efficient technology.

Target Group: Small- and medium-sized plants

Format: Direct contact with local MEP Office

Contact: National Institute of Standards and Technology, (301) 975-5020

URL: <http://www.mep.nist.gov/>

### **Small Business Development Center (SBDC)**

Description: The U.S Small Business Administration (SBA) administers the Small Business Development Center Program to provide management assistance to small businesses through 58 local centers. The SBDC Program provides counseling, training and technical assistance in the areas of financial, marketing, production, organization, engineering and technical problems and feasibility studies, if a small business cannot afford consultants.

Target Group: Small businesses

Format: Direct contact with local SBDC

Contact: Small Business Administration, (800) 8-ASK-SBA

URL: <http://www.sba.gov/sbdc/>

### **ENERGY STAR – Selection and Procurement of Energy-Efficient Products for Business**

Description: ENERGY STAR identifies and labels energy-efficient office equipment. Look for products that have earned the ENERGY STAR. They meet strict energy efficiency guidelines set by the EPA. Office equipment included such items as computers, copiers, faxes, monitors, multifunction devices, printers, scanners, transformers and water coolers.

Target Group: Any user of labeled equipment.

Format: Website

Contact: U.S. Environmental Protection Agency

URL: [http://www.energystar.gov/index.cfm?c=business.bus\\_index](http://www.energystar.gov/index.cfm?c=business.bus_index)

### **Training**

#### **ENERGY STAR**

Description: As part of ENERGY STAR's work to promote superior energy management systems, energy managers for the companies that participate in ENERGY STAR are offered the opportunity to network with other energy managers in the partnership. The networking meetings are held monthly and focus on a specific strategic energy management topic to train and strengthen energy managers in the development and implementation of corporate energy management programs.

Target Group: Corporate and plant energy managers

Format: Web-based teleconference

Contact: Climate Protection Partnerships Division, U.S. Environmental Protection Agency

URL: <http://www.energystar.gov/>

#### **Best Practices Program**

Description: The U.S. DOE Best Practices Program provides training and training materials to support the efforts of the program in efficiency improvement of utilities (compressed air, steam) and motor systems (including pumps). Training is provided regularly in different regions. One-day or multi-day trainings are provided for specific elements of the above systems. The Best Practices program also provides training on other industrial energy equipment, often in coordination with conferences.

Target Group: Technical support staff, energy and plant managers

Format: Various training workshops (one day and multi-day workshops)

Contact: Office of Industrial Technologies, U.S. Department of Energy

URL: <http://www1.eere.energy.gov/industry/bestpractices/training.html>

### **Compressed Air Challenge®**

**Description:** The not-for-profit Compressed Air Challenge® develops and provides training on compressed air system energy efficiency via a network of sponsoring organizations in the United States and Canada. Three levels of training are available: (1) Fundamentals (1 day); (2) Advanced (2 days); and (3) Qualified Specialist (3-1/2 days plus an exam). Training is oriented to support implementation of an action plan at an industrial facility.

**Target Group:** Compressed air system managers, plant engineers

**Format:** Training workshops

**Contact:** Compressed Air Challenge: Info@compressedairchallenge.org

**URL:** <http://www.compressedairchallenge.org/>

### **Financial Assistance**

Below major federal programs are summarized that provide assistance for energy efficiency investments. Many states also offer funds or tax benefits to assist with energy efficiency projects (see below for State Programs). However, these programs can change over time, so it is recommended to review current policies when making any financial investment decisions.

### **Industries of the Future - U.S. Department of Energy**

**Description:** Collaborative R&D partnerships in nine vital industries. The partnership consists of the development of a technology roadmap for the specific sector and key technologies, and cost-shared funding of research and development projects in these sectors.

**Target Group:** Nine selected industries: agriculture, aluminum, chemicals, forest products, glass, metal casting, mining, petroleum and steel.

**Format:** Solicitations (by sector or technology)

**Contact:** U.S. Department of Energy – Office of Industrial Technologies

**URL:** <http://www.eere.energy.gov/industry/technologies/industries.html>

### **Inventions & Innovations (I&I)**

**Description:** The program provides financial assistance through cost-sharing of 1) early development and establishing technical performance of innovative energy-saving ideas and inventions (up to \$75,000) and 2) prototype development or commercialization of a technology (up to \$250,000). Projects are performed by collaborative partnerships and must address industry-specified priorities.

**Target Group:** Any industry (with a focus on energy-intensive industries)

**Format:** Solicitation

**Contact:** U.S. Department of Energy – Office of Industrial Technologies

**URL:** <http://www.eere.energy.gov/inventions/>

### **Small Business Administration (SBA)**

**Description:** The Small Business Administration provides several loan and loan guarantee programs for investments (including energy-efficient process technology) for small businesses.

**Target Group:** Small businesses

**Format:** Direct contact with SBA

**Contact:** Small Business Administration

**URL:** <http://www.sba.gov/>

## **State and Local Programs**

Many state and local governments have general industry and business development programs that can be used to assist businesses in assessing or financing energy-efficient process technology or buildings. Please contact your state and local government to determine what tax benefits, funding grants, or other assistance they may be able to provide your organization. This list should not be considered comprehensive but instead merely a short list of places to start in the search for project funding. These programs can change over time, so it is recommended to review current policies when making any financial investment decisions.

### **Database of State Incentives for Renewables & Efficiency (DSIRE)**

Description: DSIRE is a comprehensive source of information on state, local, utility, and federal incentives and policies that promote renewable energy and energy efficiency. Established in 1995, DSIRE is an ongoing project of the NC Solar Center and the Interstate Renewable Energy Council funded by the U.S. Department of Energy.

Target Group: Any industry

URL: <http://www.dsireusa.org/>

### **Summary of Motor and Drive Efficiency Programs by State**

Description: A report that provides an overview of state-level programs that support the use of NEMA Premium® motors, ASDs, motor management services, system optimization and other energy management strategies.

Target Group: Any industry

Contact: Consortium for Energy Efficiency (CEE), (617) 589-3949

URL: <http://www.motorsmatter.org/tools/123approach.html>

### **California – Public Interest Energy Research (PIER)**

Description: PIER provides funding for energy efficiency, environmental, and renewable energy projects in the state of California. Although there is a focus on electricity, fossil fuel projects are also eligible.

Target Group: Targeted industries (e.g. food industries) located in California

Format: Solicitation

Contact: California Energy Commission, (916) 654-4637

URL: <http://www.energy.ca.gov/pier/funding.html>

### **California – Energy Innovations Small Grant Program (EISG)**

Description: The Energy Innovations Small Grant (EISG) Program provides up to \$95,000 for hardware projects and \$50,000 for modeling projects to small businesses, non-profits, individuals and academic institutions to conduct research that establishes the feasibility of new, innovative energy concepts. Research projects must target one of the PIER R&D areas, address a California energy problem and provide a potential benefit to California electric and natural gas ratepayers.

Target Group: Small businesses, non-profits, individuals, academic institutions

Format: Solicitation

Contact: California Energy Commission, (619) 594-1049

URL: <http://www.energy.ca.gov/research/innovations/>



### **California – Savings By Design**

**Description:** Design assistance is available to building owners and to their design teams for energy-efficient building design. Financial incentives are available to owners when the efficiency of the new building exceeds minimum thresholds, generally 10% better than California's Title 24 standards. The maximum owner incentive is \$150,000 per free-standing building or individual meter. Design team incentives are offered when a building design saves at least 15%. The maximum design team incentive per project is \$50,000.

**Target Group:** Nonresidential new construction or major renovation projects

**Format:** Open year round

**URL:** <http://www.savingsbydesign.com/>

### **Indiana – Commercial and Industrial Loan Program**

**Description:** The Indiana Office of Energy Development (OED) Commercial and Industrial Loan Program provides low-interest loans to Indiana's industrial and commercial sectors. This program provides funding of \$50,000-\$500,000 for projects designed to reduce energy consumption through energy efficient retrofits. Examples of appropriate technology include, but are not limited to, lighting, energy management systems, chillers, furnaces, boilers, insulation, windows, and compressed air systems. Prior to application, an energy audit must be performed; however, this is an expense that may be added to total project cost for financing.

**Target Group:** Commercial and industrial companies located in Indiana.

**Format:** Application during specific program window. Additional rounds as funding becomes available.

**Contact:** Indiana Office of Energy Development, (317) 232-8939

**URL:** [www.energy.in.gov](http://www.energy.in.gov)

### **Iowa – Alternate Energy Revolving Loan Program**

**Description:** The Alternate Energy Revolving Loan Program (AERLP) was created to promote the development of renewable energy production facilities in the state.

**Target Group:** Any potential user of renewable energy

**Format:** Proposals under \$50,000 are accepted year-round. Larger proposals are accepted on a quarterly basis.

**Contact:** Iowa Energy Center, (515) 294-3832

**URL:** <http://www.energy.iastate.edu/Funding/index.htm>

### **New York – Industry Research and Development Programs**

**Description:** The New York State Energy Research & Development Agency (NYSERDA) operates various financial assistance programs for New York businesses. Different programs focus on specific topics, including process technology, combined heat and power, peak load reduction and control systems.

**Target Group:** Industries located in New York

**Format:** Solicitation

**Contact:** NYSERDA, (866) NYSERDA

**URL:** [http://www.nyserd.org/programs/Commercial\\_Industrial/default.asp?i=2](http://www.nyserd.org/programs/Commercial_Industrial/default.asp?i=2)

### **Oregon – Energy Trust Production Efficiency Program**

**Description:** Incentives for energy efficiency projects are offered for Oregon businesses that are serviced by either Pacific Power or Portland General Electric. Current incentive levels are \$0.25/kWh saved up to 60% of the project cost. Lighting incentives are treated differently. There are standard incentive levels for specific fixture replacements (exp. \$30/fixture). If a fixture replacement does not qualify for a standard incentive, but it does save energy, a custom incentive can be calculated using \$0.17/kWh saved up to 35% of the project cost. Premium efficiency motor rebates are also offered at \$10/hp from 1 to 200 hp motors. Over 200 hp, the current incentive levels of \$0.25/kWh saved up to 60% of the project cost are used to calculate an incentive.

**Target Group:** Commercial and industrial companies in Oregon

**Contact:** Energy Trust of Oregon, (509) 529-8040

**URL:** [www.energytrust.org](http://www.energytrust.org)

### **Wisconsin – Focus on Energy**

**Description:** Energy advisors offer free services to identify and evaluate energy-saving opportunities, recommend energy efficiency actions, develop an energy management plan for business; and integrate elements from national and state programs. It can also provide training.

**Target Group:** Industries in Wisconsin

**Format:** Open year round

**Contact:** Wisconsin Department of Administration, (800) 762-7077

**URL:** <http://focusonenergy.com/>

## Appendix E: Additional Information Sources

This Energy Guide leveraged information on measures, technologies, and best practices for energy and water efficiency from a wide range of global resources. As mentioned in Chapter 5, it was not feasible to address all possible energy and water efficiency measures applicable to the U.S. pulp and paper industry in this Energy Guide. Several excellent resources exist that can offer the reader more details and rationale for a number of the measures described in this Energy Guide, as well as for measures that are not included in this Energy Guide. The text and tables below highlight important information from three of these additional resources. These additional resources can be considered in greater depth by mill personnel when researching and evaluating energy and water efficiency improvement projects.

Table E.1 summarizes selected best available technology energy consumption values per short ton of product (NCASI 2009). These values are based on spreadsheet models developed by Jacobs Engineering and the Institute of Paper Science and Technology in support of the *Pulp and Paper Industry Bandwidth Study* (Jacobs and IPST 2006). The data in Table E.1 can be used as preliminary benchmarks of mill energy consumption compared to what may be possible using best available technologies and operating procedures. Details on the best available technology assumptions, and data on best available technology energy consumption for additional processes, may be found in Jacobs and IPST (2006) and its associated spreadsheet models. The values in Table E.1 should be treated only as rough benchmarks, however, given that the unique process configurations, fuel sources, and product mixes at any specific mill will affect both its current energy use and its minimal achievable energy use. Additional guidance on using the Jacobs and IPST (2006) data and spreadsheets to evaluate mill energy consumption is offered in NCASI (2009).

Table E.2 provides a comprehensive list of energy and carbon saving technology and operations recommendations from the NCASI report *Technologies for Reducing Carbon Dioxide Emissions: A Resource Manual for Pulp, Paper, and Wood Products Manufacturers* (NCASI 2005). The report contains technology descriptions that include: applicability guidance; an overview of the technology's impact on energy use, GHG emissions, and cost; and sample calculations to illustrate how to estimate the impacts of each technology on emissions at an individual facility. While the NCASI (2005) report was leveraged in the development of this Energy Guide, much additional information can be found in the original report, including descriptions of energy and water efficiency measures that were beyond the scope of this Energy Guide. Table E.2 also indicates water efficiency measures that may also lead to energy savings (in italics) (NCASI 2009).

Table E.3 summarizes key water reduction opportunities in chemical pulp mills, as presented in the Paprican monograph *Water Use Reduction in the Pulp and Paper Industry* (Browne 2001). This monograph contains detailed chapters on savings strategies applicable to water purification and treatment, chemical pulping, bleaching, mechanical pulping, recycled pulping, papermaking, and other common mill processes. The summary in Table E.3 can be used as checklist of potential water efficiency measures in conjunction with the information presented in Chapter 19 of this Energy Guide. Further details on the measures summarized in Table E.3 are provided in Browne (2001).

**Table E.1: Selected Estimates of Best Available Technology Energy Use**

<b>Operation</b>	<b>Electricity kWh/t</b>	<b>Steam MMBtu/t</b>	<b>Direct Fuel MMBtu/t</b>
<b>Pulping Processes</b>			
Sulfite	406	7.64	1.8
Kraft, bleached, softwood	363	6.34	1.4
Kraft, bleached, hardwood	347	5.58	1.3
Kraft, unbleached	269	4.66	1.5
Stone groundwood	2,133	3	0
Thermomechanical pulp	2,088	0.58	0
Semichemical	527	5	1.2
Old corrugated containers	206	0.6	0
Mixed office waste, non-deinked (tissue)	348	0.6	0
Mixed office waste, deinked	472	1.33	0
Old newsprint, deinked	395	1.33	0
<b>Papermaking Processes</b>			
Linerboard	472	3.08	0
Recycled board	315	4	0
Bleached folding boxboard and milk	512	3.41	0.9
Kraft paper	472	3.08	0
Special Industrial	472	3.08	0
Gypsum	315	4	0
Corrugated medium	472	3.08	0
Printing and writing, bristols, bleached packaging	460	4.16	0
Newsprint	328	3.32	0
Groundwood specialties	328	3.96	0
Coated groundwood	555	4.44	0.9
Coated freesheet	500	3.83	0.9
Boxboard, unbleached	355	4.33	0.9
Tissue	669	3.96	1.9
Other paper and boards	467	4	0.4
Market pulp	160	2.53	0
<b>Wastewater and Utilities</b>	82	0.95	0

Sources: Jacobs and IPST (2006); NCASI (2009)

**Table E.2: Technology Options for Reducing Energy Use and CO<sub>2</sub> Emissions**

<b>Report section</b>	<b>Opportunity</b>
3.3.1.1	Replace low pressure boilers and install turbogenerator capacity
3.3.1.2	Switch power boiler from fossil fuel to wood (or build new wood boiler to utilize available biofuel)
3.3.1.3	Preheat demineralized water with secondary heat before steam heating
3.3.1.4	Rebuild or replace low efficiency boilers
3.3.1.5	Install a steam accumulator to facilitate efficient control of steam header pressures
3.3.1.6	Install an ash reinjection system in the hog fuel boiler
3.3.1.7	Install a bark press or bark dryer to increase utilization of biofuels
3.3.1.8	Install additional heat recovery systems to boilers to lower losses with flue gases
3.3.1.9	Implement energy management program to provide current and reliable information on energy use
3.3.1.10	Switch power boiler fuel from coal or oil to natural gas
3.3.1.11	Install gas turbine cogeneration system for electrical power and steam generation
3.3.2.1	Replace pneumatic chip conveyors with belt conveyors
3.3.2.2	<i>Use secondary heat instead of steam in debarking</i>
3.3.3.1	<i>Rebuild the mill hot water system to provide for separate production and distribution of warm (120°F) and hot (160°F) water</i>
3.3.3.2	Install blow heat (batch digesters) or flash heat (continuous digester) evaporators
3.3.3.3	Replace conventional batch digesters with cold blow systems
3.3.3.4	Use flash heat in a continuous digester to preheat chips
3.3.3.5	<i>Use evaporator condensates on decker showers</i>
3.3.3.6	Use two pressure level steaming of batch digesters to maximize back-pressure power generation
3.3.3.7	<i>Optimize the dilution factor control</i>
3.3.4.1	<i>Optimize the filtrate recycling concept for optimum chemical and energy use</i>
3.3.4.2	Preheat ClO <sub>2</sub> before it enters the mixer
3.3.4.3	Use oxygen based chemicals to reduce the use of ClO <sub>2</sub> (O <sub>2</sub> or O <sub>3</sub> delignification, EP, EOP, etc.)
3.3.5.1	<i>Eliminate steam use in the wire pit by providing hot water from heat recovery and/or pulp mill and by reducing water use on the machine</i>
3.3.5.2	Upgrade press section to enhance water removal
3.3.5.3	Enclose the machine hood (if applicable) and install air-to-air and air-to-water heat recovery
3.3.5.4	<i>Install properly sized white water and broke systems to minimize white water losses during upset conditions</i>
3.3.5.5	Implement hood exhaust moisture controls to minimize air heating and maximize heat recovery

<b>Report section</b>	<b>Opportunity</b>
3.3.5.6	Implement efficient control systems for the machine steam and condensate systems to eliminate excessive blow through and steam venting during machine breaks
3.3.6.1	Convert recovery boiler to non-direct contact and implement high solids firing
3.3.6.2	<i>Perform evaporator boilout with weak black liquor</i>
3.3.6.3	Convert evaporation to seven-effect operation (install additional evaporator effect)
3.3.6.4	Install high solids concentrator to maximize steam generation with black liquor
3.3.6.5	Implement an energy efficient lime kiln (lime mud dryer, mud filter, product coolers, etc.)
3.3.6.6	Replace lime kiln scrubber with an electrostatic precipitator
3.3.6.7	Integrate condensate stripping to evaporation
3.3.6.8	Install a methanol rectification and liquefaction system
3.3.6.9	Install a biofuel gasifier, use low Btu gas for lime reburning
3.3.7.1	Implement heat recovery from TMP process to steam and water
3.3.7.2	Add third refining stage to the TMP plant
3.3.7.3	Replace the conventional groundwood process with pressurized groundwood (PGW) operation
3.3.7.4	<i>Countercurrent couple paper machine and mechanical pulping white water systems</i>
3.3.8.1	Supply waste heat from other process areas to deinking plant
3.3.8.2	Install drum pulpers
3.3.8.3	<i>Implement closed heat and chemical loop</i>
3.3.9.1	<i>Optimize integration and utilization of heat recovery systems</i>
3.3.9.2	Implement preventive maintenance procedures to increase equipment utilization efficiency
3.3.9.3	<i>Implement optimum spill management procedures</i>
3.3.9.4	<i>Maximize recovery and return of steam condensates</i>
3.3.9.5	Recover wood waste that is going to landfill
3.3.9.6	Install energy measurement, monitoring, reporting, and follow-up systems
3.3.9.7	Convert pump and fan drives to variable speed drives
3.3.9.8	Install advanced process controls
3.3.9.9	Replace oversized electric motors
3.3.9.10	Use high efficiency lighting
3.3.10.1	Use advanced controls to control the drying process
3.3.10.2	Install heat recovery systems on the drying kiln exhaust
3.3.10.3	Insulate the kiln and eliminate heat leaks
3.3.10.4	Use heat pump for lumber drying
3.3.10.5	Convert batch kiln to progressive kiln
3.3.10.6	Implement steam load management system
3.3.11.1	Use advanced controls to control the drying process
3.3.11.2	Insulate the dryer and eliminate air and heat leaks
3.3.11.3	Install heat recovery systems on the dryer exhaust

<b>Report section</b>	<b>Opportunity</b>
3.3.11.4	<i>Use boiler blowdown in the log vat</i>
3.3.12.1	Measure and control the dryer exhaust moisture content to minimize air heating
3.3.12.2	Recover heat from dryer exhaust
3.3.12.3	Use wood waste as fuel for drying (suspension burning)
3.3.13.1	Install heat recovery
3.3.13.2	Preheat drying air with steam
3.3.14.1	Screen flakes before drying; dry fines separately
3.3.14.2	Use advanced controls to optimize the drying process
3.3.14.3	Use powdered resins

*Sources: NCASI (2005, 2009)*

**Table E.3: Water Reduction Opportunities in Chemical Pulp Mills**

<b>Mill Area</b>	<b>Opportunity</b>
Wood and Chip Preparation	<ol style="list-style-type: none"> <li>1. Collect and reuse water from log cleaning showers</li> <li>2. Use machine white water for log thawing showers</li> <li>3. Use mechanical debarkers</li> <li>4. Use drum debarkers with steam injection</li> <li>5. Implement good design and maintenance</li> </ol>
Digestion and Brown Stock Washing	<ol style="list-style-type: none"> <li>1. Pre-steam chip bin with flash steam</li> <li>2. Use cold blow pump-out</li> <li>3. Use condensate from relief and flash steam</li> <li>4. Upgrade to pressurized knotting and screening systems</li> <li>5. Increase final washer discharge consistency</li> <li>6. Improve shower water patterns with modified heads and nozzles</li> <li>7. Use excess warm water for pump seals</li> <li>8. Improve spill recovery</li> </ol>
Bleaching	<ol style="list-style-type: none"> <li>1. Increase washer discharge consistency</li> <li>2. Improve shower water patterns with modified heads and nozzles</li> <li>3. Reuse cooling water from hydraulic drive units</li> <li>4. Use filtrates on wire cleaning showers</li> <li>5. Use filtrates on medium consistency pump standpipe dilution</li> <li>6. Replace water doctors with air doctors</li> <li>7. Reuse machine white water</li> <li>8. Implement flow control on washer showers</li> <li>9. Convert D stage from low to medium consistency</li> </ol>
Pulp Machine	<ol style="list-style-type: none"> <li>1. Substitute fresh water with machine white water where possible</li> <li>2. Collect and reuse cooling water from cooling systems</li> </ol>
Chemical Preparation	<ol style="list-style-type: none"> <li>1. Increase concentration of ClO<sub>2</sub> solution</li> <li>2. Recirculate ClO<sub>2</sub> absorption water on start-up and shut-down</li> <li>3. Reuse cooling water from indirect condensing units</li> </ol>
Recovery Systems	<ol style="list-style-type: none"> <li>1. Collect surface condensing cooling water in warm water tank or header</li> <li>2. Reuse warm water and stripped condensate in brown stock systems</li> <li>3. Reuse warm water in recausticizing, e.g., lime mud washing</li> <li>4. Reuse cooling water from indirect cooling units</li> <li>5. Use alkaline liquor in slake scrubbers</li> <li>6. Improve spill recovery</li> </ol>

Sources: Browne et al. (2001); NCASI (2009)