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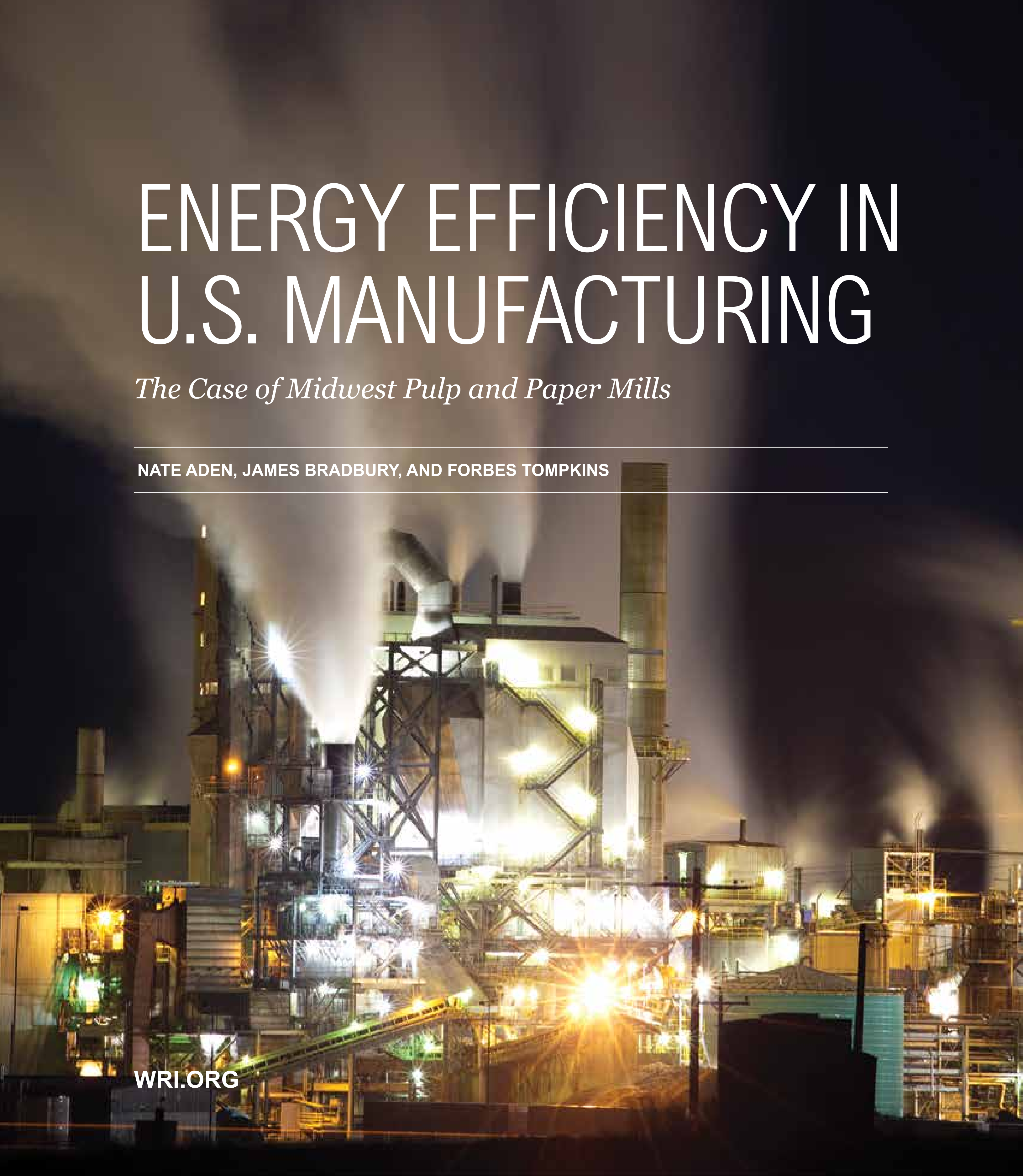

ENERGY EFFICIENCY IN U.S. MANUFACTURING

The Case of Midwest Pulp and Paper Mills

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FOREWORD

Energy efficiency saves jobs. Across all sectors, companies can boost their profits—and secure their workforce—by cutting their energy costs.

The Midwest's energy-intensive pulp and paper industry is a case in point. Across the region, pulp and paper mills have long been economic mainstays of their communities. But changing paper use, rising international trade, and fluctuating energy prices are forcing mills to lay off workers or even shutter their doors. For mills looking to stay competitive in a changing global market, finding new ways to keep money in the till is crucial.

Of course, increased energy efficiency at pulp and paper mills makes sense not only for bottom lines, but also for the environment. In 2011, industry accounted for more than a quarter of U.S. greenhouse gas emissions, with the lion's share from the manufacturing sector. As one of the largest energy-using manufacturing subsectors in the United States, pulp and paper is a significant contributor to those emissions.

This report highlights the critical role of energy efficiency in improving the economic and environmental performance of Midwest pulp and paper mills. WRI's analysis finds that less efficient facilities could realize significant annual energy cost savings, and decrease their greenhouse gas emissions, by investing in initiatives to meet the industry's national average efficiency level. Through energy efficiency measures like those detailed in this report, pulp and paper mills in Minnesota, Wisconsin, and elsewhere are reducing their energy use even while increasing production. And such improvements can reduce mills' greenhouse gas emissions even more than switching from coal or oil to natural gas.

The unmet opportunities for efficiency improvements reveal an urgent need for new approaches. Energy efficiency standards and incentives can help companies make more of these prudent, cost-saving investments and should be a key pillar in any U.S. climate policy. The experiences of forward-thinking pulp and paper companies make it clear: energy efficiency can make all the difference in keeping companies competitive and protecting jobs.

Andrew Steer
President
World Resources Institute

EXECUTIVE SUMMARY

Many pulp and paper mills operating in the U.S. today were built nearly a century ago. These mills have historically served as economic anchors and vital sources of employment for their communities, particularly in rural areas. In recent years changing patterns of paper use, increased international competition, and natural gas price spikes in the mid-2000s put increasing pressure on the industry. In the past decade hundreds of pulp and paper mills have closed nationally and more than one hundred thousand jobs, or three in ten, have been lost. However, amid this consolidation and attrition, there have also been success stories that demonstrate an emerging model of lower-carbon manufacturing.

ABOUT THIS REPORT

"Energy Efficiency in U.S. Manufacturing: The Case of Midwest Pulp and Paper Mills" presents the business case for investment in manufacturing sector energy efficiency. In order to provide practical and actionable information for policymakers, manufacturers, and related stakeholders, we focus on energy efficiency opportunities in Midwest pulp and paper mills. As the U.S. region with the largest industry share of overall economic activity, the Midwest is of central importance for industrial energy efficiency and forging a new low-carbon economy. Pulp and paper manufacturing is the third-largest energy-using manufacturing subsector in the U.S. Energy cost reduction, improved competitiveness, and reduced environmental compliance costs provide a compelling business case for Midwest pulp and paper mills to invest in facility-appropriate energy efficiency improvements, as well as energy management programs. The report uses mill-level data to assess the energy efficiency of Midwest pulp and paper manufacturing and presents technology and policy options for increasing regional energy productivity.

As described in Section 2 and Appendix I, Wisconsin has the most mills in the Midwest, followed by Michigan and Ohio. The Midwest has been a focus area of World Resources Institute research for several years. Earlier WRI publications include the 2007 report entitled "Charting the Midwest: An Inventory and Analysis of Greenhouse Gas Emissions in America's Heartland," (Larsen, Damassa, and Levinson 2007) and the 2012 working paper entitled "Midwest Manufacturing Snapshot: Energy Use and Efficiency Policies" (Bradbury and Aden 2012). In 2012 WRI also published an online Power Almanac of the American Midwest to visualize recent energy use and emissions trends.[1] The impacts of climate change are already being felt in the U.S. and are expected to be amplified with the rise of global emissions (USGCRP 2013). Higher temperatures, rising sea levels, and more extreme weather highlight the pressing need for government and industry to further reduce greenhouse gas emissions from all sectors.

Rising international energy and labor costs are combining with historically low natural gas prices and improving productivity in the U.S. to create an intermittent resurgence of American manufacturing. In a 2012 survey of company decision makers, the Boston Consulting Group found that 37 percent of manufacturers with sales greater than $1 billion were planning to bring back production to the United States from China or were actively considering it. At the same time that companies are looking to grow their American manufacturing capacity, the long-anticipated publication of the final Boiler Maximum Achievable Control Technology (MACT) rule in January 2013 provided regulatory certainty that will generate new investments for compliance actions. These developments bring new opportunities for low- and net-negative-cost energy efficiency investments that improve economic competitiveness.

On a national scale, the pulp and paper sector has recently experienced contraction and consolidation. While production remains below year 2000 levels and employment has dropped steeply, the sector has recorded increasing levels of economic activity as reflected in total value-added. Between 2002 and 2011 U.S. paper manufacturing value-added grew by 8 percent while the number of employees declined by 30 percent. In this environment of consolidation, attrition, and increasing competition, energy efficiency serves as a determinant of pulp and paper mill survival. The information and case studies in this report demonstrate that investment in energy efficiency improvements can help facilities successfully compete while reducing greenhouse gas emissions.

Key Findings

Midwest mills have numerous energy efficiency improvement opportunities

Based on facility energy use and production in 2010, Midwest pulp and paper mills are slightly less energy-efficient than the national average. While there is a broad range of performance among regional pulp and paper mills, the less efficient facilities could save $120 million in annual energy costs by investing in initiatives to meet the industry average efficiency level. With additional investment, these Midwestern manufacturers could save $240 million annually if all pulp and integrated paper mills achieved an ENERGY STAR® energy performance score in the top 25 percent of comparable U.S. facilities.

Efficiency improvements can reduce carbon emissions more than fuel switching in the near term

Scenario analysis shows that investments that brought Midwest pulp and paper mills to the ENERGY STAR benchmark level for top performance would also result in greater carbon dioxide emissions reductions than would be achieved through fuel switching from end use of coal or oil to natural gas. The specific impact of increased biomass use depends on life-cycle emissions assumptions; however, it is clear that biomass use can reduce mill costs and displace fossil fuel use. Likewise, the longer-term transition of electricity systems away from fossil fuels can also reduce pulp and paper sector greenhouse gas emissions to the extent that mills increase their use of renewably generated electricity. Combined efficiency improvements and fuel switching can improve resource productivity while reducing environmental impacts.

A range of proven, market-scale technologies is available for improving mills' efficiency

Pulp and paper manufacturing includes a range of processes, fuels, technologies, and products—there is not a "typical" mill. To cover the variety of established and emerging technologies and practices in the paper sector, this report uses a national cost curve approach to summarize costs and energy savings potential for established energy efficiency improvement options. This analysis shows that facilities that introduce proven energy efficiency technologies and practices could cost-effectively reduce their energy use by 25 percent on average, depending on the particular mill configuration.

While there is a broad range of performance among regional pulp and paper mills, the less efficient facilities could save $120 million in annual energy costs by investing in initiatives to meet the industry average efficiency level.

Successful pulp and paper mills are investing in energy efficiency

The viability of efficiency improvement technologies is demonstrated by pulp and paper mill case studies. In Wisconsin, Flambeau River Papers has used energy efficiency investments to emerge from bankruptcy, cut costs, and increase facility production. In Washington State, the Weyerhaeuser NORPAC mill has successfully partnered with its local utility to implement advanced continuous improvement programs that reduce energy use and emissions. At the corporate level, the International Paper company's continued investment in energy efficiency helped to reduce its greenhouse gas emissions and helped the company earn Environmental Protection Agency's (EPA) only pulp and paper sector 2012 Climate Leadership Award. Outside of the mill gate, these case studies demonstrate the win-win role of energy efficient manufacturing in moving toward a more robust and low-carbon U.S. economy.

Recommendations

To increase Midwest pulp and paper manufacturing energy efficiency and develop a more sustainable path for American industry, this report makes five recommendations.

Measure pulp and paper mill energy efficiency performance

Albert Einstein famously noted that "Not everything that can be counted counts, and not everything that counts can be counted." Manufacturing energy efficiency performance is something that counts and can be counted. Benchmarking can help facilities identify energy efficiency opportunities and track performance. In particular, this report recommends expanded industry use of existing energy efficiency benchmarking tools such as the ENERGY STAR Energy Performance Indicators tool. On a national level, benchmarking assessment tools can be improved with thorough Census industry data collection programs. From a facilities and manufacturing company perspective, development of national benchmarks for specific processes and equipment, such as paper dryers, could support energy management programs.

Introduce a mix of minimum standards and "reach" incentives

American industry played an internationally pioneering role in many manufacturing subsectors. As manufacturing facilities become antiquated, policy has a role to play in helping manufacturers remain competitive while reducing environmental impacts. This report recommends the introduction of minimum energy performance standards for new equipment—such as motors, boilers, and pumps—with facility-level auditing requirements to help manufacturers identify and address the areas with the greatest potential for improvement. Targeted policy support can help facilities use benchmarking, auditing, and assessment information to achieve tangible efficiency gains. As illustrated in this report's case studies, local incentives and institutional adjustments can enable continuous improvements.

Support CHP utilization through state and federal policies

Combined heat and power (CHP) can help to reduce industrial energy use and emissions by more fully utilizing the products of fuel combustion. While the U.S. pulp and paper sector deploys large amounts of CHP, previous studies suggest substantial remaining CHP potential for Midwest pulp and paper mills. CHP utilization can be increased through inclusion in state energy resource standards and

through less burdensome interconnection rules, standardized standby fee structures, and other regulatory reforms to enable consistent access to electricity markets.

Develop new regulatory frameworks to promote electric utility-manufacturer collaboration

Electric utilities do not always have incentives to help reduce their customers' energy use. To address utility incentives, the U.S. Congress passed the Public Utility Regulatory Power Act (PURPA) in 1978. PURPA introduced new requirements and incentives for efficiency, renewables, and distributed power generation that helped boost CHP utilization, among other things. However, PURPA has since been amended to reduce these incentives, particularly in the area of distributed generation. The development of a 21st century PURPA could usefully include new cost-recovery models in which utilities continue to earn reasonable profits even as manufacturing customers self-generate electricity and reduce demand through energy efficiency. Case study experience suggests that efficiency and environmental goals are most often achieved in the pulp and paper sector when they are integrated with state and local utility efficiency programs.

Build on current research to develop geographically and sectorally integrated climate policy

The 2012 American Energy Manufacturing Technical Corrections Act (H.R. 6582) directed the government to conduct a study of energy-intensive manufacturing. Understanding the energy and emissions performance of pulp and paper mills compared with chemical refineries, iron and steel mills, and other energy-intensive subsectors will help to identify the most cost-effective areas for policy support. Regional disparities—such as the one highlighted in this report—need to be addressed for new policies to be politically feasible and equitable.

Implementation of the efficiency improvements and innovations described in this report could help the pulp and paper sector reduce emissions while preserving manufacturing in rural communities. The turnaround of the European pulp and paper sector and the possibility of long-term, low-cost domestic natural gas availability suggest that a combination of investments and policies tailored to U.S. Midwest pulp and paper mills could foster sustainable and clean production.

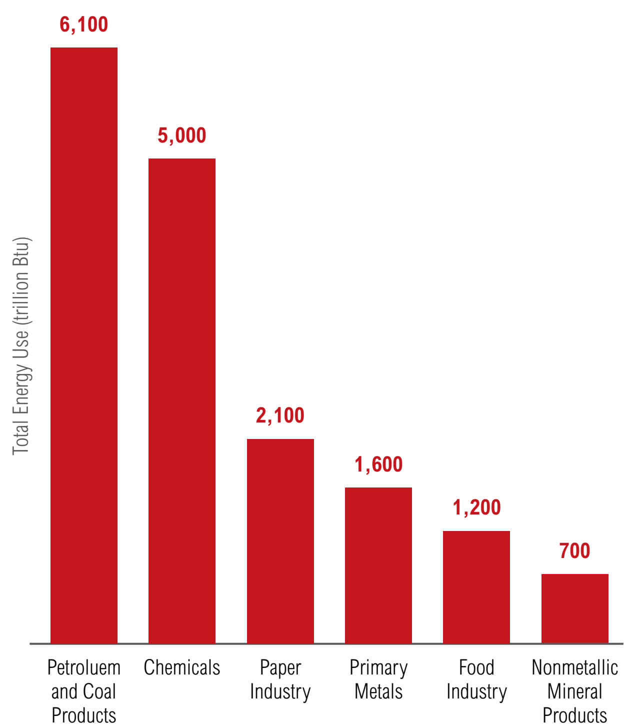
Section 1

INTRODUCTION

Pulp and paper is the third largest energy-using manufacturing subsector in the U.S. In 2010 this sector accounted for 11 percent of total U.S. industrial energy use and 5 percent of industrial greenhouse gas (GHG) emissions. To build a tangible, bottom-up understanding of U.S. industrial energy efficiency improvement potential, this report focuses on pulp and paper manufacturers located in the Midwest.

Data for identifying manufacturing energy efficiency opportunities are collected and managed separately by geographic scope, year of analysis, and sector. This analysis brings together these scattered statistics, facility-level energy use and production data, and information on best practices and established technologies. On a national scale, the pulp and paper sector has recently experienced intermittent growth with reduced employment—between 2002 and 2011 U.S. paper manufacturing value-added grew by 8 percent while the number of employees declined by 30 percent (U.S. Census Bureau 2013). The drop in pulp and paper employment has been accompanied by paper subsector consolidation and attrition in some areas. Recent pulp and paper mill experiences have demonstrated that investment in energy efficiency improvements can help facilities to survive in a challenging business environment while supporting a lower emissions pathway for the U.S. economy.

Figure 1 | **U.S. Industry Sub-Sector First Use of Energy for All Purposes (Fuel and Nonfuel), 2010**



Source: U.S. DOE 2013a.

During the past decade, a host of studies have highlighted the potential for U.S. industries to reduce their energy costs through energy efficiency (EE) upgrades, while also improving competitiveness and reducing emissions. For example, a National Academy of Sciences 2010 report—entitled "Real Prospects for Energy Efficiency in the United States"—included an industrial sector assessment that finds 14 to 22 percent of U.S. industrial energy use could be cut through cost-effective efficiency improvements, and 25 to 41 percent from the pulp and paper subsector, depending on continued research and technology development (NAS 2010). Yet, despite the evidence for untapped cost-effective efficiency potential and a persuasive business case for maximizing the energy efficiency of industrial activity (see Box 1), several challenges prevent U.S. manufacturers from capitalizing on available EE opportunities.

The benefits of efficiency improvements include reduced greenhouse gas emissions, which recent studies have definitively linked to climate change. In 2010, at the request of Congress, the National Research Council of the U.S. National Academies published an assessment report, which concluded that: "Climate change is occurring, is caused largely by human activities, and poses significant risks for—and in many cases is already affecting—a broad range of human and natural systems" (NRC 2010). The study was one of several recent comprehensive science assessments— including the draft *National Climate Assessment* report (USSGCRP 2013)—that details observed and projected climate impacts for specific sectors and regions of the U.S. In particular, the *National Climate Assessment* finds that while Midwest forests are relatively resilient, forests throughout the country will be stressed by climate change, with increased risk of wildfire, drought, pest infestation and shifting ecosystems. Furthermore, the report finds that the increased frequency and intensity of extreme weather and climate events can be disruptive to energy systems and reduce water quality and water availability for power generation and other industrial uses.

Recognizing the multiple benefits of a more energy efficient economy (Laitner et al. 2012), some federal and state policies have been enacted to help address common barriers to industrial EE investments. In addition to the economic benefits for domestic manufacturing, there may also be a growing recognition of the untapped opportunity of efficiency as an energy resource and the co-benefits of reduced pollution. Prominent examples of this growing political trend include a recent Executive Order to achieve a 50 percent increase in U.S. CHP capacity by 2020.[2] In addition, the Shaheen-Portman energy efficiency bill (S 761)[3] passed through committee early in 2012 with near unanimous bipartisan support and portions passed unanimously through the U.S. Senate in September 2012. On December 18, 2012, President Obama signed the American Energy Manufacturing Technical Corrections Act (H.R. 6582) into law. The act incorporated provisions from the Shaheen-Portman energy efficiency bill, including a mandate for further study of energy-intensive manufacturing and development of a Federal Energy Management and Data Collection Standard. In many cases, state lawmakers have gone further. Since 1999, twenty-four states have set binding energy efficiency targets, requiring electric and natural gas utilities to help their customers achieve annual energy savings (Nowak et al. 2011). (For further discussion of policy, see section 4.)

Research Objectives

To help inform ongoing policy deliberations and to also encourage greater consideration of EE investments by U.S. manufacturing companies, this report focuses on one energy-intensive sector in a U.S. region that is politically, culturally, and economically geared toward manufacturing. This study is unique for using facility-level analysis with state-specific detail, plus representative case studies from different companies. The intent is to make industrial energy efficiency opportunities more visible and less abstract to state-level policymakers, utilities, businesses, and other interested stakeholders.

BOX 1 | THE BUSINESS CASE FOR INDUSTRIAL ENERGY EFFICIENCY IN THE U.S.

Each year energy losses cost U.S. manufacturers billions of dollars and generate millions of metric tons of greenhouse gas emissions (Brueske et al. 2012). Energy cost savings can be highly valuable for boosting near-term profitability, but also as a strategy to reduce a facility's exposure to future price increases. This improves a company's competitiveness, which is especially important for energy-intensive manufacturers of internationally traded goods such as pulp and paper, since competitors may operate newer and more efficient plants or have lower costs for labor or energy.

Lower pollution levels resulting from energy savings come with a host of related benefits for the company, public health, and the environment. From the company perspective, lower pollution means lower costs for a number of reasons. First, lower pollution often means reduced compliance costs associated with current environmental regulations. While helping to manage current regulatory compliance, lowering emissions enhances a company's sustainability, which reduces legal risk. Being proactive about reducing emissions also limits a company's exposure to financial, credit (Venugopal et al. 2011), and legal risks associated with future legislative or regulatory measures to reduce greenhouse gas emissions from existing industrial sources (Litz et al. 2011).

Finally, many states encourage industrial efficiency with financial incentives as a part of their SO_2 and NO_X emissions reduction programs. When faced with energy supply constraints or state policies requiring energy efficiency improvements, electric and natural gas utilities are increasingly offering demand-response and other programs that make efficiency investments even more economically attractive to industrial customers (Chittum and Nowak 2012).

Source: NAS 2010.

Specifically, this report answers the following questions:

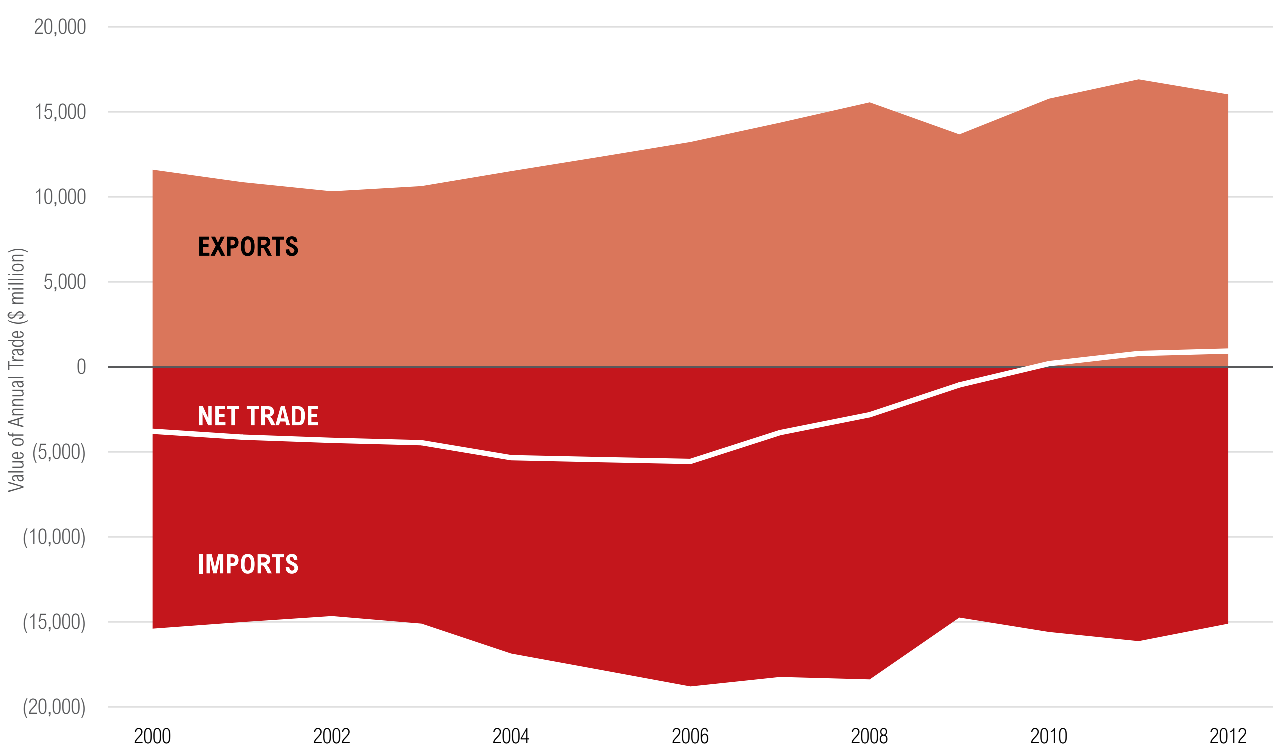
- How do Midwest pulp and paper manufacturers compare with facilities located in other regions of the country in terms of their energy intensity?
- What is the potential for near-term energy efficiency improvements in Midwest pulp and paper manufacturing? How do the impacts of efficiency improvements compare with the energy and emissions impacts of fuel switching from coal and oil to natural gas alone?
- What are the most cost-effective options available for reducing the energy- and emissions-intensity of Midwestern mills?
- What policies currently affect paper sector energy use and emissions? What are the key barriers and policy solutions for pulp and paper, as well as other energy-intensive sectors?

A detailed description of the data, assumptions, and methods that went into the benchmarking and analysis is provided in Appendixes I, II, and III.

The Role of the Paper Sector in Midwest Manufacturing

The modern U.S. pulp and paper sector has its roots in the nineteenth century. By 2010 the average U.S. pulp and paper mill had been built in 1937. The average Midwest mill operating in 2010 was built in 1922. This 15-year gap is largely a result of technological innovations during the 1930s that enabled resinous southern pine to be pulped in kraft recovery furnaces (Reed 1995; Toivanen 2012). By 2010 the Midwest produced more printing and writing paper than any other region, while the Southeast produced more packaging and market pulp (Fisher International 2013; see Appendix I). Diverse forest resources and production technologies comprise the U.S. pulp and paper sector and supply a wide range of markets from newsprint to tissue to specialty paper.

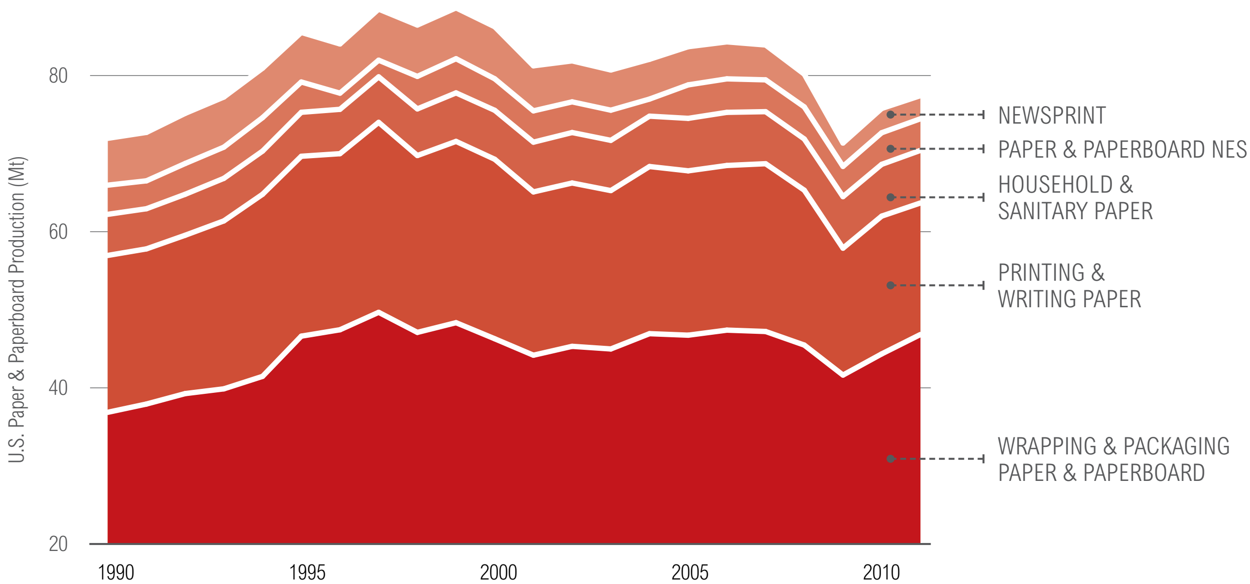
Figure 2 | **Value of U.S. International Paper & Paperboard Trade, 2000-2012**



Source: U.S. Department of Commerce 2013.

Note: This figure shows the value of U.S. international paper trade as defined by Harmonized System code HS 48 (Paper,Paperboard).

Figure 3 | **U.S. Paper Production by Category, 1990-2011**



Source: UN FAOSTAT 2012.

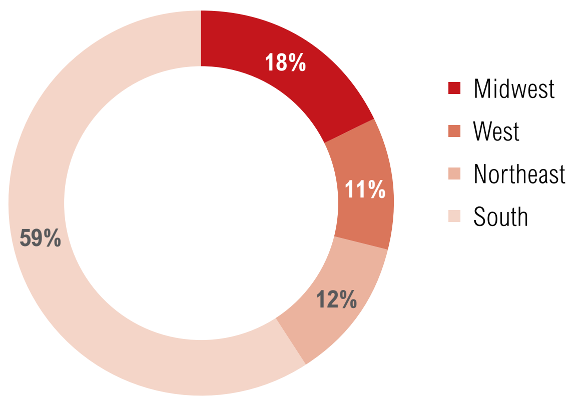
Notes: This figure displays select categories of U.S. paper production as defined by the UN FAO; y-axis not zero-based so as to illustrate production trends.

In 2010 the U.S. produced 78 million metric tons of paper and paperboard, accounting for 19 percent of global production. Between 2009 and 2012, the value of U.S. paper exports grew by an average annual rate of 5 percent.[4] Paper mills often serve as community anchors, generating local tax revenue and employment, with additional local benefits from supply chain impacts (AF & PA 2012). The paper sector is among the many U.S. manufacturing sectors that contributed to the post-2008 U.S. economic recovery. However, at the same time, many mills have closed, and many others have struggled to compete in the face of changing market conditions.

Between 2000 and 2011, the gross nominal value of U.S. international trade in paper products increased by 22 percent. Growth of exports led the U.S. to become a net paper exporter by 2010 (Figure 2). In 2008 China surpassed the U.S. to become the largest paper manufacturing country. While weak domestic demand and international competition create challenges for U.S. pulp and paper manufacturers, increasing international exports helped drive the 2010 and 2011 growth of production (Figure 3), though these levels remain below the pre-crash production plateau.

In 2011, wrapping and packaging paper and paperboard accounted for 60 percent of total production by mass, followed by printing and writing paper with 22 percent. Production data, categories, and short-term sector trends vary by source and scope. The United Nations Food and Agriculture Organization (FAO) reported total U.S. paper sector production of 77 million metric tons in 2011. This is largely consistent with the private survey-based Fisher database, which reports 78 million metric tons in the same year, not including market pulp and captive slurry.[5] Both data sources show a trend of declining U.S. paper production after the year 2000, in part due to increased internet usage. The 21st century decline of U.S. paper production accelerated in 2008, when economic recession and reduced advertising combined with rising energy and input costs. While FAO data show a slight U.S. rebound in 2010 and 2011 (Figure 3), the Fisher data indicate continued gradual decline.

Figure 4 | **Regional Distribution of U.S. Paper Production, 2011**



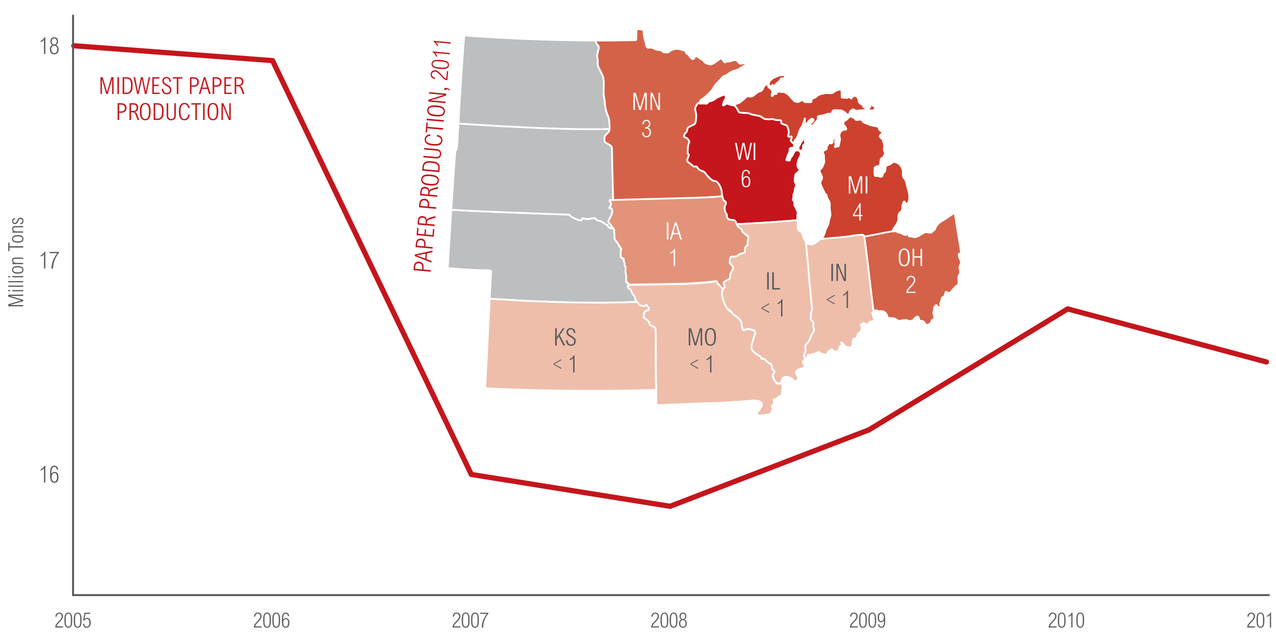
Source: Fisher International 2013.

Note: Excludes market pulp and captive slurry.

Figure 4 illustrates the geographic distribution of U.S. paper production in 2011. Most U.S. paper production takes place in the South.[6] In 2011 Alabama was the state with the most paper production, followed by Georgia, Louisiana, and Wisconsin. In the period of attrition since 2008, the South has retained more mills than other regions of the country. As described in Appendix I, the Midwest produces a higher portion of tissue and towel and printing and writing paper than the rest of the country. Product mix, mill type, and differences in pulp production processes affect economic competitiveness and energy intensity comparisons among regions and mills.

The Midwest is an important region for understanding U.S. manufacturing energy use and greenhouse gas emissions, as well as state programs and policies. Manufacturing represents a greater share of total GDP and total workforce in the Midwest than in any other U.S. region. The industrial sector, which is predominantly made up of manufacturing, consumes more energy than any other sector in the Midwest region (Bradbury and Aden 2012). In 2010 the pulp and paper sector accounted for roughly 7 percent of total energy use by Midwest manufacturers, which was nearly twice as much as total regional energy consumption by vehicle manufacturers (U.S. DOE/EIA 2013). Figure 5 illustrates state-level paper production for the Midwest region between 2005 and 2011.

Figure 5 | **Midwest Paper Production, 2005-2011 (million tons)**



Source: Fisher International 2013.

Notes: Excludes market pulp and captive slurry; y-axis not zero-based so as to illustrate production trends.

BOX 2 | A SNAPSHOT OF U.S. PULP AND PAPER MANUFACTURING

In 2010 pulp and paper manufacturing accounted for 11 percent of total U.S. manufacturing energy use (U.S. DOE 2013). According to the American Survey of Manufacturers, in economic terms this subsector consumed more than $6.6 billion of electricity and fuels to generate value-added worth more than $79 billion in the same year (U.S. Census Bureau 2013). Table 1 provides a snapshot of various metrics for economic and energy-related activity by the U.S. paper industry, which includes manufacturers of pulp, paper, paperboard, and "other converted paper products."

Paper is the third highest energy-consuming industry subsector in the United States, behind (1) petroleum and coal products and (2) chemicals (U.S. DOE/EIA 2013). The paper industry accounted for 5 percent of industrial CO_2 equivalent emissions in 2010—a lower share than other energy-intensive manufacturing sectors largely due to extensive use of wood-based fuels (U.S. DOE/EIA 2012a). Of the five industries that consume the most energy in the United States, paper manufacturing has the second highest electricity intensity behind primary metals.[8] Within the sector, pulp mills, paper mills and paperboard mills consume 95% of energy used by the pulp and paper sector.

TABLE 1 | U.S. PULP AND PAPER SECTOR METRICS, 2010

METRIC	PULP & PAPER	PULP MILLS	PAPER MILLS	PAPERBOARD MILLS	CONVERTED PAPER PRODUCTS
NAICS Code	322	32211	32212	32213	3222
Value of Shipments ($ billion)	170	4.5	48	27	91
Cost of Purchased Fuel and Electricity ($ billion)	8.1	0.33	3.5	2.8	1.4
Number of employees	351,000	7,000	68,000	35,000	242,000
Electricity Use (Purchases + Generation - Sales) (TWh)	98	5	48	32	13
Total Annual Energy Use (trillion Btu)[i]	2,109	249	922*	825	113
Electricity Intensity (1000 kWh Electricity Purchased + Generated per Value Added) (2010)	1.34	2.86	2.04	2.66	0.34
GHG Emissions Intensity** (2009) (%)	1.3	1.8	1.9	2.9	N / A

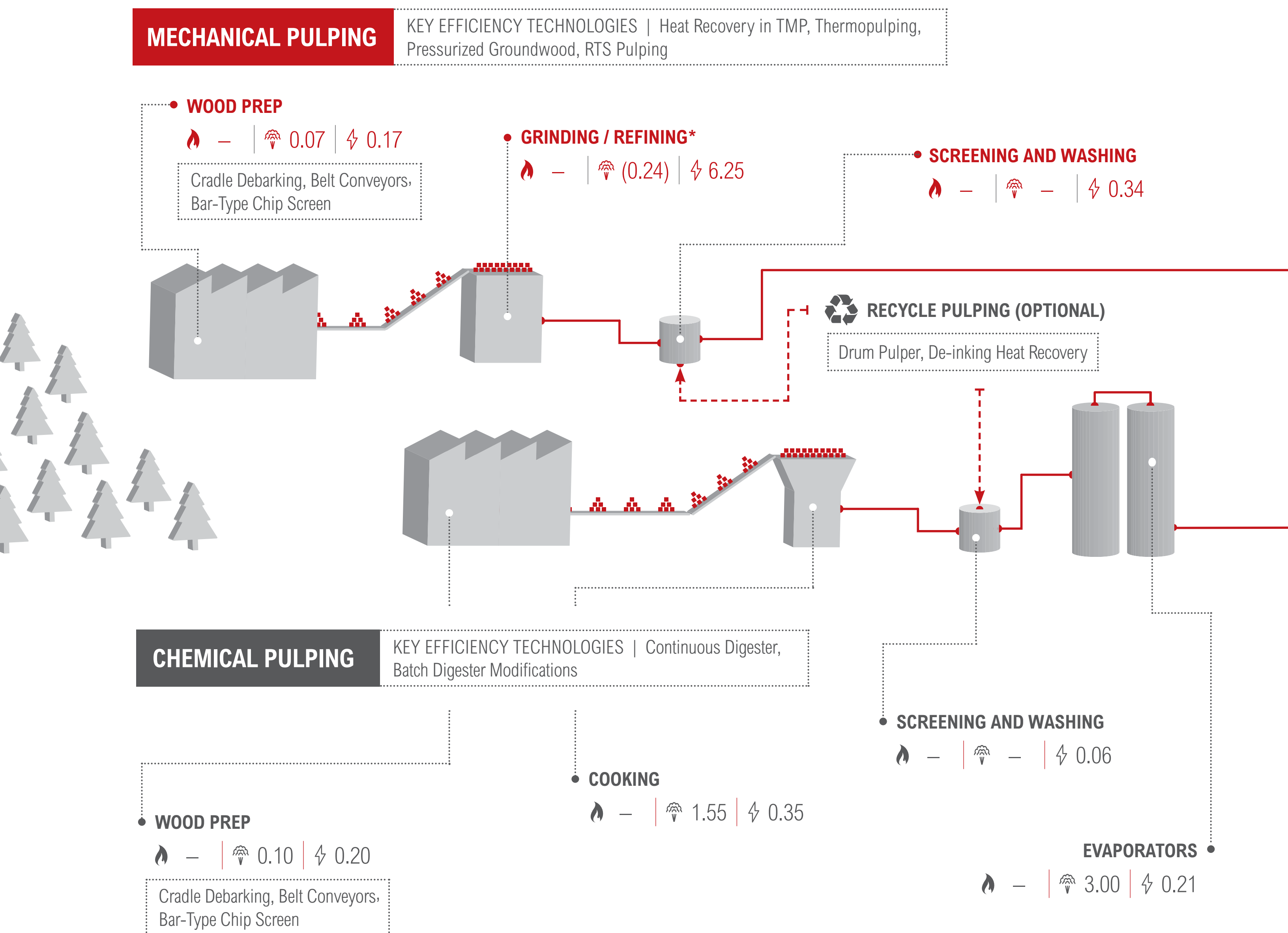
Sources: U.S. Census Bureau 2013. [i]U.S. DOE/EIA 2013a.

Notes: *This value represents the total energy consumption of NAICS 322121 (paper mills, except newsprint) and NAICS 322122 (newsprint), which consumed 821 trillion Btu and 101 trillion Btu, respectively. **Based on the interagency report on the Waxman-Markey proposed legislation in 2009, GHG emissions intensity is defined here as the added cost to a sector associated with a carbon price of $20 per ton of CO_2e, divided by the sector's total value of shipments. See: <http://www.epa.gov/climatechange/EPAactivities/economics/legislativeanalyses.html#interagencyReport>.

Figure 6 | **Energy Intensity and Efficiency Options for Pulp and Paper Manufacturing Processes**

The paper industry generally includes three types of mills: pulp mills, paper mills, and integrated mills (integrated mills include pulping and papermaking operations at one facility). Among these different mill types, a range of technologies and processes are used for production. Figure 6 illustrates components of the pulp and paper manufacturing process, which begins with wood preparation (i.e., debarking and chipping) and the chemical or mechanical pulping processes (i.e., grinding/cooking, washing, screening, and bleaching). The pulping process can be differentiated between three major types: chemical pulping, mechanical pulping, and pulp recycling. Once the pulp is produced it is either transferred to an on-site papermaking facility—in integrated mills—or transported to another facility (i.e. a paper-only or recycle mill). After entering the papermaking facility (right side of figure below), the pulp is formed, pressed, dried, and calendared to create a finished paper product.

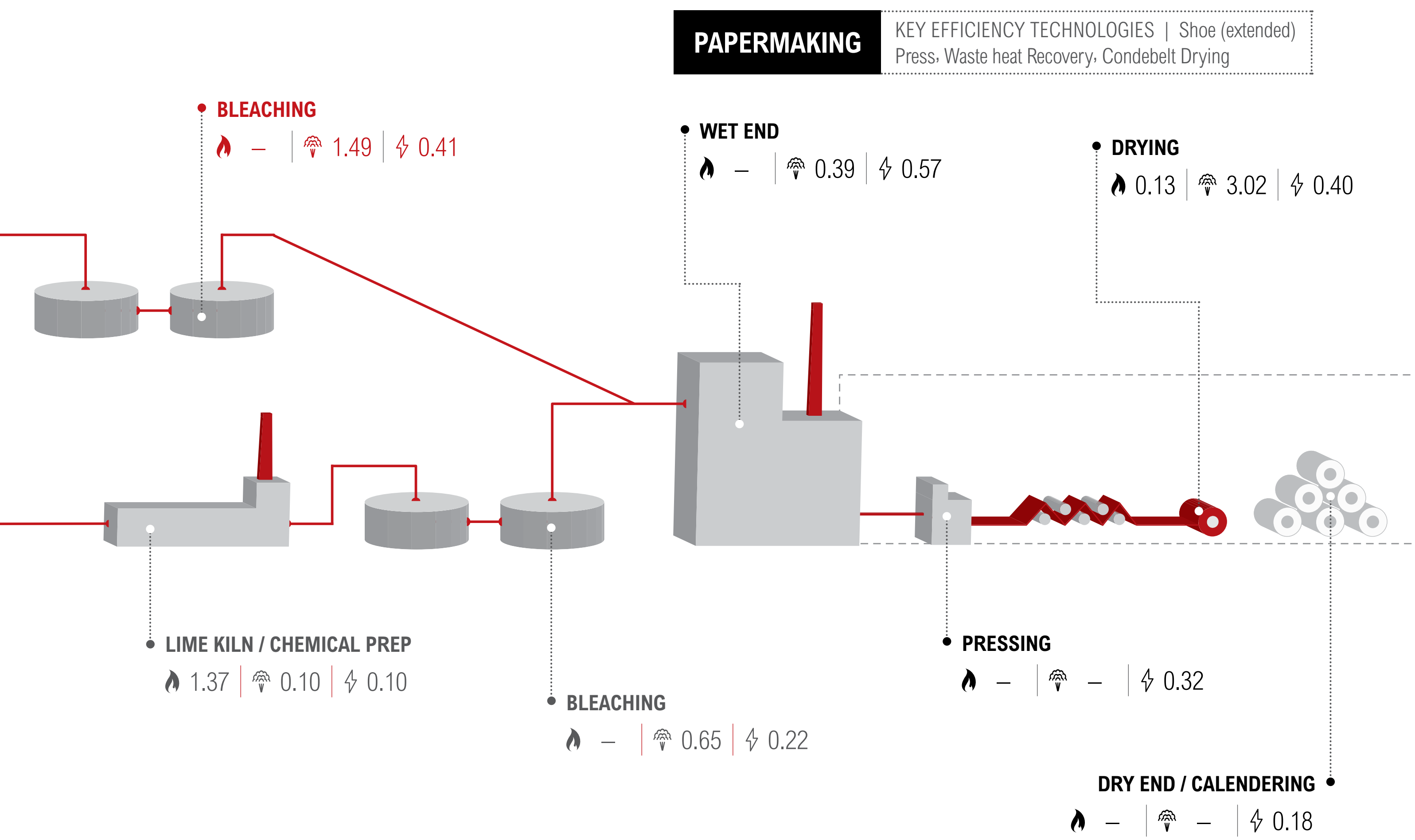
In addition to the processes involved in pulp and paper manufacturing, the figure below shows the final energy intensity of processes using Best Available Technologies (Jacobs, et al. 2006) and key efficiency technology options. The processes involved in pulp and paper



manufacturing demand substantial amounts of heat: 81 percent of the sector's energy use goes toward heating and cooling systems (U.S. EPA 2007). Water evaporation during the drying process constitutes the largest energy-consuming process in papermaking (U.S. DOE 2005a). The energy intensity of particular mills depends primarily on equipment configuration, product mix, fuel availability, and energy management practices. Previous analysis has found that key steps in the paper manufacturing process—including paper drying, paper machine wet end processing, liquor evaporation, chemical preparation including lime kilns, pulp digesting, bleaching, and other processes—could save 28 percent of energy use by adopting best available technologies (Jacobs et al. 2006). The key efficiency technology options listed in the figure are further described in Appendix V and Section 3 below.

FUEL TYPE AND KEY

- Direct Fuel (MMBtu/ton)
- Steam (MMBtu/ton)
- Electricity (MMBtu/ton)
- Key Efficiency Technologies



* Jacobs et al. data show that mechanical pulping grinding and refining is electricity intensive; steam energy can be recovered in thermomechanical pulping facilities.

Notes: The data in this process figure are from the Appendix, Tab H, with BAT data in Jacobs et al. (2006). Recovery boilers are not included in this figure due to insufficient data. This figure presents published average energy intensity associated with pulping and papermaking process best available technologies. Electricity consumption data in this figure were converted from units of kWh/adt and kWh/mdt to MMBtu/adt and MMBtu/mdt, respectively, using a final energy conversion factor of 1kWh=3,412 Btu. For more information on the energy intensity associated with Midwest mill types and pulping processes, see Appendix I.

Paper manufacturing is energy and emissions-intensive. Though other sectors, such as chemicals and petroleum and coal processing, consume more energy and produce more economic value-added, pulp and paper manufacturing was the most energy-intensive manufacturing[7] subsector in the country in 2006 (U.S. DOE/EIA 2009b). High energy intensity makes the sector more vulnerable to energy price increases, but also gives pulp and paper manufacturers more to gain through energy efficiency investments.

Description of Energy Use and Emissions in the Paper Sector

Energy use and Emissions

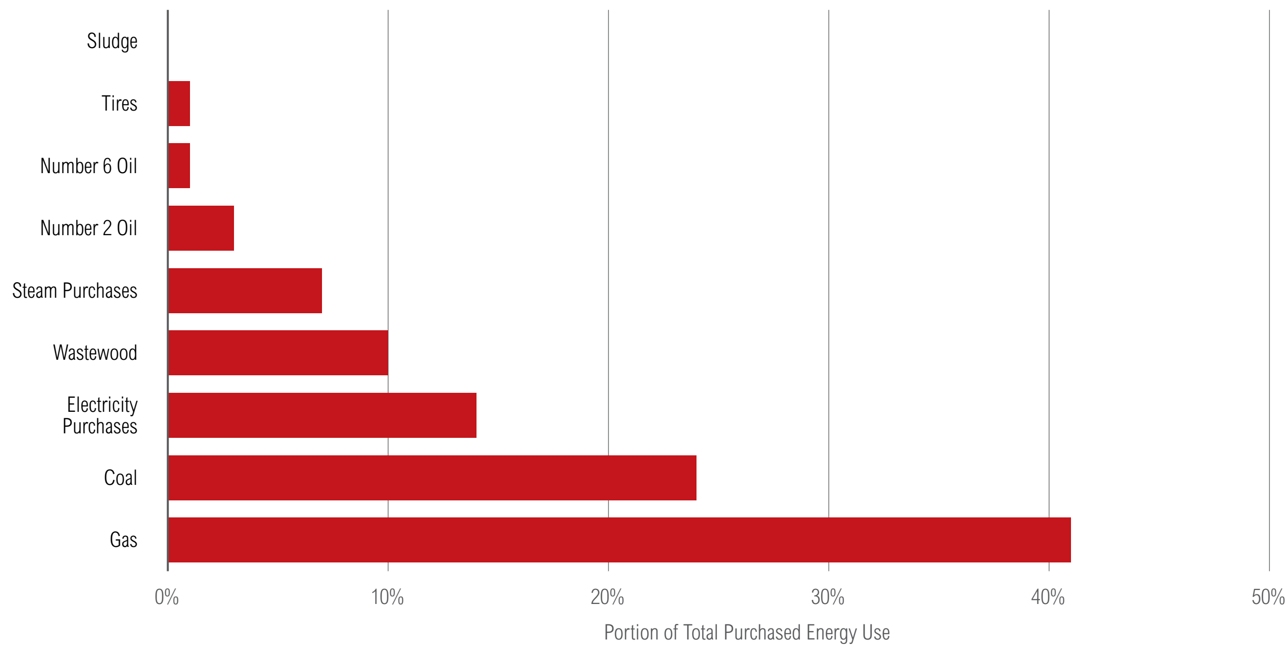
Figure 7 illustrates Midwest pulp and paper purchased energy use by fuel in 2010. Natural gas is the largest purchased energy source, followed by coal, in Midwest pulp and paper mills. Purchased energy use does not include pulping liquor or internal wastewood (both processing byproducts) that are combusted for onsite energy generation. In 2010 pulping liquor and internal wastewood accounted for 23 percent of total energy use in Midwest mills.

Due to its extensive use of bio-based fuels, the U.S. pulp and paper sector is on average less fossil fuel-intensive than U.S. industry, where 76 percent of total delivered energy use is from fossil fuels (U.S. DOE/EIA 2012a). Pulp and paper mills in the Midwest are more fossil fuel-intensive—and therefore more carbon emissions-intensive—than other mills in the U.S. In energy terms, fossil fuels accounted for 53 percent of Midwest mills' total final energy use in 2010, compared to 33 percent of total U.S. paper industry final energy use (Fisher International 2013; U.S. DOE/EIA 2012a).

The U.S. pulp and paper sector has a large remaining potential for decarbonizing its energy mix. In its 2007 report, the International Energy Agency found that the U.S. emitted more carbon dioxide per metric ton of pulp and paper production than any other OECD country (IEA 2007). The same report found that U.S. pulp and paper mills use average amounts of electricity per ton of product and have room for efficiency improvements.

The pulp and paper sector plays an important role in Midwest manufacturing. In Wisconsin, the largest paper manufacturing state in the Midwest,

Figure 7 | **Midwest Pulp and Paper Mill Purchased Energy Sources, 2010**



Source: Fisher International 2013.

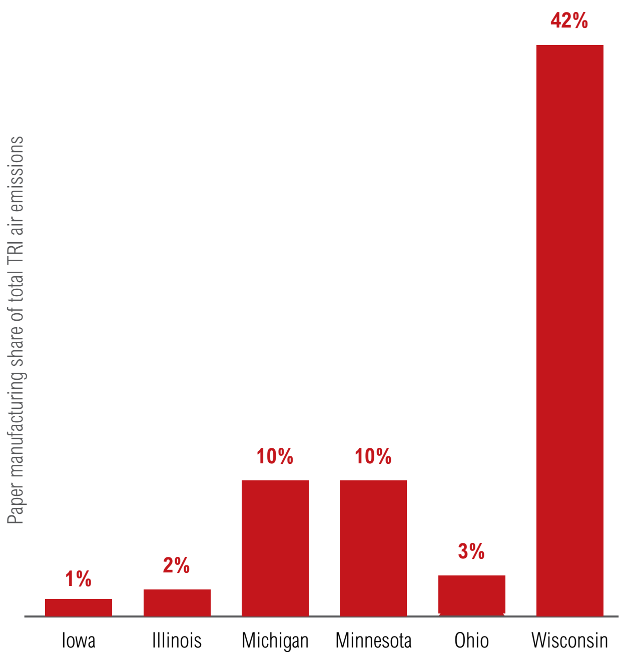
Note: purchased energy use does not include energy generated from mill by-products such as back liquor.

pulp and paper mills used an estimated 24 percent of total statewide energy for manufacturing—more than a third more than the next largest manufacturing sector (Bradbury and Aden 2012). The extent of Midwest pulp and paper manufacturing combines with its fuel mix and energy intensiveness to create substantial environmental impacts.

Pulp and paper manufacturing is responsible for a host of air and water pollutants, depending on fuel-types used on site. Figure 8 shows that the paper sector was responsible for 42 percent of Wisconsin's total toxic air emissions in 2010, according to the EPA's Toxic Release Inventory (TRI) (U.S. EPA 2012d). Whereas the pulp and paper sector share of toxic air emissions is quite high in Wisconsin, it is lower in Ohio and Illinois due to the presence of other pollution-intensive manufacturing sectors in those states.[9]

Because of their pollution-intensiveness, many pulp and paper manufacturers spend a significant portion of their revenue on mitigating environmental impacts. In fact, to conform to state and federal regulations, the pulp and paper subsector (NAICS 322) spends more than 1 percent of its total value of shipments on compliance, which is more than any other U.S. manufacturing sector.[10] In addition, most of these facilities will soon face emissions performance standards required by the recently finalized Boiler MACT rule. However, federal and state environmental regulations are increasingly designed to recognize energy efficiency as cost-effective options for compliance (Dietsch et al. 2012). Some facilities are also fuel switching to natural gas and using combined heat and power (CHP) technologies to conform to the Boiler MACT rule. Through the adoption of best practice energy efficient technologies, previous studies have found that the U.S. pulp and paper sector could cut total

Figure 8 | **Paper Manufacturing Air Toxics Emissions Impacts per State, 2010**



Source: U.S. EPA 2012d.

Note: States accounting for less than 1 percent of both categories (Indiana, Kansas, and Missouri) and states with no paper manufacturing (Nebraska, North Dakota, and South Dakota) are not included.

energy use by over 25 percent (Jacobs et al.2006); associated fuel savings would be comparable to the sector's total environmental compliance costs (Bradbury 2010).

Recent Market Trends: Challenges and Efficiency Opportunities

Since the 1990s, many pulp and paper facilities in the U.S. have been forced to idle or close as a result of changing market conditions. The cost of fuels and purchased electricity increased 26 percent within the U.S. pulp and paper sector between 2000 and 2005, at the same time that competition intensified through expanded international trade (see, for example, Figure 2) (NREL 2009).

The high energy intensity of U.S. pulp and paper production makes the sector comparatively vulnerable to energy price increases. In 2006, purchased energy for heat and power represented 8.4 percent of total direct production costs (NREL 2009). Rising energy costs and other challenges contributed to the closure of 10 percent of Midwest pulp and paper mills between 2005 and 2010 (Fisher International 2013).[11] According to the Census Bureau, the number of U.S. pulp and paper sector employees dropped by 30 percent, from 491,000 in 2002 to 346,000 in 2011 (U.S. Census Bureau 2013).

As part of a strategy to stay competitive (see Section 4), U.S. pulp and paper mills have improved their energy efficiency in the last 20 years. When energy prices rose in the 1990s, the sector used energy efficiency investments and fuel switching from petroleum fuel sources to natural gas and biomass as a means of reducing costs (U.S. EPA 2007). According to the American Forest and Paper Association (AF&PA), member companies reduced the amount of purchased energy use per ton of production by 15 percent between 2000 and 2010 (AF & PA 2012). For 2020, AF&PA has set a goal of improving purchased energy efficiency by 10 percent over the 2005 average level.

Process cooling and heating systems comprise 81 percent of the pulp and paper industry's energy use (U.S. EPA 2007). According to the ENERGY STAR Guide for the Pulp and Paper Industry, drying is generally the most energy-intensive step in the paper manufacturing process (Kramer et al. 2009).[12] This has led industry to pursue a variety of efficiency measures that reduce energy use associated with drying. Given the high heat and electricity requirements of pulp and paper production, more efficient combined heat and power is widely used and considered as a technology option (see Section 3).

A central advantage of CHP is that energy conversion efficiencies increase from the 33 percent—typical of central station power plants—to between 50 and 80 percent depending on fuel type and CHP equipment configuration (Brown et al. 2011). The pulp and paper sector has achieved long-term reductions in energy intensity through process improvements and increased utilization of CHP (NREL 2009). Looking forward, published policy scenarios suggest that additional CHP utilization in the pulp and paper sector could lead to total electricity generation of approximately 75 billion kWh by the year 2035, compared to total 2010 pulp and paper sector electricity use of 98 billion kWh (Table 1) (Brown et al. 2011).

The academic and technical literature presents a range of estimated remaining potential for U.S. pulp and paper sector efficiency improvements. The National Academy of Sciences found that by applying current practices used by the most modern mills, the pulp and paper sector's energy consumption could be reduced by 25 percent with current technologies, and up to 41 percent pending continued research and technology development (NAS 2010). According to another DOE estimate, implementation of cost-effective EE potential in 2020 could reduce the pulp and paper sector's energy consumption between 6 and 37 percent (Brown et al. 2011). Within that range, McKinsey and Company estimate that an acceleration of adopting proven technologies and process equipment could reduce the sector's energy usage by 26 percent by 2020 (McKinsey & Company 2009). In their study of the U.S. pulp and paper sector in 2006, Xu et al. (2012) found technical final energy savings potential of 62 percent and cost-effective final energy savings potential of 25 percent. As discussed in Section 3, a range of technologies and processes can help to improve pulp and paper manufacturing energy efficiency, including fiber substitution, steam trap maintenance, papermaking, and multi-process improvements.

A central advantage of CHP is that energy conversion efficiencies increase from the 33 percent—typical of central station power plants—to between 50 and 80 percent depending on fuel type and CHP equipment configuration.

Section 2

SECTOR ASSESSMENT WITH EFFICIENCY BENCHMARKING AND EMISSIONS INVENTORY

This section evaluates the relative energy performance of the Midwest pulp and paper sector and estimates potential energy cost savings associated with energy efficiency improvements by regional mills. Greenhouse gas emissions reductions are also assessed under energy efficiency and fuel switching scenarios.

This bottom-up analysis is based on facility-level energy-use and production data from the Fisher database. Benchmarking is conducted to assess the relative energy intensity of pulp-only mills and integrated pulp and paper mills in the region using an ENERGY STAR Energy Performance Indicator (EPI) tool published in 2012.

Benchmarking is a well-established method for quantifying facility, sector, or national-level energy and emissions performance. The methods involved in benchmarking industry energy use and emissions involve several considerations that influence final results. Five key issues include definition of product or sector (such as total pulp and paper versus market pulp), calculation methods and boundaries (such as whether to include indirect emissions associated with purchased energy), units for normalizing the benchmark (such as tons of output or value added), benchmark ambition (such as average versus best practice), and data sources (such as government surveys versus industry associations) (SEI 2010). This study uses a publicly available benchmarking framework established by the U.S. Environmental Protection Agency (Boyd and Guo 2012).

Table 2 | **Midwest Pulp and Paper Mills, 2010**

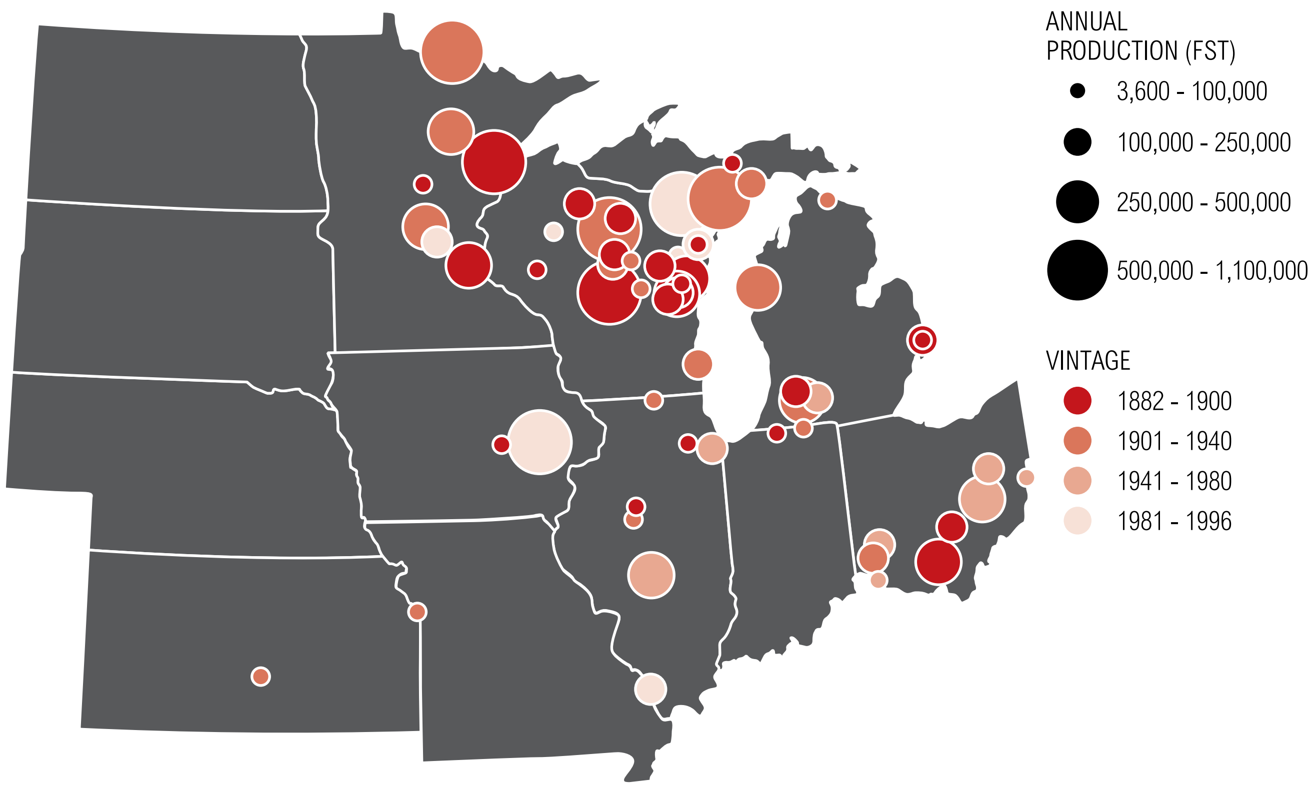
MILL TYPE	MILLS	ANNUAL PRODUCTION (TONS)[i]
Integrated Mills	20	7,325,000
Pulp-only Mills	5	416,000
Paper-only Mills	68	9,003,000
Midwest Total	93	16,744,000

Source: Fisher International 2013.

Notes: Most pulp and paper sector production data are reported in finished short tons (FST). Unless labeled otherwise, this report uses FST.

Benchmarking provides a quantitative basis for comparative assessment and identification of energy efficiency gaps. Numerous publications have assessed the energy efficiency gap across multiple sectors of the U.S. economy as a whole (Jaffe and Stavins 1994; McKinsey & Company 2009; NAS 2010; Allcott and Greenstone 2012), largely from an economic perspective. Within industry, a number of engineering-accounting studies have quantified the energy efficiency gap for particular sectors (Worrell, Price, and Martin 1999; U.S. DOE/EIA 2007; Oda et al. 2012). As an economic and geographical center of U.S. manufacturing, the Midwest region, and individual Midwest states, also have been the subject of energy efficiency gap assessments (Livingston, Mason, and Rowe 2009; U.S. DOE/EIA 2009b; Energy Center of Wisconsin 2009; DeWahl et al. 2010). Compared to prior publications, this report provides a uniquely detailed assessment of paper sector energy efficiency opportunities throughout the Midwest.

Map 1 | **Midwest Pulp and Paper Mills by Year Built and Production Capacity, 2010**



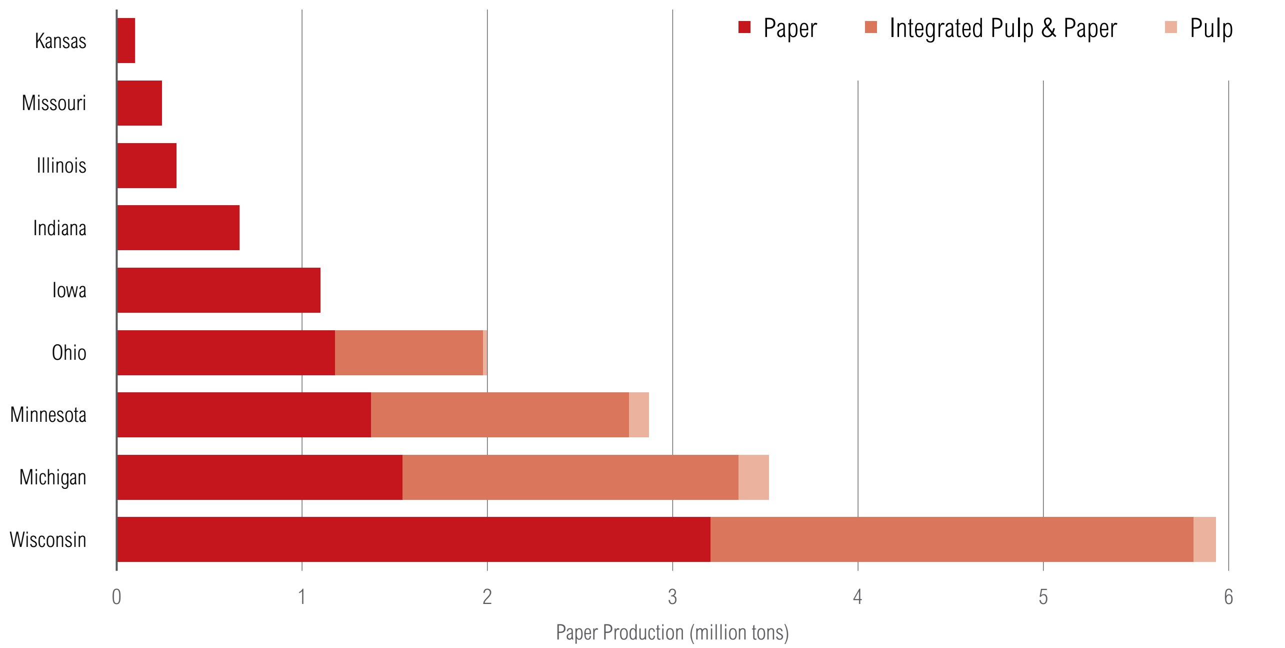
Source: Fisher International 2013.

To align with available data from the U.S. GHG reporting tool and the release of the 2010 Manufacturing Energy Consumption Survey (MECS) database (US. DOE/EIA 2013), this study benchmarks Midwest pulp and paper mills in 2010. Table 2 and Figure 9 show the distribution of 2010 Midwest mills and production by mill type. Note that most Midwest mills don't produce pulp on-site and therefore purchase it from offsite providers. Integrated and pulp-only mills accounted for 46 percent of total Midwest production in 2010.

Wisconsin has more than twice as many mills as any other Midwestern state. In 2010, Wisconsin mills, many of which are relatively small, produced nearly 6 million tons of paper products, accounting for more than a third of Midwest paper production. As illustrated in Figure 9, the Midwest has a comparatively high share of tissue and towel, as well as printing and writing production. Map 1 shows the geographic distribution of Midwest pulp and paper mills by 2010 production amount and vintage. In 2010 the average Midwest pulp and paper mill was built in 1922. For more information on the distribution of pulp and paper mills by state within the Midwest, see Appendix I.

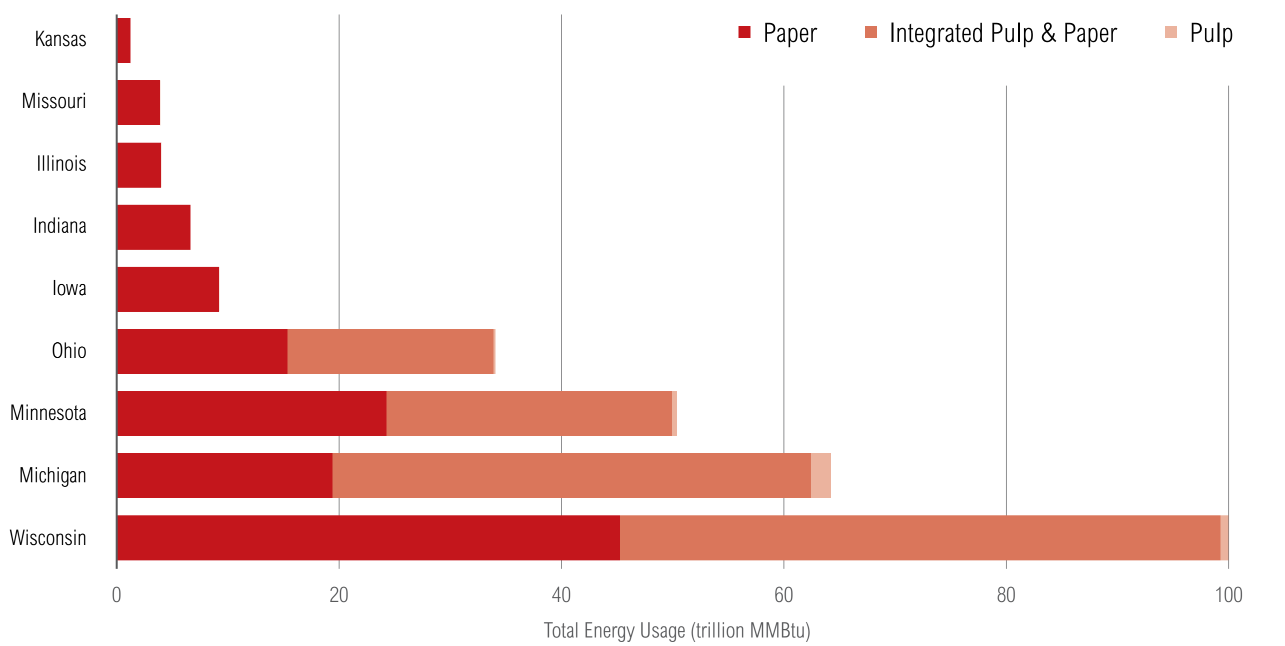
Figure 9 illustrates the distribution of Midwest pulp and paper production by state and mill type. Among the four largest pulp and paper producing states, integrated and pulp-only mills accounted for 49 percent of 2010 production and 53 percent of 2010 total energy use. Figure 10 shows the distribution of Midwest pulp and paper energy use by state and mill type. In 2010 all the production in the smaller five states was from paper-only mills.

Figure 9 | **Midwest Paper Production by State, 2010**



Source: Fisher International 2013.

Figure 10 | **Midwest Pulp and Paper Energy Use by State, 2010**



Source: Fisher International 2013.

Pulp and Paper Mill Energy Efficiency Benchmarking

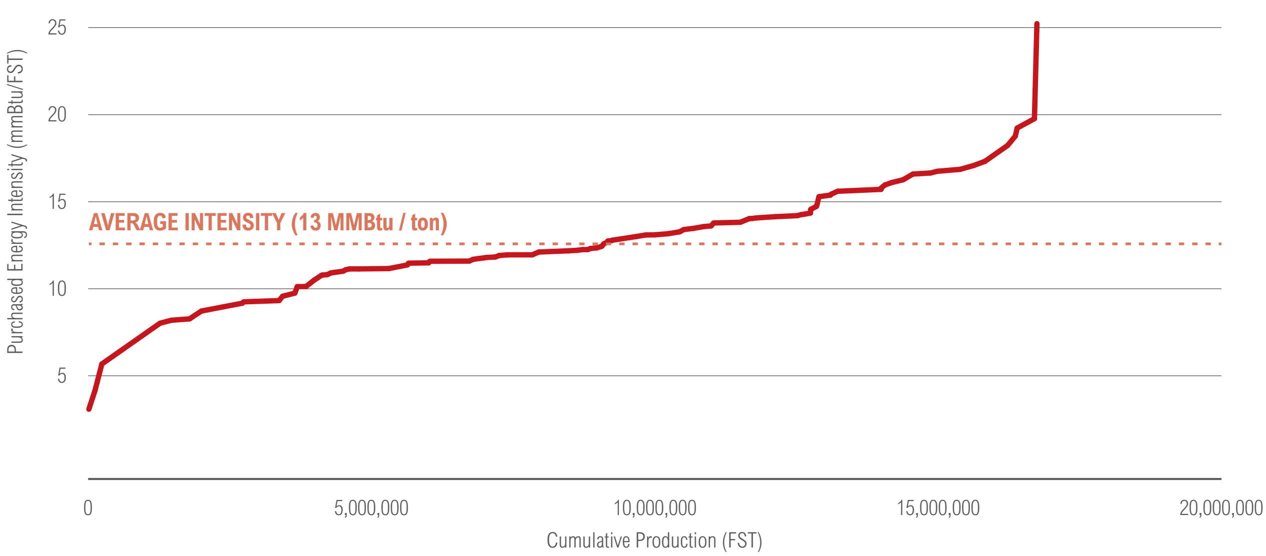
Midwest pulp and paper mills vary widely in their purchased energy intensity.[13] As illustrated in Figure 11, the amount of purchased energy per finished short ton of paper product ranges between 3 million Btu and 25 million Btu, with an overall average intensity of 13 million Btu per ton. While it captures the range of existing mills, this one-size-fits-all benchmarking approach does not differentiate by product or mill type.

In order to better assess paper mill energy performance on a comparable basis, the U.S. Environmental Protection Agency's ENERGY STAR program collaborated with industry representatives to develop an energy performance benchmarking tool for pulp mills and integrated pulp and paper mills. The core of the program is a piece of software called the Energy Performance Indicator (EPI) tool that compares an individual mill's energy performance with comparable mills throughout the U.S. The ENERGY STAR Industrial program has developed EPI tools for various manufacturing subsectors based on confidential facility-level Census data.[14] In order to move beyond the one-size-fits-all benchmarking approach described above, the following analysis uses facility-level energy use and production data with the EPI tool that was developed for pulp-only mills and integrated pulp and paper mills (but not for paper-only mills; see Box 3). This EPI assessment covers more than 40 percent of total regional paper production by mass and 59 percent of total energy used by the Midwest pulp and paper industry in 2010.

The results of the EPI analysis for the 25 pulp and integrated pulp and paper mills located in the Midwest are shown in Figure 12.

This report's EPI analysis finds that Midwest pulp-only mills and integrated pulp and paper mills are less efficient than the average U.S. mill. The lower dashed grey line in Figure 12 illustrates the average Midwest benchmarked facility Energy Performance Score (EPS) of 46—slightly below the normalized U.S. average EPS of 50.[15] The upper dashed red line shows the minimum EPS score required for ENERGY STAR certification. As illustrated by the light red bars in Figure 12, Midwest pulp-only mills are overall less efficient than other U.S. pulp mills and have an average EPS of 38.

Figure 11 | **Purchased Energy Intensity of Midwest Paper Production, 2010**



Source: Fisher International 2013.

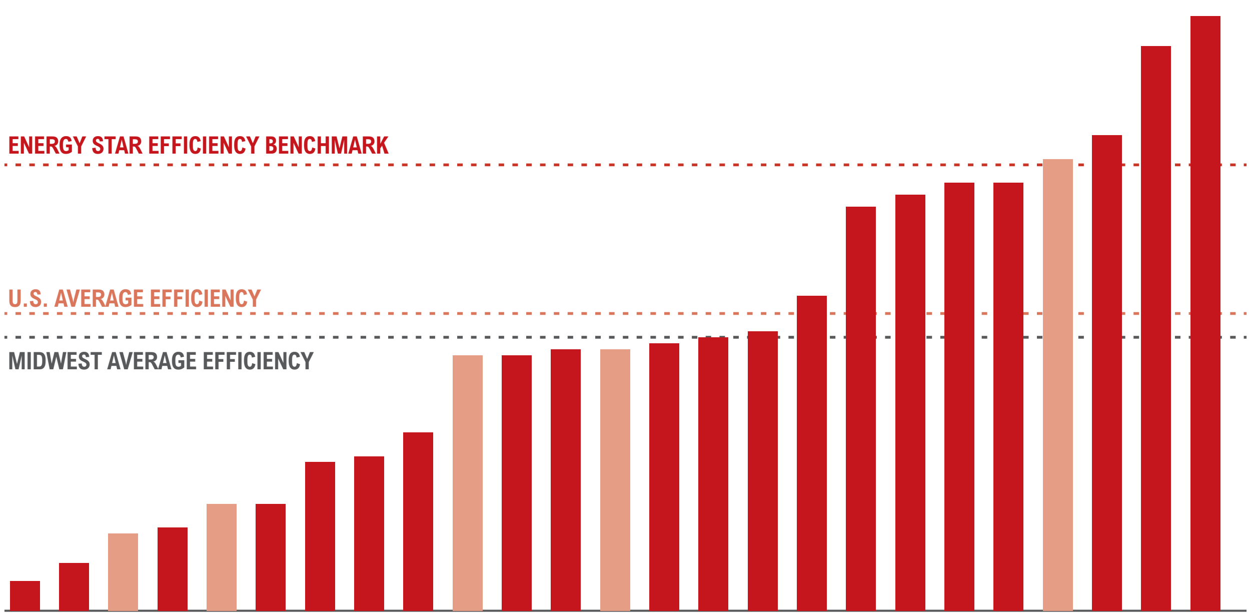
BOX 3 | NUTS AND BOLTS OF THE EPI TOOL

The ENERGY STAR EPI tool normalizes mill energy performance by separating pulp and integrated mills. Within each mill type, the tool assesses performance for a given production mix (such as coated free sheets versus tissue or packaging) and production level (such as tons per year). In addition to annual production by type, tool inputs include the amount of purchased materials (recycled fiber, sodium hydroxide, etc.) and annual energy use by fuel. The primary output of the tool is an Energy Performance Score (EPS) that rates the particular mill between 1 and 100, where a score of 50 is equivalent to the U.S. average. Another output of the tool is the purchased energy that would be consumed by that mill if it were at the U.S. average (EPS of 50) and if it was considered efficient (EPS of at least 75).

If all twenty-one of the Midwest mills below the ENERGY STAR efficiency benchmark line invested in energy efficiency to achieve this level of performance they would realize gross energy savings of 36 trillion Btu per year according to results of the EPI analysis.[16] Among these mills, improvement to the ENERGY STAR benchmark efficiency performance level would reduce total purchased energy use by 30 percent. At the average Midwest 2010 paper sector purchased energy cost of $6.69/million Btu (see Appendix III), these energy savings would have saved Midwest pulp-only mills and integrated pulp and paper mills approximately $240 million annually.

On the state level, Michigan has the largest amount of potential energy and cost savings from efficiency improvements that would bring its mills to the ENERGY STAR performance level. Table 3 shows the breakdown of 2010 state level Energy Performance Scores and estimated energy and cost savings that would accrue from efficiency improvements.

Figure 12 | **Midwest Integrated and Pulp Mill Energy Performance Indicator Assessment, 2010**



Sources: WRI Analysis; Fisher International 2013.

Note: Integrated mills are displayed as red bars and pulp-only mills are displayed as light red bars.

Table 3 | **Energy and Cost Savings from Mill Efficiency Improvements, 2010**

STATE SUBTOTAL	NUMBER OF MILLS	AVERAGE EPS	POTENTIAL ENERGY SAVINGS WITH ENERGY STAR PERFORMANCE (TRILLION BTU/YEAR)	POTENTIAL ENERGY COST SAVINGS WITH ENERGY STAR PERFORMANCE ($ MILLION/YEAR)
Wisconsin	7	62	10	$64
Minnesota	6	40	11	$73
Michigan	4	20	13	$84
Ohio	4	39	3	$18
Midwest Subtotal	**21**	**46**	**36**	**$240**

Note: This table covers Midwest integrated or pulp-only mills with a 2010 EPS below 75; other Midwest states only have higher performing mills or paper-only mills.

The 64 percent of Midwest pulp and integrated paper mills with EPI scores below 50 indicate that the sector has substantial "low-hanging fruit" with potential for cost-effective energy efficiency improvements (see Section 3).

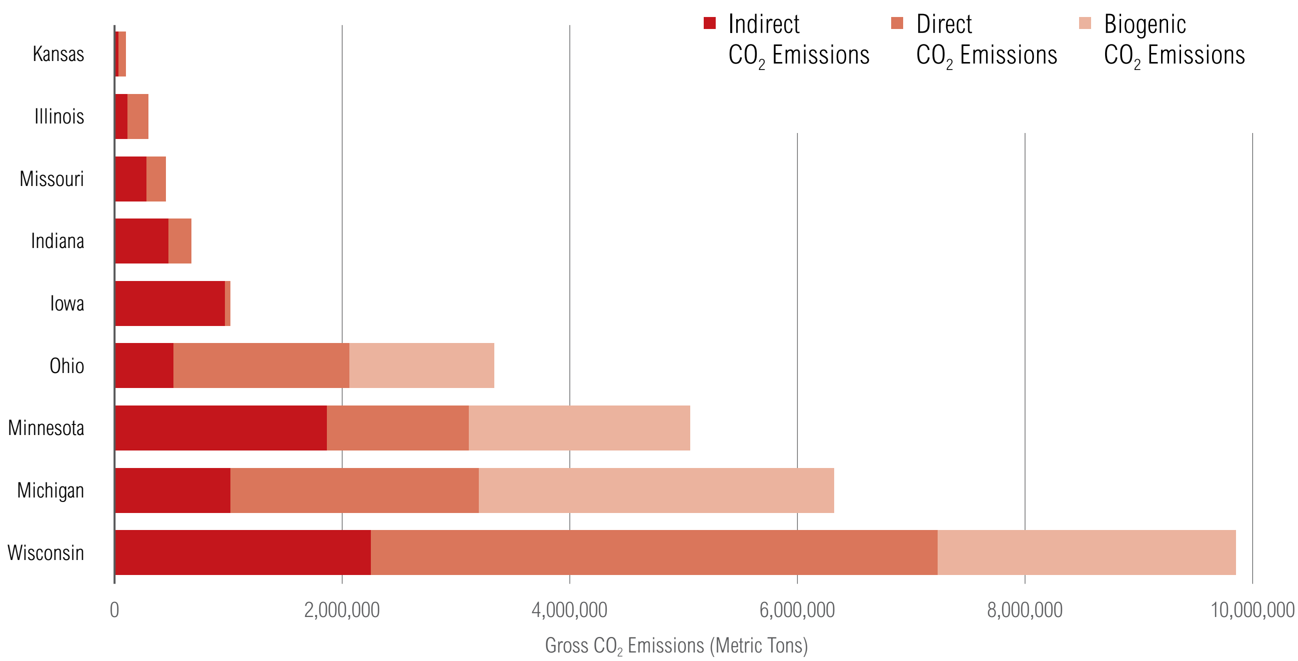
In its long-term industry analysis, the IEA has separately estimated that the U.S. pulp and paper sector would need to invest at least $40 billion between 2010 and 2050 to move from a baseline to a high-efficiency/low-emissions scenario (IEA 2010). Through a combination of cost-effective efficiency improvements, fuel switching, and new CCS technology, the IEA 2050 high-efficiency scenario would require 11 percent less energy use than a baseline scenario.

Carbon Dioxide Emissions Inventory

To quantify the extent and distribution of greenhouse gas emissions from the Midwest pulp and paper sector, this study presents an inventory of energy-related nonbiogenic CO_2 emissions from each of the ninety-three pulp and paper mills operating in the Midwest in 2010.[17] As with energy efficiency benchmarking, calculation of emissions inventories involves a range of assumptions and intermediate variables that influence final results. This study uses a GHG emissions calculation tool developed for the U.S. pulp and paper sector by the National Council for Air and Stream Improvement (NCASI)—an independent, nonprofit research institute that focuses on environmental topics of interest to the forest products industry. Energy-related CO_2 emissions are calculated using version 1.3 of the NCASI pulp and paper manufacturing GHG tool, which is publically available.[18] The NCASI GHG tool was developed in 2005 to conform to the WRI/WBCSD GHG Protocol, and updated in 2008 to incorporate revised data from the 2006 IPCC guidelines for national GHG inventories.

Pulp and paper mills use a range of fuels, including fossil fuels, purchased electricity, and biomass. To quantify the full CO_2 emissions from Midwest pulp and paper mills, this inventory calculates direct emissions (from on-site fossil fuel combustion),

Figure 13 | **Total Midwest State-level Pulp and Paper Mill CO_2 Emissions, 2010**



Sources: Fisher International 2013; NCASI 2008; IPCC 2006; U.S. DOE 2007; U.S. DOE 2010; U.S. EPA 2010.

indirect emissions (from purchased electricity and steam), and emissions from biomass combustion. For more information on this report's emissions inventory (e.g., emissions factors assigned to each fuel type) see Appendix II.

State-level total emissions are displayed in Figure 13. The contrast between state-level CO_2 emissions (Figure 13) and production levels (Figure 9) shows the importance of scope when considering net emissions implications of different policy options. For example, when indirect emissions are accounted for, Minnesota pulp and paper mills generate 50 percent more emissions than mills in Ohio; yet direct CO_2 emissions from mills in Ohio are more than 20 percent greater than direct emissions from Minnesota mills.[19] This report utilizes direct and indirect energy-related carbon dioxide emissions in its analysis, not including biogenic emissions.[20]

To ensure consistency with the Environmental Protection Agency's (EPA) three-year deferral of permitting requirements for carbon dioxide from biomass sources (announced in July 2011),[21] emissions from biogenic emissions were not included in this analysis. While industry considers carbon dioxide emissions from biogenic sources to be carbon neutral (because they are offset by the sequestration of carbon dioxide in regenerating forests; AF & PA 2012), this remains a matter of ongoing debate (e.g., see U.S. EPA, 2011). In addition, some states with Renewable Energy Standards (RES), such as Maryland, qualify forms of biomass as renewable energy sources.[22] The qualification of biomass as a renewable energy source permits paper mills that use biomass as a fuel source to sell renewable energy credits (REC) to electric utilities, which can count toward a utility's requirement that a percentage of their electricity come from a renewable energy source under their respective state's RES.

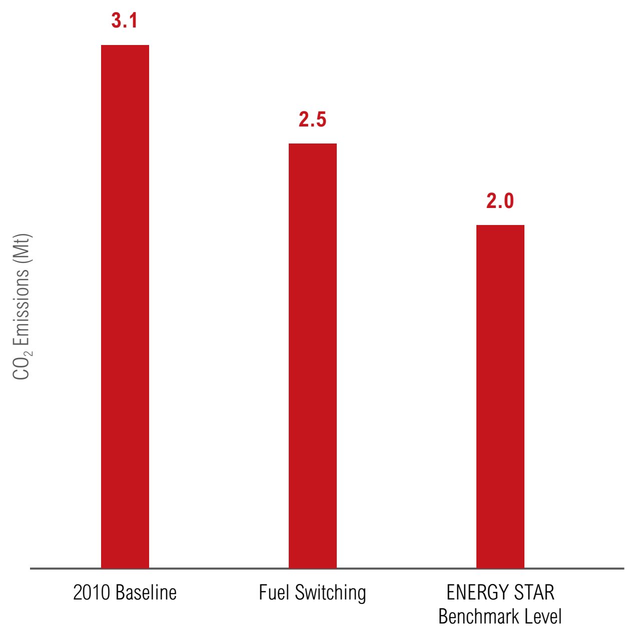
This analysis finds that Midwest pulp and paper mills generated 18 million metric tons of direct and indirect carbon dioxide emissions in 2010. The EIA 2012 *Annual Energy Outlook* separately estimates total U.S. pulp and paper sector emissions of 77 million metric tons of carbon dioxide equivalent in 2010 (U.S. DOE/EIA 2012a). Midwest pulp and paper mills produced 18 percent of total U.S. output by weight in 2010 (Fisher International 2013), yet regional mills accounted for 24 percent of the sector's total national aggregate CO_2 emissions in the same year, largely due to their higher use of fossil fuels (U.S. DOE/EIA 2012a).

Emissions Scenarios: Savings from Fuel Switching and Efficiency Improvements

Based on the CO_2 emissions inventory developed in this project, CO_2 emission reduction potentials were estimated for the Midwest pulp and paper sector under two scenarios. The first scenario examines the emissions implications of fuel switching from coal and oil to natural gas. The second scenario assumes that facilities with low ENERGY STAR EPS scores increased their efficiency to reach an EPS of 75—the score necessary to achieve the ENERGY STAR benchmark for superior energy performance. Fuel switching to biomass could further reduce carbon dioxide emissions, depending on biogenic accounting factor assumptions.

Among the twenty-five pulp and integrated pulp and paper mills in the Midwest, twenty-one have an EPS below 75. Within that group of twenty-one mills, seven mills use coal or oil and therefore have potential to switch fuels. If each of the seven Midwest pulp and paper mills considered here were to use natural gas as an alternative to coal and oil, 2010 baseline emissions would be reduced by 19 percent (Figure 14).[23] If these same seven mills were to increase their energy efficiency to achieve ENERGY STAR benchmark efficiency, emissions reductions would be greater than the fuel switching scenario—34 percent lower than 2010 baseline emissions. This result is consistent with Xu et al. (2012), who found total U.S. pulp and paper technical emissions reduction potential to range between 20 and 45 percent in 2006. While the potential for emissions reductions is represented by two scenarios separately, fuel switching and efficiency improvements are not exclusive, and ideally are complementary.

Figure 14 | **Midwest Pulp and Paper Mill Direct and Indirect Carbon Emissions Scenarios**



Sources: Fisher International 2013; NCASI 2008; IPCC 2006; U.S. DOE/EIA 2007; U.S. DOE/EIA 2010; U.S. EPA 2010.

Note: Fuel switching is ideally combined with efficiency improvements; however, data are currently insufficient to display the emissions results from the combined scenario.

Both fuel-switching and energy efficiency improvements have potential for reducing Midwest pulp and paper carbon dioxide emissions. This scenario analysis demonstrates that efficiency improvements to the ENERGY STAR benchmark level of proven best-practice technologies would mitigate emissions more than maximizing sector natural gas usage. This finding suggests that policies that stimulate fuel switching—such as the final Boiler MACT rule—have less of a near-term CO_2 emissions mitigation impact than policies that specifically track and incentivize energy efficiency improvements.[24]

Section 3

ENERGY EFFICIENCY OPTIONS IN PULP AND PAPER MANUFACTURING

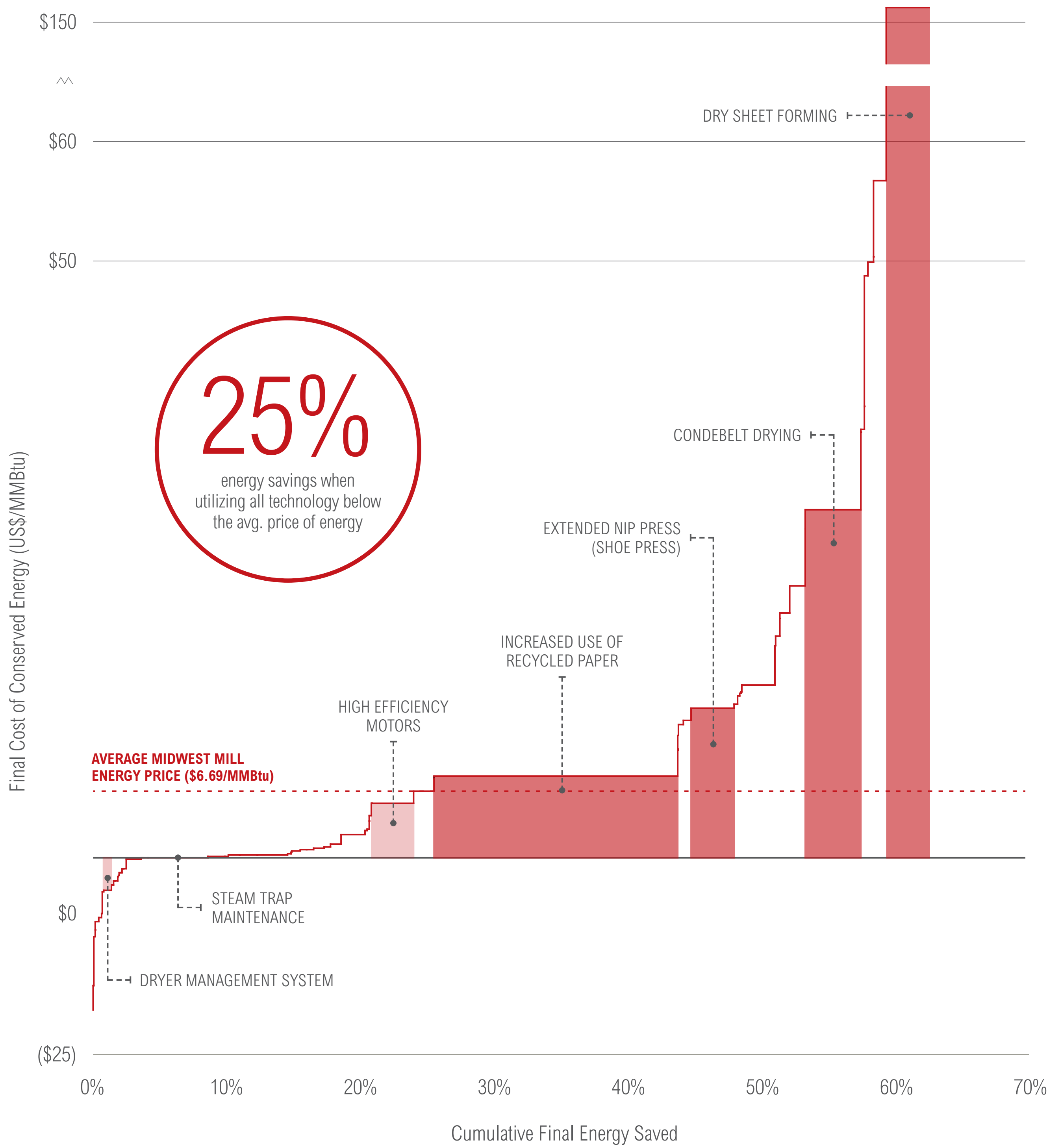
A range of proven technologies and processes are available to help pulp and paper mills reduce their total energy use. Cost curve analysis suggests that Midwest mills could cost-effectively reduce their energy intensity by 25%. Case studies demonstrate that leading mills are already using efficiency investments to improve their environmental performance and competitiveness.

Section 2 presented a bottom-up assessment of mill energy efficiency performance and carbon emissions. This section uses aggregate, national-level data to describe the range of available energy efficiency options. Energy efficiency cost curves illustrate the relative cost and energy savings potential of existing energy efficiency technologies. The cost curve display has been popularized through studies of industrial energy efficiency potential in California (Coito et al. 2005) and on a national scale by McKinsey & Company (2009), who previously estimated negative costs associated with the net present value of energy efficiency improvements for the residential, commercial, and industrial sectors by the year 2020. This study presents an updated, regionalized version of the U.S. pulp and paper sector cost curve developed by the Lawrence Berkeley National Laboratory (Xu, Sathaye, and Kramer 2012).[25] The cost curve data show that the U.S. pulp and paper sector could cost-effectively reduce its energy intensity by more than 5 million Btu per metric ton of production. Cross referencing the cost curve analysis with Wisconsin-specific information shows that many available energy efficiency options have less than two-year payback periods.

Data limitations prevent a facility-level assessment of how widely particular EE measures have already been adopted by mills in the Midwest or elsewhere in the U.S. However, results of the EPI analysis (Section 2) show that many Midwest pulp and paper mills are less efficient than the U.S. average, which suggests that they have not yet fully implemented the energy efficiency options described in this section. This section offers a menu of EE options for Midwest mills to consider for cost-effective energy savings; available data do not support mill-specific recommendations.

Figure 15 presents a U.S.-scale EE cost curve with each measure's cost of conserved energy (2010$/MMBtu) and saved final energy (percent of total average energy intensity). Within the curve, the width of each horizontal segment indicates the energy savings potential for each measure, while the vertical height corresponds to the discounted cost per unit energy saved for each measure. Individual energy efficiency options for the paper sector were ordered from least expensive to most expensive. The curve is based on aggregated data for the pulp and paper sector across the entire U.S., illustrating the range of proven technology options available for cost-effective energy efficiency investments.

Figure 15 | **Cost Curve of U.S. Pulp and Paper Manufacturing Energy Efficiency, 2010**



Sources: Xu,Sathaye, and Kramer 2012; Bureau of Labor Statistics 2012.

Table 4 | **Top Five Pulp and Paper Manufacturing Energy Efficiency Improvement Measures**

MEASURE	PROCESS DESCRIPTION	APPLIED FINAL ENERGY SAVINGS (MMBTU/T)	COST OF CONSERVED ENERGY (2010$/MMBTU)
Increased use of recycled paper	Fiber substitution	3.46	$6.84
Steam trap maintenance	Steam production	0.85	< $0.05
Condebelt drying	Papermaking	0.80	$29.16
Extended nip press (shoe press)	Papermaking	0.61	$12.53
Dry sheet forming	Papermaking	0.61	$157.00

Source: Xu, Sathaye, and Kramer 2012.

This U.S. pulp and paper sector cost curve displays information for 101 established energy-saving technologies with the average final cost of conserved energy. These technologies have a cumulative final energy savings potential of 62 percent of total average energy intensity.[26] The Y axis values of Figure 15 range from negative $13/MMBtu to positive $157/ MMBtu in order to clearly display key energy efficiency options. Options with a negative cost below $50/MMBtu and positive cost above $200/MMBtu account for less than 1 percent of the identified final energy savings potential, and are not shown in the figure. For comparison, the horizontal dotted orange line in Figure 15 shows the average energy price for Midwest pulp and paper mills in 2010 (see Appendix III).[27]

By comparing the cost curve with the average energy price,[28] we learn that cumulative savings of 25 percent are available for less than the average cost in 2010 for a typical Midwest mill to purchase energy. Figure 15 also shows that the typical cost of increased use of recycled paper is within $0.15/ MMBtu (2 percent) of the 2010 average Midwest energy price and would yield an additional 18 percent of savings. The overall finding that Midwest paper mills could cost-effectively reduce their energy use by 5–8 MMBtu/metric ton is consistent with the IEA's assessment that the U.S. pulp and paper sector could reduce energy intensity by 5.3 MMBtu/metric ton with implementation of best available technologies (IEA 2010). Research shows that cost-effective energy efficiency opportunities are often not pursued due to behavioral limits on adoption and policy program costs (Huntington 2011). With higher energy prices, cost-effective energy savings would increase. Between 2010 and 2012 average industrial natural gas prices dropped by 57 percent; further energy price drops could undermine the cost-effectiveness of energy efficiency improvements, though they could facilitate fuel switching away from coal and oil, perhaps in combination with installation of CHP equipment.

The most energy-effective measures in the cost curve (i.e., those that would achieve the most total energy savings) are labeled in Figure 15 and described in greater detail in Table 4. Taken together, the top five most energy-effective measures displayed in Table 4 account for 6.33 MMBtu/ metric ton of energy savings. These are not the lowest-cost options, but are described in greater detail below to indicate technical potential.

Increased use of Recycled Paper

Increased paper recycling is the energy efficiency option with by far the greatest energy savings potential. Compared to copy paper made from virgin forest fiber, the same product made from recycled content consumes an estimated 44 percent less energy and produces 50 percent less waste water (EPN 2007). However, use of recycled paper can degrade product quality and impede production of some grades of paper. From an industry perspective limited deinking capacity can make recycling fiber more costly than using virgin fiber in some cases—such as with coated mechanical paper (EPN 2007). Overall U.S. paper and paperboard recovery rates have doubled from 34 percent of total production in 1990 to 67 percent in 2011.[29]

Steam Trap Maintenance

Annual failure rates of steam traps are estimated to be at least 10 percent. According to the EPA, steam trap maintenance programs can reduce steam distribution system malfunctions by 15 to 20 percent (U.S. EPA 2010). Numerous case studies have shown that repairing or installing new steam traps can be accomplished at very low costs, paying back the capital investment in a matter of months, while improving productivity (Kramer et al. 2009).

Condebelt Drying

The potential exists to completely replace the drying section of a conventional paper machine by utilizing a chamber to dry paper through continuous contact with a hot steel band. Using heat from the metal band to evaporate the water from paper has the potential to increase drying rates 5 to 15 percent higher than conventional steam drying (U.S. EPA 2010).

Extended Nip Press (Shoe Press)

Much of the energy use in papermaking is related to heat used for water extraction. One part of water extraction process involves pressing – traditionally done using two rotating cylinders (Xu, Sathaye, and Kramer 2012). The extended nip press differs from the traditional pressing process by replacing one of the cylinders with a concave shoe. This alteration increases drying efficiency due to the large concave shoe of the extended nip press creating additional dwell time in the press, which extracts 5 to 7 percent more water than a rotating cylinder press. Increased water extraction at this stage of paper drying decreases the amount of steam necessary for drying later in the process, reducing the plants overall dryer load (U.S. EPA 2010).

The U.S. pulp and paper sector could cost-effectively reduce its average energy intensity by more than 5 million Btu per metric ton of production… Many available energy efficiency options have less than two-year payback periods.

Dry Sheet Forming

Dry sheet forming produces paper without the addition of water. With this technology pulp fibers are dispersed through carding (mechanical disbursement) or air-layering techniques. The air-layering technique suspends fibers in air and spays resins on the sheet, which are then polymerized. While this technology requires additional electricity use and is currently more costly than traditional papermaking technologies, it yields overall energy savings (Xu, Sathaye, and Kramer 2012). This technology has been deployed for non-woven products such as baby wipes; commercial deployment for paper manufacturing would require additional R&D investment.[30]

Supplemental Midwest-specific Information on Return on Investment

Beyond specific energy savings and the cost of conserved energy, another common metric for assessing the cost effectiveness of EE measures is the return on investment (ROI). In order to gain further perspective on Midwest pulp and paper sector energy efficiency opportunities, we also provide complementary ROI information from a 2005 publication entitled "Pulp and Paper Energy Best Practice Guidebook" published by the Wisconsin Focus on Energy program (WFoE 2005). Mill managers have communicated to their trade association, the American Forest & Paper Association (AF&PA), a preference for EE projects with an investment ROI of at least 25 percent—making for a maximum payback period of four years (U.S. EPA 2007). The Focus on Energy guidebook presents fifty-seven energy efficiency improvement options for seven manufacturing process groups, including chemical pulp mills, mill-wide measures, paper machines, secondary fiber plants, thermal-mechanical (ground wood) pulp mills, utility plants, and wood yards.

Table 5 displays the expected payback period of five EE measures, which have been estimated through cost-of-conserved-energy-analysis to be cost-effective best practices (Xu, Sathaye, and Kramer 2012). These measures were covered by both the Wisconsin Focus on Energy Guidebook and the LBNL cost

Table 5 | **Estimated Payback Period for Pulp and Paper EE Measures**[i]

TECHNOLOGY	MIN (YEARS)	MAX (YEARS)
Use of a Shoe Press[ii]	2.5	5
Dryer Management System[iii]	1	2.5
Heat up Felt Water	> 0	1
Compressed Air, Water and Steam Leaks	> 0	1
High Efficiency Motors	> 0	1

Sources: Wisconsin FoE 2005.

Notes:

[i] The $5.00/MMBtu price of energy assumed by FoE in their calculations is notably less than the $6.69 baseline energy price for 2010 for the 2012 Midwest pulp and paper sector. Since higher energy prices result in greater monetary savings from reduced energy consumption, assuming an energy price of $6.69/MMBtu would reduce the estimated payback period.

[ii] The average length of payback period for the Use of a Shoe Press is 3.33 years.

[iii] The average length of payback period for a Dryer Management System is 1.43 years.

curve analysis. Other more energy effective measures described in the cost curve are not covered by the guidebook. Due to its focus on Wisconsin mills, Table 5 also includes additional measures not highlighted in Figure 15. The cost curve and return on investment tables show that Midwest pulp and paper manufacturers have several proven technology options for improving energy efficiency.

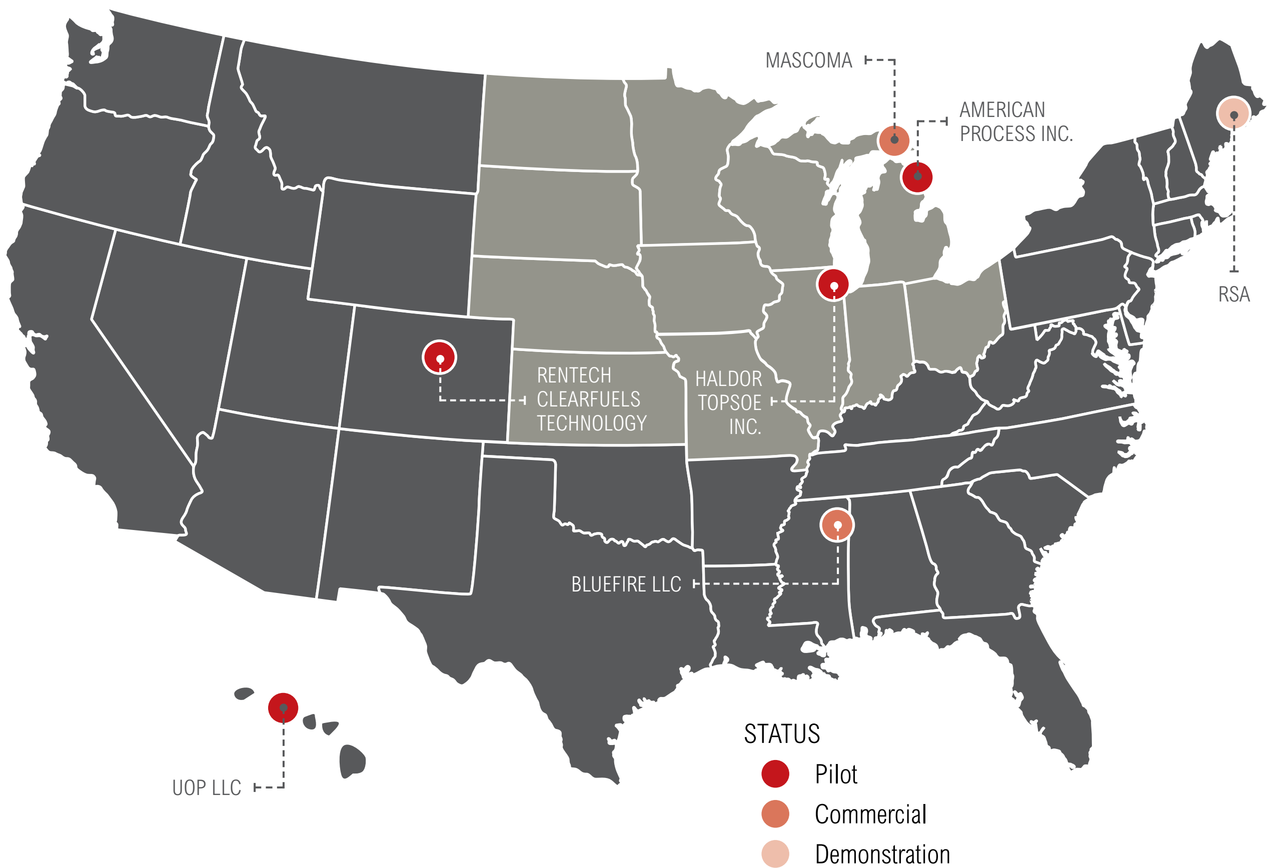
New and Emerging Pulp and Paper Technologies

This report's EPI analysis indicates that the majority of pulp and paper mills in the Midwest could improve their energy efficiency by investing in best practices that have already been adopted by other U.S. mills. New and emerging technologies also can offer additional energy savings and could position mills throughout the U.S. to better compete with the next generation of pulp and paper manufacturing.

Within the chemical pulping process, for example, black liquor gasification has potential to save energy as improvements are made in reliability. The environmental and economic benefits of black liquor gasification are likely to depend on characteristics of individual installations and will be better understood as the technologies and applications are demonstrated and evaluated at scale (Kramer et al. 2009). Another technology that can increase biomass use and improve pulp and paper mill competitiveness is biomass conversion to fuels and chemicals, particularly through biomass-integrated gasification with combined cycle (BIGCC) plants. Given the amount of thermal energy used for paper drying, additional savings potential is also available in advanced water removal technologies. In the long term, application of carbon capture and sequestration (CCS) technology to black liquor gasifiers and BIGCC units could help turn pulp and paper mills into a net carbon sink, thereby reducing global greenhouse gas emissions. The development of pulp and paper biorefineries could simultaneously lower purchased energy intensity, reduce carbon intensity, and boost profitability.[31]

While the majority of federal bioenergy policy is focused on ethanol production for liquid transport fuels, some programs— such as the DOE Integrated Biorefinery Platform—include R&D support for biorefinery development. In addition, the Energy Independence and Security Act of 2007 (EISA, P.L. 110-140) included an updated Renewable Fuel Standard (referred to as RFS2) that mandated a minimum of 36 billion gallons of biofuel use annually in 2022, of which no more than 15 billion gallons can be ethanol from corn starch, and no less than 16 billion must be from cellulosic biofuels. Ethanol and dimethyl ether (DME) have been demonstrated as technically viable coproducts in European pulp mills.[32]

Map 2 | **U.S. Integrated Biorefinery Projects Using Forest Resources, 2012**



Source: U.S. Department of Energy, Integrated Biorefinery Platform. Accessible online at: <http://www1.eere.energy.gov/biomass/integrated_biorefineries.html>..

In addition to minimum renewable fuel usage requirements, federal U.S. policy measures include blending and production tax credits, an import tariff, loans and loan guarantees, and research grants (Schnepf and Yacobucci 2012). Map 2 shows that three out of seven forest-resource-based integrated biorefinery projects in the U.S. are located in the Midwest.[33]

In the European Union, climate and energy policies have helped the pulp and paper industry to maintain production growth while reducing environmental impacts. In Sweden, for example, the primary mechanism driving pulp and paper sector adaptation has been rising fossil fuel prices that were shaped by fiscal policy, including implementation of a carbon tax in 1991.[34] As part of its Integrated Pollution Prevention and Control program and in accordance with Article 16(2) of Council Directive 96/61/EC, the European Commission in 2001 also published extensive documentation on best available techniques for the pulp and paper industry.[35] In 2011 the European Commission published a "Roadmap for moving to a competitive low-carbon economy in 2050," which has been further elaborated by the Confederation of European Paper Industries.[36] While the U.S. has its own policy framework and market dynamics, the EU experience exemplifies sustainable paper sector business models and a positive role for policy in helping this sector modernize into a more energy-efficient and less emissions-intensive industry.

CHP in the Pulp and Paper Sector

Combined heat and power refers to a set of integrated technologies located onsite at a manufacturing plant, providing at least a portion of the facility's demand for electric energy and for thermal energy. Two distinct forms of CHP apply to the pulp and paper sector:

- Conventional or Topping Cycle CHP is the sequential production of electric and thermal energy from a single dedicated fuel source. The dedicated fuel source is combusted (burned) in an engine whose sole purpose is to generate electricity, and the heat from the engine is used to provide the useful thermal energy. These systems are normally sized to meet the thermal load of the industrial facility; the level of electric generation is dependent on the thermal load.

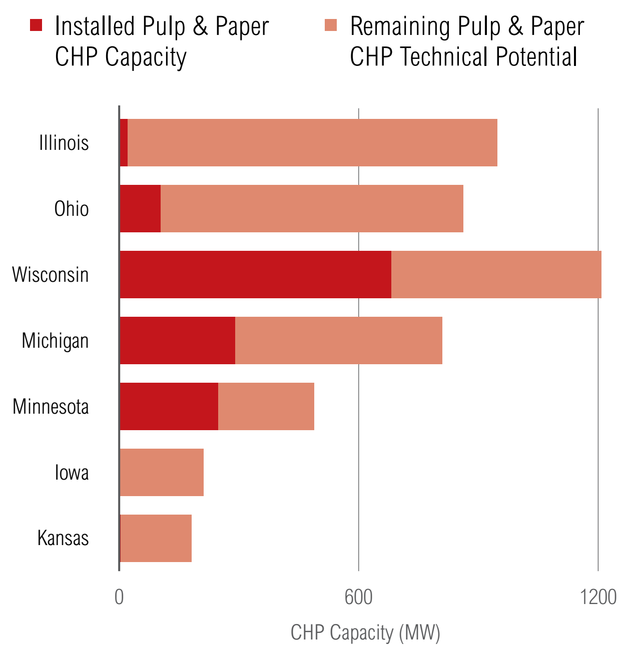
- Waste Heat Recovery (WHR) or Bottoming Cycle CHP captures heat otherwise wasted in an industrial or commercial process and uses it to produce electricity and thermal energy. In the paper drying process, several opportunities exist to recover thermal energy from steam and waste heat. Most pulp and paper sector energy savings are related to heat savings potential. In a WHR CHP system, no additional fuel is combusted and no additional emissions are generated from the CHP system.

The concept of CHP as applied to an industrial plant consists of replacing at least a portion of the electricity normally purchased from the local electric utility with what is often baseload-quality electricity produced from an on-site CHP system. CHP can serve as a new source of electricity that inherently matches the electric grid's industrial load profiles; in this sense, new CHP capacity can be particularly useful in situations of retiring grid electric capacity (Chittum 2012).

Within the pulp and paper sector, CHP can recover exhaust steam from electricity generating turbines and apply it to heat pulp and papermaking processes—such as evaporation and drying—and to power equipment (AF & PA 2012). Estimates of pulp and paper sector CHP utilization and remaining potential vary by source. In 2005, the Department of Energy reported that the forest products sector (including pulp, paper, and wood products) had the largest installed CHP capacity of any U.S. manufacturing industry—65 percent of electricity consumption by the sector was supplied through cogeneration (U.S. DOE 2005b). In 2012, data from the combined heat and power installation Database indicate that the pulp and paper sector had the third highest level of installed CHP capacity, behind chemicals and refining sectors, and that pulp and paper remains the third largest whether or not wood products are added to the sector subtotal. AF&PA notes in its 2012 *Sustainability Report* that over 97 percent of electricity produced by the sector in 2010 was CHP-generated (AF & PA 2012). This estimate is higher than the DOE number cited above because it refers to production rather than consumption. While the pulp and paper industry has clearly installed substantial amounts of CHP, ICF International estimates that pulp and paper still has the second largest remaining technical potential among all industrial sectors—second only to the chemicals industry (Hedman 2010). Figure 16 illustrates the state-level distribution of paper sector installed and remaining CHP technical potential.

The combined heat and power installation Database estimates that the Midwest pulp and paper sector has 1.3 GW of installed CHP capacity. In its 2012 *Annual Energy Outlook*, the Department of Energy estimated that the total U.S. pulp and paper sector had 7.2 GW of CHP capacity in 2010.[37] According to the ICF 2010 analysis, Midwest pulp and paper mills have 3.4 GW of remaining CHP technical potential. While technical potential is not equivalent to economically viable potential, the ICF analysis suggests that the Midwest pulp and paper sector could cogenerate substantially more energy on site, thus potentially playing a supporting role in achieving the ambitious White House target of 40 GW of new CHP capacity by 2020.[38]

Figure 16 | **Paper Sector Installed CHP Capacity and Estimated Remaining Technical Potential by State**



Source: Hedman 2010. Accessible online at: <http://www.eea-inc.com/chpdata/>.

Notes: Remaining technical potential estimates are derived from Hedman (2010) state industrial CHP estimates and national industrial subsector estimates; complete data are not available for the other two Midwest states with paper production.

Previous studies have found that regulatory, policy, and institutional barriers are impeding CHP installations from realizing their remaining capacity potential (NREL 2009). One regulatory barrier is emissions standards that account for emissions limits based on heat input. A better approach, which is becoming more popular with state air regulators and EPA, is output-based emissions standards (Dietsch et al. 2012), which provide a fuller assessment of environmental performance and take into account energy efficiency benefits of CHP (U.S. EPA 2007). From a utility perspective, decoupling of revenues from kilowatt-hours sold can support increased on-site generation; however, decoupling policies can also reduce industry incentives for financing and installing CHP (Kowalczyk 2013). Another regulatory and institutional challenge involves interconnection standards, which vary by state and utility, and often create barriers that are too costly for prospective CHP developers to overcome (Shipley et al. 2008).

To help address these and other barriers, the U.S. Department of Energy has established eight regional Clean Energy Application Centers (CEAC), which provide information, education, and technical assistance for development of CHP. The Department of Energy is also managing a pilot program to provide state-level technical assistance on using CHP to reduce environmental compliance costs.[39] The final Boiler MACT rule creates incentives for increased pulp and paper sector CHP utilization by allowing use of output-based emissions standards for calculating boiler-specific emissions limits.

Mill and Company Case Studies

Forward-thinking pulp and paper companies throughout the U.S. have used energy efficiency investment to successfully reduce energy use and emissions while improving economic competitiveness. Table 6 illustrates a range of recent energy efficiency projects conducted by U.S. pulp and paper companies.[40] To provide tangible, in-depth information, case studies are presented on the Flambeau River Papers mill in Park Falls, Wisconsin, and the Weyerhaeuser NORPAC facility in Longview, Washington.

Technical and Financial Programs to Support Mill Retrofits: Flambeau River Papers

Flambeau River Papers' recent experience is a notable example of a Midwestern mill that successfully overcame common institutional, technical, and financial barriers to place energy efficiency at the core of its business strategy of cutting costs while boosting production in an increasingly competitive market.[41]

High energy costs and antiquated equipment caused the Smart Papers Company's Park Falls integrated mill to close in March of 2006. Through smart energy management and capital investments in energy efficient equipment, the company was able to reduce costs and reopen as Flambeau River Papers (FRP) in August 2006 (U.S. DOE/EERE/ITP 2009a). Since then, FRP has achieved energy cost and carbon emissions savings while increasing production, and has planned for additional EE investments.[42]

Table 6 | **Overview of Recent U.S. Pulp and Paper Company Efficiency Improvement Projects**

COMPANY	FACILITY	PROJECT IMPACT	CONTEXT
Flambeau River Papers[i]	Flambeau River Papers (Park Falls, WI)	Aggregate energy savings through 2010 exceeded $10 million, reducing electricity requirements to produce each ton of paper by 15 percent.[ii]	After high energy costs and dated equipment forced the mill to close in 2006, energy efficiency investments subsequently allowed the mill to resume operations and increase paper production while decreasing energy consumption
Weyerhaeuser / Nippon Paper Industries	NORPAC (Longview, WA)	$60 million energy efficiency investment projected to save 100 million kWh/year.[iii]	Largest industrial energy efficiency investment in Bonneville Power Administration history
International Paper	Company-wide	2011 energy efficiency projects projected to reduce annual fossil fuel usage by 5.9 million GJ.[iv]	Only forest products company to receive inaugural Climate Leadership Award from EPA
Rock-Tenn	St. Paul, MN	Insulation of steam and condensate lines that resulted in annual savings of $171,000 from reduced energy consumption.[v]	Example of technical assistance programs such as MnTAP
West Linn Paper	West Linn, OR	$176,000 energy efficiency investment that saved $379,000 in annual costs (< 6 month simple payback period) and 58,200 MMBtu in natural gas consumption.[vi]	Example of government technical assistance programs such as DOE Save Energy Now
Liberty Paper	Becker, MN	$15 million investment in a water pretreatment plant with a bio-gas generator. The facility will pretreat the 550,000 gallons/day of water used by the mill.[vii]	One of the first anaerobic digesters to be implemented at a paper mill in the state of Minnesota.

Sources: Flambeau River Papers; Weyerhaeuser; International Paper 2012 Sustainability Report; Minnesota Technical Assistance Programs; U.S. Department of Energy Industrial Technologies Program (now known as the Advanced Manufacturing Office); St. Paul Port Authority.

Notes: [i]Per correspondence with the Wisconsin Economic Development Corporation, loans between Flambeau River Papers, LLC and the Wisconsin Economic Development Corporation were current as of February 7, 2013. [ii]See: <http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/case_study_flambeau.pdf>. [iii]See: <http://www.weyerhaeuser.com/Company/Media/NewsReleases/NewsRelease?dcrId=2012-08-09_WYNORPACBPACowlitzPUDEnergyProject>. [iv]See: <http://www.internationalpaper.com/documents/EN/Sustainability/SustainabilityReport.pdf>. [v]See: <http://www.mntap.umn.edu/paper/resources/rocktenn.pdf>. [vi]See: <Http://www1.eere.energy.gov/manufacutring/tech_deployment/pdfs/42352.pdf>. [vii]See: <http://www.sppa.com/wp-content/uploads/2012/05/AprilReport.pdf>.

After the Department of Energy's (DOE) Industrial Technologies Program performed an energy savings assessment (ESA)[43] in 2007, the company initiated fuel switching strategies and EE measures that best suited its Park Falls facility (U.S. DOE/EERE/ITP 2009a). Since then, FRP has reported a 60 percent decrease in its annual coal use and 40 percent in its natural gas use, and completely eliminated its use of number six oil as a fuel source.[44] Even as electricity costs have increased by 23 percent over a recent three-year period,[45] the facility's fuel switching and efficiency efforts have contributed to a 10 percent annual energy cost savings.[46] Meanwhile, FRP has increased its annual production by 11 percent between 2006 and 2012.[47]

Past and Future Planned Energy Efficiency Investments at FRP

Investments in steam system improvements helped FRP reduce its annual steam energy requirements by 36 percent between 2007—when investments began to be implemented—and 2011.[48] Over that same period, installing frequency drives, pump replacements, lighting projects, and machine production efficiency projects have helped reduce the amount of electricity required to produce each ton of paper by 15 percent.[49] In 2009, the reported energy savings from these projects since their reopening amounted to $2.6 million annually, reaching nearly $10 million in total cumulative energy savings and putting FRP on pace for a payback period of 5.25 years (U.S. DOE/EERE/ITP 2009a). FRP's willingness to invest in EE measures with payback periods of longer than four years has not only proven to be economically viable, but has also been credited by FRP's CEO Butch Johnson as essential in the mill's ability to achieve long-term competitiveness.

Bill Granzin, FRP's energy manager, credits three major projects as being instrumental in FRP's successful turnaround.[50] First, extensive modifications to FRP's number three paper machine introduced efficiency gains that have played a crucial role in allowing the mill to increase its annual production by 15 percent since 2005. Although this modification required an investment of $6.2 million, it saves FRP around $760,000 annually, resulting in a simple payback period of more than 8 years. Granzin says the efficiency gains are accelerating project payback.[51] The second improvement is FRP's $2.3 million investment in a low-pressure acid accumulator, which has made it possible for the mill to capture and use heat that used to be wasted, saving an estimated $448,000 annually in energy costs. Third, by installing wastewater treatment fine bubble diffusers at a capital cost of $500,000, FRP saves an estimated $189,000 in annual energy costs. Without these and other EE investments that reduced FRP's natural gas and coal consumption, Granzin states "there's no question, we would be closed today."[52]

Given their success to date, FRP is planning to make an additional investment amounting to nearly $10 million in energy projects that will continue achieving their goal of reducing energy use.[53] FRP management has estimated the annual savings from these new EE investments will amount to almost $2.5 million, paying back their capital costs in approximately four years.[54] FRP expects their energy projects to help reduce energy demand, while increasing annual production.[55]

Industrial Energy Efficiency Takeaways from Flambeau

FRP's experience offers lessons for other energy-intensive manufacturers to overcome common barriers to EE investment. For starters, FRP overcame technical and informational barriers with the help of DOE's ESA process, in addition to consultations with Wisconsin's Focus on Energy and CleanTech Partners (U.S. DOE/EERE/ITP 2009a). State and federal government loans also supported FRP's initial energy investments, which helped the integrated mill overcome a financial hurdle.[56] "If it weren't for the insight on energy reduction projects provided by our employees and the help from the DOE, Focus on Energy, and Cleantech Partners, FRP would not have been able to reduce our energy consumption and remain a viable business," said Randy Stoeckel, FRP's Vice President of Operations, commenting on the role the public and private sector had in FRP's economic recovery. Finally, in considering capital projects with a payback period of more than five years, FRP overcame a common institutional barrier to pulp and paper EE investment by aggregating multiple investments (U.S. EPA 2007).

The types of EE measures FRP has pursued are applicable to mills throughout the pulp and paper sector, as illustrated by the cost curve analysis highlighted in this report (Figure 15). For example, energy efficiency measures implemented by FRP include lighting efficiency upgrades and paper machine hood heat recovery—each estimated by the cost curve analysis to result in applied energy savings of 0.01 MMBtu/t (at $10/MMBtu) and 0.12 MMBtu/t (at $12/MMBtu), respectively. By investing in multiple efficiency measures with a range of estimated simple payback periods, FRP was able to invest in individual measures with longer payback periods—such as the eight-year payback period associated with paper machine modifications—while maintaining an estimated simple payback period for their aggregated portfolio of efficiency investments of four years.

While the U.S. paper industry experienced a 12 percent decrease in the number of paid employees from 2006 to 2009,[57] FRP's success allowed the plant to recover 100 percent of the workforce lost due to their 2006 closure.[58] FRP was able to increase its production by 15 percent from 2005 to 2011,[59] even while U.S. pulp and paper production declined by 7 percent nationwide during the same period (UN FAOSTAT 2013). The use of EE and better energy management helped make these strides possible for FRP—even in the face of a struggling national industry. This experience sheds light on the remaining potential for facilities that are yet to take advantage of EE opportunities.

Advanced Energy Efficiency Savings: Weyerhaeuser's NORPAC Facility[60]

In the first quarter of 2013, Weyerhaeuser Company is completing an energy efficiency improvement project (Chip Pretreatment Interstage Screening, or CPIS) expected to save 100,000,000 kWh per year. The NORPAC project is an example of an advanced, process-oriented approach to energy efficiency that can provide economic savings in thermo-mechanical pulp mills. In addition to highlighting cost-

effective efficiency investments, the NORPAC case study illustrates the importance of partnerships with local institutions and supportive programs for reducing the energy and emissions footprint of manufacturing while maintaining competitiveness.

The North Pacific Paper Corporation (NORPAC)—a joint venture between Weyerhaeuser and Nippon Paper Industries—started operations in 1979. NORPAC produces more than 750,000 tons per year of newsprint and high-brightness publication papers. The mill started up in 1979 with the first paper machine and thermo-mechanical pulp mill. In 1980, a second paper machine and thermo-mechanical pulp mill was added. In 1991, the third paper machine and a recycled pulp mill were brought on line.

NORPAC Mill Energy Efficiency Investments

The CPIS project adds two components to the NORPAC facility: (1) chip pretreatment equipment that reduces pulp bleaching and brightening costs; and (2) inter-stage screening that reduces electricity use by identifying paper-ready fibers that don't require additional processing. The two components use existing commercially available equipment applied in an innovative configuration in the existing TMP mills to achieve multiple process benefits: brightness improvement, capacity increases, chemical cost savings, and energy use reduction.

The interstage screening concept came from a technical paper presented at the 1999 Mechanical Pulping conference. Pilot and small-scale mill trials were run to verify the energy savings potential. Water balance issues prevented immediate installation of the technology. Combining chip pretreatment with interstage screening solved the water balance issues and added additional benefits to help justify the combined project investment.

Key NORPAC project benefits include:

- Electrical energy savings of roughly 12 MW for both TMP mills
- Capacity increase due to improved chip delivery capability
- GHG emissions reductions of 3,500 MT CO_2e/year for both mills
- Chemical cost savings from chip quality improvement
- Higher TMP pulp brightness, enabling production of a 92 brightness paper grade.

NORPAC is the only Weyerhaeuser operation with a TMP mill. This project supports progress toward Weyerhaeuser's 2020 goal to improve energy efficiency by 20 percent. The company's sustainability strategy is built upon past sustainability performance with an expanded set of commitments that are integrated into their business planning and processes. For each commitment, Weyerhaeuser sets specific targets to achieve by 2020; each year the company reports on progress against these targets. To achieve continuous sustainability improvements, the company leverages support and expertise found through government and utility-sponsored programs, as well as the experience of other companies in various industries. Weyerhaeuser is actively involved in the Department of Energy's Better Buildings, Better Plants Program, through which they have committed to reduce the energy intensity of cellulose fibers and wood products businesses by 25 percent over 10 years.

The first phase of the project has already exceeded the expected 6.3 MW of electricity savings and yielded an additional unexpected benefit that allows NORPAC to offer a new product called 92 bright ground wood sheet. "This project is a win-win," said Dan Fulton, president and chief executive officer for Weyerhaeuser. "NORPAC's energy efficiency project will allow this mill to remain competitive in an increasingly challenging global economic market by significantly reducing the mill's energy costs and decreasing its environmental impact through reduction of energy consumption and chemical use on-site. We are thankful BPA and Cowlitz PUD have partnered successfully with us to make this remarkable energy efficiency project a reality."

Corporate Energy Efficiency Leadership: International Paper

Another example of corporate leadership in energy efficiency has been International Paper (IP). The pulp and paper company's continued investment in energy efficiency has been driven by the success of their efficiency initiatives over the last decade. Since 2000, IP has used energy efficiency to help reduce their GHG emissions by 40 percent, exceeding their initial goal of 15 percent (IP 2011). Their energy efficiency success and GHG emissions reduction efforts recently earned them one of EPA's 2012 Climate Leadership Awards. In addition, their energy and environmental efforts have been acknowledged by AF&PA, who awarded IP one of their "Leaders in Sustainability" awards and made the company one of five recognized in the trade association's inaugural Better Practices, Better Plants 2020 Sustainability Awards program.

In 2011, IP invested $87 million in capital projects to improve overall energy efficiency and further reduce fossil fuel use and associated GHG emissions (IP 2011). Initial results of those investments and others contributed to company-wide increases in mill energy efficiency by 1.7 percent, reduction of water usage by 8 percent, and reduced landfill waste by 20 percent in 2011.[61] Moving forward, IP expects the benefits of its energy efficiency projects initiated in 2011 to reduce annual fossil fuel usage and GHG emissions by 5.9 million GJ and 460,000 metric tons, respectively (IP 2011). To optimize future energy efficiency investments that will help the pulp and paper company achieve their 2020 goals of reducing GHG emissions by an additional 20 percent[62] and increase energy efficiency by 15 percent,[63] IP recently established an internal Energy Council. The Energy Council will also help ensure IP achieves its commitment as a voluntary partner of the U.S. Department of Energy (DOE) Better Plants program, which requires a reduction of at least 25 percent in energy intensity over ten years across the company's U.S. facilities.[64]

In combination with the cost curve of established EE technologies, the review of new and emerging energy efficiency technologies, and the discussion of CHP opportunities in the pulp and paper sector, these case studies demonstrate the economic and competitiveness benefits of pulp and paper mill energy efficiency investments.

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Section 4

THE ENERGY EFFICIENCY POLICY LANDSCAPE

The efficiency gap between existing Midwest pulp and paper mills and established U.S. best practices suggests an opportunity for policies to help manufacturing facilities optimize their energy use. Local, state, and federal policies can help address barriers and market failures that prevent cost-effective investments in energy efficiency.

This section discusses the policy landscape for paper sector energy efficiency in three parts: (1) identification of market failures and barriers, (2) review of existing policies at the state and federal level, and (3) recommendations for new policies to improve paper manufacturing energy efficiency (and thereby achieve significant cost savings and reduce GHG emissions). One successful solution to the pervasive problem of energy efficiency financing is presented in a short description of Minnesota's Trillion Btu revolving loan program. The case study and other information in this section demonstrate that well-designed policies can help energy-intensive industrial companies realize the economic and environmental benefits of energy efficiency investments.

Barriers to Energy Efficiency Investment

Previous studies have highlighted a range of barriers that prevent optimal realization of energy efficiency potential (Brown 2001; NAS 2010; Brown et al. 2011). Results from our analysis of facility-level energy performance (Section 2) demonstrate that Midwest pulp and paper mills are less efficient than other U.S. mills and likely face barriers to realizing potential energy efficiency improvements. Five types of challenges limit Midwest pulp and paper mill energy efficiency investment: (1) prohibitive costs for project financing, (2) limited information about efficiency opportunities, (3) inconsistent or nonexistent regulations, (4) technical obstacles, and (5) prolonged investment cycles/slow capital turnover rates. These barriers, and historically low Midwest energy costs, help explain why Midwest pulp and paper mills are less efficient than the rest of the country.

Financial barriers broadly include factors both internal and external to each firm's investment decisionmaking process. Internally, short-term profit motives often prioritize investments with quick payback periods. The combination of a desired short-term payback period and equipment that is capital-intensive and has a long useful lifetime—such as boilers—poses a substantial hurdle for energy efficiency investments by pulp and paper manufacturers. When seeking external financing for energy efficiency investments, firms may also face liquidity constraints in capital markets. Finally, there is a broader challenge: energy-related capital investments are often perceived as risky, given uncertainty about future economic, policy, and energy market conditions.

Informational barriers are also common and often vary by facility. For example, energy efficiency opportunities for reducing costs may not be visible to financial officers who ultimately make capital investment decisions (IEA 2012a). Companies and individual facility managers may not have comprehensive energy management policies to help ensure that appropriate staff resources are dedicated to achieving continuous efficiency improvements.[65] Plant managers also may not be aware of new cost-effective technologies or practices that allow for greater energy efficiency, in part because competing companies are often reluctant to share best practices. Another common barrier is the misperception that there is limited potential for additional EE in the manufacturing sector, which has resulted in some states excluding the sector from new programs and policies (Chittum 2011).

Regulatory barriers have also presented persistent challenges for pulp and paper industry investments in efficiency. In particular, thermal and electric energy producing equipment—such as boilers and turbines—have historically been regulated using input-based emissions standards (U.S. EPA 2004). Input-based emissions standards account for emissions limits based on heat input and do not differentiate between energy conversion efficiency, thus failing to provide a full assessment of environmental performance that would take into account efficient energy use. In addition, increased regulations of volatile organic compounds—emitted during paper coating operations and regulated under the National Ambient Air Quality Standard—can create the potential for increased energy use through the addition of pollution control systems (U.S. EPA 2007). However, environmental regulations are increasingly designed to recognize EE, either as a direct means of compliance (e.g., BACT guidance for GHGs), or as an option that reduces compliance costs (Dietsch et al. 2012).

As noted above, pulp and paper manufacturing facilities benefit from the broad applicability of CHP technologies and the availability of biomass as an alternative fuel. These factors can help to reduce some of the technical and institutional barriers to

BOX 4 | THE MINNESOTA TRILLION BTU PROGRAM: A LOCAL PATHWAY FOR ENERGY EFFICIENCY FINANCE

An important and prevalent barrier to industrial energy efficiency is the difficulty of financing, particularly for smaller enterprises. Minnesota's Trillion Btu Program exemplifies the positive role that policies can play in facilitating industrial energy efficiency investment.

The Trillion Btu Program is a revolving loan program that offers low-interest financing for implementing energy efficiency solutions. The program was jointly developed by Xcel Energy and the St. Paul Port Authority in 2010 to help achieve the 1.5 percent annual electricity- and gas-usage reduction goal stipulated in Minnesota's Energy Efficiency Resource Standard. Under the program, industrial and commercial customers of Xcel Energy can use voluntary facility-level energy audits to identify opportunities for increased energy efficiency. If Minnesota businesses choose to pursue the opportunities identified in the audit, the St. Paul Port Authority, a local economic development organization, offers loans that cover all equipment and installation costs.

"Energy efficiency is the cheapest investment you can make," states Peter Klein, St. Paul Port Authority's Vice President of Finance. From 2010 through 2012, Mr. Klein has overseen thirty-five energy efficiency projects that have saved more than $3 million per year. Through the Trillion Btu Loan Program, these projects have helped to generate estimated savings of approximately 100 billion Btu of energy per year. As indicated by its name, the goal of the program is to grow to a level where it is helping to generate more than one trillion Btu of energy savings per year. In December 2012 the program was a little more than 10 percent toward its target, with 106 billion Btu of estimated indirect annual savings.

The Trillion Btu Loan Program was initially funded by $5 million of stimulus funds from the American Recovery and Reinvestment Act of 2009 (ARRA). After administering an energy efficiency audit with Xcel Energy that resulted in more than 20 percent energy savings for the RockTenn paper mill in St. Paul, Peter Klein developed the Trillion Btu Program to pursue Minnesota's other energy efficiency opportunities. The average payback of his projects is four years and the program is growing quickly. In recent years the program has continued beyond the period of ARRA funding based on the savings achieved by targeted efficiency investments. Unlike the majority of ARRA-funded projects, the Trillion Btu Program is financially sustained by its revolving loan structure.

The Trillion Btu Program exemplifies the benefits that can accrue from collaboration between government, utilities, manufacturers, and building owners. State policies such as Minnesota's Energy Efficiency Resource Standard can serve as catalysts for collaborative efficiency improvements. Mr. Klein summarizes the impacts of the Trillion Btu Loan program by pointing out that "It's a win-win-win for everybody, with reduced utility capacity requirements, environmental improvements, and increasing customer savings."

For more information on the Trillion Btu Loan Program, see:< http://www.sppa.com/wp-content/uploads/2011/03/SPPA_Trillion_Brochure8.pdf>.

EE. Nevertheless, equipment configuration remains a technical hurdle for some facilities. Technical issues such as equipment vintage and mill design can restrict a facility's capacity to accommodate new process equipment, and the proximity of facilities to different fuel sources—for example, natural gas pipeline infrastructure—can affect the cost-effectiveness of switching to cleaner fuels.

Slow capital turnover is also an important impediment to efficiency improvement by manufacturers. The uptake of newer cutting-edge EE technologies tends to be slow for many manufacturing sectors due to its capital-intensive nature and long depreciation periods (Brown et al. 2011). However, as domestic manufacturers become increasingly exposed to international market competition, many older and less efficient U.S. facilities compete with companies using new state-of-the-art facilities located in developing countries. This highlights one impetus for policymakers to revisit existing policies and programs to ensure that appropriate incentives are in place for U.S. manufacturers to exploit as many cost-effective energy-saving measures as possible.

Existing Authorities and Policy Trends

While barriers within the pulp and paper industry present persistent challenges, opportunities to benefit both economically and environmentally from energy efficiency investments are readily available. Policymakers at the local, state, and federal level are showing a growing interest in supporting industrial EE investments. Key motivating factors include a strong interest in competitiveness that supports economic development of domestic manufacturing, growing recognition of the untapped efficiency resource opportunity, projected growth in energy costs, and environmental concerns. This section reviews the range of policies that support pulp and paper sector energy efficiency improvements based on existing government authorities.

Federal Policies and Programs

At the federal level, executive and legislative branches of the U.S. government have promulgated programs and policies to support industry energy efficiency. Executive Order 13624, issued by President Obama in August 2012, seeks to accelerate investments by making industrial energy efficiency more cost-effective.[66] To encourage energy efficiency and reduce greenhouse gas emissions, the U.S. Congress has debated and/or authorized three primary types of federal policy: voluntary programs, direct regulations, and market-based cap and trade programs for air emissions. Initially spurred by the U.S. Supreme Court decision in Massachusetts vs. EPA, the Environmental Protection Agency is now using the Clean Air Act to mitigate greenhouse gas emissions.[67]

Aside from Clean Air Act implementation, the majority of U.S. industry-focused energy efficiency policies are voluntary, with a strong focus on providing technical assistance that is sometimes tied to grant funding for investments.

Technical assistance programs offered by the U.S. Department of Energy's (DOE) Advanced Manufacturing Office (AMO)—including the new Better Plants Program, the twenty-six regional Industrial Assessment Centers (IAC), and the eight regional Clean Energy Application Centers (CEAC), combined with the National Institute for Standards and Technology's Manufacturing Extension Partnership (MEP)—comprise a comprehensive network of technical assistance providers throughout the country. The EPA CHP Partnership Program and the EPA's ENERGY STAR Program for Industry are other examples of voluntary federal industry energy efficiency programs. In addition, the eight regional CEACs established by DOE are working to address institutional barriers by providing information and education in the application of CHP technologies—technologies that have the potential to reach energy efficiencies of 70 to 85 percent.

Historically, the federal policy that has most effectively promoted CHP in the U.S. is the 1978 Public Utility Regulatory Power Act (PURPA). By promoting the adoption of energy efficiency and distributed generation at Qualifying Facilities, PURPA helped to double CHP and small-scale renewable electricity generation from 4 percent of total U.S. capacity in 1978 to more than 8 percent in 1998. However, CHP capacity in the U.S. has largely plateaued since the reversal of key PURPA provisions in the Energy Policy Act of 2005, which removed mandatory purchase obligations for utilities and established new impediments to CHP vis-à-vis reliability requirements.[68] At the same time, the Federal Energy Regulatory Commission (FERC) established regional transmission organizations (RTO) and independent system operators (ISO) that treat CHP like merchant or utility power plants and fail to recognize the differences between CHP and these other facilities (Kowalczyk 2013). The lack of a broad federal successor to PURPA has reduced CHP investment in U.S. manufacturing.

On the legislative side, Congress passed a new bill during its 2012 lame duck session that could help build a better understanding of the policies and practices needed to spur broader adoption of industrial energy efficiency among energy-intensive sectors such as pulp and paper manufacturing. On December 18, 2012, President Obama signed the American Energy Manufacturing Technical Corrections Act (H.R. 6582). The act includes provisions to establish collaborative research and development partnerships that support innovative manufacturing processes for improving efficiency. It also requires a study examining the legal, regulatory, and economic barriers to the deployment of industrial energy efficiency.[69]

Policymakers at the local, state, and federal level are showing a growing interest in supporting industrial EE investments. Key motivating factors include a strong interest in competitiveness that supports economic development of domestic manufacturing, growing recognition of the untapped efficiency resource opportunity, projected growth in energy costs, and environmental concerns.

Federal Regulations

The Clean Air Act (CAA) is the primary vehicle for regulation of air emissions from U.S. industry. On January 31, 2013, EPA adopted new standards for limiting hazardous air emissions from commercial and industrial boilers through Section 112 of the CAA. These Boiler MACT (Maximum Achievable Control Technology) standards are expected to have a significant impact on manufacturing subsectors, including pulp and paper mills. The Boiler MACT rule directly targets industry energy users and is notable for including output-based emissions standards (OBES) as a compliance option, as well as other measures to account for or encourage on-site energy efficiency (Aden 2012). While the Boiler MACT standard regulates air toxic emissions, complying with the rule will also affect energy use and GHG emissions.

As of 2011, the Clean Air Act (CAA) also requires air permitting to ensure that major new sources of GHGs use the Best Available Control Technologies. EPA narrowed the scope of stationary-source GHG permitting with its "tailoring rule," which sets a 100,000-ton-per-year CO_2e emissions threshold for new facilities or major modification at existing facilities that would be subject to the new permitting requirements (U.S. CIBO 2003).[70] Meanwhile, EPA also released proposed New Source Performance Standards (NSPS) in March 2012 limiting CO_2 emissions from new fossil-fired electricity generation units under Section 111(b) of the CAA.[71] The NSPS can help to reduce indirect emissions related to pulp and paper manufacturing. EPA published the NSPS proposal in the Federal Register and is developing a final rule based on public comments received during the solicitation period, which closed in June 2012. The utility NSPS will have greater impact on pulp and paper mills if and when standards are promulgated for existing power plants by reducing current indirect emissions. Existing source performance standards could further incentivize pulp and paper mill energy efficiency investments if utility compliance costs are passed on to electricity purchasers.

State Policies and Programs

At the state level, common policy and program types include (a) annual binding energy efficiency targets and related ratepayer-funded programs for utilities to achieve end-use energy savings; (b) technical assistance that includes energy audits and support for efforts to expand the adoption of combined heat and power (CHP); (c) tax incentives for installation of more efficient equipment; and (d) other financing in the form of grants or low-interest loans (Bradbury and Aden 2012).

Within the Midwest, states are increasingly focused on industrial EE, including through the use of combined heat and power (CHP) and waste heat recovery (WHR) technologies. A 2012 WRI working paper outlined this broader trend and documented the details of policies and programs that individual Midwestern states are using to promote energy efficiency investments by local manufacturers (Bradbury and Aden 2012). As noted in Section 1 of this report, twenty-four states have adopted energy efficiency resources standards (EERS), which require utilities to reduce electricity or natural gas consumption by their customers through the use of energy efficiency (Nowak et al. 2001; ACEEE 2012). This includes seven Midwestern states: Illinois, Indiana, Iowa, Michigan, Minnesota, Ohio, and Wisconsin. The Trillion Btu revolving loan program (see Box 4) is designed to support the goals of Minnesota's EERS.[75]

Notable state initiatives include Ohio's CHP Pilot Program, which was launched in collaboration with DOE to provide additional technical and financial assistance for facilities with industrial boilers to comply with Boiler MACT standards.[76] In 2012 Ohio also enacted legislation (S.B. 315) to include waste energy recovery and CHP systems in existing Ohio renewable energy, energy efficiency, and advanced energy targets. The bill allows new CHP systems with more than 60 percent overall efficiency and at least 20 percent of the system's total useful energy output in the form of thermal energy to count toward compliance with Ohio's existing energy efficiency resource standard. Inclusion of CHP in energy efficiency resource standards is a useful state-level policy tool for promoting manufacturing and power sector energy efficiency investment. Another initiative is Wisconsin's Focus on Energy program, which works with local residents and businesses to install cost-effective EE

BOX 5 | BOILER MACT: BACKGROUND ON NEW FEDERAL STANDARDS

In 1990 the U.S. Congress amended the Clean Air Act to require EPA regulation of air toxics through Section 112. Under the amendment, EPA was required to identify sources of 187 hazardous air pollutants (HAPs), including particulate matter (PM), hydrogen chloride (HCl), carbon monoxide (CO), mercury (Hg), and dioxin/furan emissions. Major sources of these pollutants are defined as those that emit at least 10 tons per year of a single HAP, or 25 tons per year in aggregate of several HAPs. Facilities with emissions below these thresholds are considered "area sources." Once new and existing sources are identified, EPA promulgates performance-based standards for reducing HAP emissions using maximum achievable control technology (MACT). The MACT approach calculates limits based on performance of the best-performing 12 percent of existing sources. This limit is known as the "MACT floor."

EPA developed Boiler MACT standards based on data showing that industrial, commercial, and institutional (ICI) boilers and process heaters are major sources of HAP emissions. Because major source boilers are used as sources of power and heat throughout industry, there has been extensive public interest in the development of these standards. The U.S. Council of Industrial Boiler Owners highlights boiler diversity, noting that: "There are two identically designed, constructed side by side, stoker fired boilers in Indiana burning the same fuel that have very different performance characteristics" (U.S. CIBO 2003). The broad usage of boilers and their diversity has helped to explain the protracted development of Boiler MACT standards.

When the final Boiler MACT rule was published in January 2013, it initiated a three-year compliance clock for major source facilities. All major source boilers also will be required to perform a one-time energy assessment to identify cost-effective energy conservation measures. Three criteria are used to determine whether major source boilers are subject to emissions limits or work practice standards. The affected group includes (a) boilers with capacity above 10 million Btu per hour; (b) boilers that are used more than 10 percent of the year; and (c) boilers that burn fuels other than natural gas, refinery gas, or other gaseous fuels that meet a specific contaminant requirement.

Boilers that fit all three of these criteria are subject to emissions limits. Smaller, limited-use, or gas-fired boilers can comply with Boiler MACT rules through work practice standards. As a flexible alternative to numeric emissions limits, work practice standards require annual tune-ups with submission of informational reports back to the EPA.[72]

In its final published version, the Boiler MACT rule requires seventy boilers used in the Midwestern paper manufacturing industry to comply with emissions limits (U.S. EPA 2012a; Litz et al. 2010).[73] Table 7 shows that Wisconsin has more than half of the major source boilers in the Midwest paper sector (included in NAICS 322) that will be subject to emissions limits. The seventy boilers subject to emissions limits account for less than half the total one-hundred-fifty-three pulp and paper sector major source boilers located in the Midwest; the eighty-three other boilers will be subject to work practice standards.[74] On a capacity basis, two-thirds of Midwest pulp and paper sector major source boilers will be subject to emissions limits.

The application of the Boiler MACT rule will lead some mills to replace older, less efficient boilers with newer units fired by natural gas or biomass. Other mills will install end-of-stack pollution controls, some of which can increase energy consumption. Inclusion of output-based emission standards in the published Boiler MACT rule will help to incentivize CHP and other efficiency investments. As shown in Section 3, these investments can help mills lower their energy costs while improving their environmental performance.

TABLE 7 | MIDWEST PULP AND PAPER SECTOR MAJOR SOURCE BOILERS SUBJECT TO BOILER MACT EMISSIONS LIMITS

STATE	NUMBER OF MAJOR SOURCE BOILERS	TOTAL CAPACITY (MMBTU/HR)
Iowa	2	144
Michigan	12	5,450
Minnesota	10	2,100
Ohio	8	2,709
Wisconsin	38	8,515
Midwest Total	**70**	**18,918**

Source: U.S. EPA 2012a.

projects.[77] For example, Focus on Energy helped Flambeau River Papers' integrated pulp and paper facility to identify, finance, and implement new energy efficiency measures (see section 3).

Policy Recommendations

Industrial energy efficiency policies vary by scope and enforcement mechanism. The scale of these policies ranges from equipment to processes to facilities/mills, to companies, to industrial subsectors, and finally to the entire economy. Policy mechanisms are focused over multiple jurisdictions and regulatory frameworks, but generally can be separated into four groups: prescriptive measures, economic measures, support, and direct investment.[78] Midwest pulp and paper mills are affected by prescriptive, economic, support, and direct investment measures at varying scales. This section presents five policy recommendations to facilitate the energy efficiency improvements described earlier in the report.

Benchmark industrial energy efficiency performance

The first recommendation is to require periodic measurement of pulp and paper sector energy efficiency performance. Benchmarking can facilitate energy efficiency improvements from the equipment scale up to the scale of the entire national economy. Development of national benchmarks for specific equipment and processes, such as paper drying, could support facility energy management programs. At the facility level, it can help energy managers identify energy efficiency opportunities and track performance. On a regional or national level, it can also serve as the basis for inter-sector comparisons and policy prioritization. In particular, this report recommends expanded industry use of existing energy efficiency benchmarking tools such as the ENERGY STAR Energy Performance Indicators tool. On a national level, benchmarking assessment tools can be improved with thorough Census industry data collection programs. At the whole economy scale, reliable and comprehensive benchmarking data can also serve as the basis for regulations or allowance allocations under national cap-and-trade or carbon tax programs.[79]

Introduce a mix of minimum standards and "reach" incentives

Efficiency and energy management standards can improve follow-through on opportunities for industrial energy efficiency. To address lower-efficiency mills, this report recommends minimum efficiency and emissions standards for new equipment (such as motors, boilers, and pumps) with facility-level auditing requirements to help manufacturers identify and address the areas with the greatest potential for improvement. In order to address mill-specific circumstances and opportunities, this report recommends development of a pulp and paper sector or broader policy similar to Australia's 2012 energy and climate policy for industry. In addition to providing financial and technical assistance for emissions-intensive and trade-exposed industry subsectors, Australia's policy requires facilities to perform regular energy efficiency audits and publish the results.[80] A similar pulp and paper sector approach in the United States would help antiquated mills overcome financial and informational barriers to efficiency improvements.

At the high-performance end of the spectrum, incentives such as financing programs, R&D investments, preferential tax policy, and/or recognition programs can help motivate facility-appropriate improvements such as increased use of recycled fibers. Given the long capital-asset cycles for pulp and paper mill equipment (Davidsdottir and Ruth 2004), a concerted approach to both ends of the mill performance spectrum is most likely to spur investment and subsector improvement. On the state level, this approach could complement public benefit funds and other ratepayer-supported energy efficiency funds allocated to the sectors and facilities with the lowest cost of conserved energy. As illustrated in this report's case studies, prescriptive measures can be complemented with economic measures, including preferential loans, tax incentives, and other supportive measures such as technical assistance and capacity building.

Support CHP utilization through state and federal policies

While the U.S. pulp and paper sector deploys large amounts of CHP, this analysis and other published studies suggest substantial remaining CHP potential for Midwest pulp and paper mills, particularly for pulp and paper-only mills. The cost-effectiveness of CHP depends on fuel availability, local facility heat and power loads, and the regulatory framework for electricity market access. Persistent barriers to increased CHP in U.S. industry can be addressed through regulatory, economic, and other supportive measures. In particular, inclusion of qualified CHP in state energy efficiency resource standards, feed-in tariffs for CHP-generated electricity, less burdensome interconnection rules, and standardized standby fee structures could help U.S. industry improve its resource efficiency.

Develop new regulatory frameworks to promote electric utility-manufacturer collaboration

Electric utilities do not always have incentives to help reduce their customers' energy use. To address utility incentives, the U.S. Congress passed the 1978 Public Utility Regulatory Power Act (PURPA). PURPA introduced new requirements and incentives for efficiency, renewables, and distributed power generation that helped to boost CHP utilization, among other things. However, PURPA has since been amended to reduce these incentives, particularly in the area of distributed generation. The development of a 21st century PURPA could usefully include new cost-recovery models in which utilities continue to earn reasonable profits while manufacturing customers self-generate electricity and reduce demand through energy efficiency. Case study experience suggests that efficiency and environmental goals are most often achieved in the pulp and paper sector when they are integrated with state and local utility efficiency programs.

Build on current research to develop geographically and sectorally integrated climate policy

As the largest greenhouse gas emitting sector in end-use terms, industry must be addressed in any U.S. climate policy.[81] This final recommendation builds on the American Energy Manufacturing Technical Corrections Act (H.R. 6582), which was signed by President Obama in December 2012 and included a mandate for the government to conduct a study of energy-intensive manufacturing. Understanding the energy and emissions performance of pulp and paper mills compared with chemical refineries, iron and steel mills, and other energy-intensive subsectors will help to identify the most cost-effective areas for policy support. Better understanding regional differences among energy-intensive economic activities can help to inform sound policy, thereby ensuring that new climate and energy policies are economically efficient, environmentally effective, and equitable (Heilmayr and Bradbury 2011). Integrated, well-designed climate policy can help energy-intensive subsectors such as Midwestern pulp and paper mills reduce their environmental impacts while improving economic competitiveness.

International experiences suggest that policy can play an important role in moving energy-intensive industry toward a path of lower energy use and greenhouse gas emissions. Integrated policy approaches to industry subsector emissions mitigation have been demonstrated in the pulp and paper sector of Sweden, where combined EU and national policies helped to create clean and efficient growth opportunities (Ericsson, Nilsson, and Nilsson 2011). Coordinated federal and state policies could generate these benefits in the U.S.; for example, through sector-specific energy and climate targets designed along the lines of state energy efficiency and renewable energy standards. The higher costs of energy create different investment incentives for mills in Sweden than the U.S. However, as a heavily industrialized country with a large pulp and paper sector, Sweden's experience is instructive. Through a mix of policies, capital renewal, and energy market shifts, Sweden's pulp and paper sector reduced its carbon dioxide emissions by 80 percent between 1973 and 2006, while increasing production by more than 50 percent (Lindmark et al. 2011). Over the long term, coordinated policies and investments can help the U.S. pulp and paper sector become a low-emissions source of economic activity.

Section 5

SUMMARY AND CONCLUSIONS

Energy-intensive industry is undergoing a transition in the United States driven by energy market dynamics, aging equipment, competitive pressure, and the urgent need to reduce greenhouse gas and toxic air emissions. The experiences of the pulp and paper sector demonstrate that energy efficiency investments can help mills weather the transition and build the foundations for a robust low-carbon economy.

In 2010 industry accounted for 31 percent of total U.S. energy use (30 out of 98 Quadrillion Btu of final energy use) and 28 percent of total direct and indirect U.S. greenhouse gas emissions (1.9 out of 6.8 billion metric tons CO_2e) (U.S. DOE/EIA 2012b; U.S. EPA 2013). Although transportation, residential, and commercial-sector energy use and greenhouse gas emissions have grown since 1980, industry remains the largest sector in end-use terms for both energy use and emissions. As the third largest energy-using manufacturing subsector, U.S. pulp and paper mills have opportunities for significant energy and emissions savings through efficiency improvements.

This study's energy performance indicator analysis shows that in 2010 Midwest pulp and paper mills were slightly below the national average performance. Improvements in Midwest pulp and paper mill efficiency to the minimum ENERGY STAR qualification levels would reduce purchased energy use by 30 percent and generate annual energy cost savings of $240 million. In terms of greenhouse gas emissions, Midwest pulp and paper mills (which are more fossil-fuel intensive than the U.S. average) generated 18 million metric tons of direct and indirect carbon dioxide emissions in 2010, thereby accounting for 24 percent of national energy-related pulp and paper sector greenhouse gas emissions. Scenario analysis shows that aggressive efficiency improvements to existing performance levels have the potential to reduce Midwest pulp and paper sector carbon dioxide emissions by 34 percent, 15 percent more than fuel switching from coal or oil to natural gas (though these options are not exclusive and could beneficially be done in combination).

Given that Midwest pulp and paper mills are less efficient than the U.S. average, the business case for energy efficiency investment in this region is particularly strong. Based on analysis of the cost of conserved energy, Midwest mills could reduce their energy use by 25% through cost-effective investments in energy efficiency improvements (that have a cost per Btu below 2010 average regional energy market rates). A review of existing and emerging technologies shows that Midwest pulp and paper mills have a range of low-cost technology options for improving their energy efficiency. At the facility level, the Flambeau River Papers case study demonstrates the opportunity for mills to reduce energy costs while increasing production and competitiveness through energy efficiency investments. In a climate of increasing competition, the case study experiences suggest that energy efficiency investments are an important factor in determining which mills will survive the transition.

> Improvements in Midwest pulp and paper mill efficiency to ENERGY STAR levels would reduce purchased energy use by 30 percent and generate annual energy cost savings of $240 million.

On a federal level, relevant policies such as the final Boiler MACT rule are being developed under the existing authority of the Clean Air Act. To achieve the efficiency improvements highlighted in this report, there may be a need for additional legislative action. On the national level, Congress could revisit PURPA to more fully align the interests of utilities with customer goals of self-generation and energy efficiency. At the state level, Illinois, Wisconsin, Minnesota, Michigan, and Ohio have implemented ratepayer funded energy efficiency policies; however, more could be done to achieve significant energy cost savings and emissions reductions from the most energy-intensive industries in their states.

This report recommends introduction of minimum standards with facility-auditing requirements to identify and address the areas with the greatest potential for improvement. For high-performing facilities we recommend introduction of incentives and institutional adjustments to motivate continued improvements.

Implementation of the efficiency improvements and innovations described in this report could help the pulp and paper sector become a low greenhouse gas emissions engine for economic growth. The turnaround of forward-thinking mills and companies, including the case studies in this report, suggests that a proper combination of investments, policies, and practices could lead Midwest pulp and paper mills to achieve significant cost savings and emissions reductions. These examples also can inform broader and longer-term strategies to cost-effectively save energy and reduce emissions from other manufacturing sectors and regions of the country.

APPENDIX I. MIDWEST PULP AND PAPER DATA

The Midwest was the second-largest pulp and paper producing region in 2010. As illustrated in Figure 17, packaging was the largest production category in the Midwest, followed by printing and writing paper. In terms of the mill-level assessment presented in Section 2, it should be noted that each mill can produce a range of products with varying energy intensities.

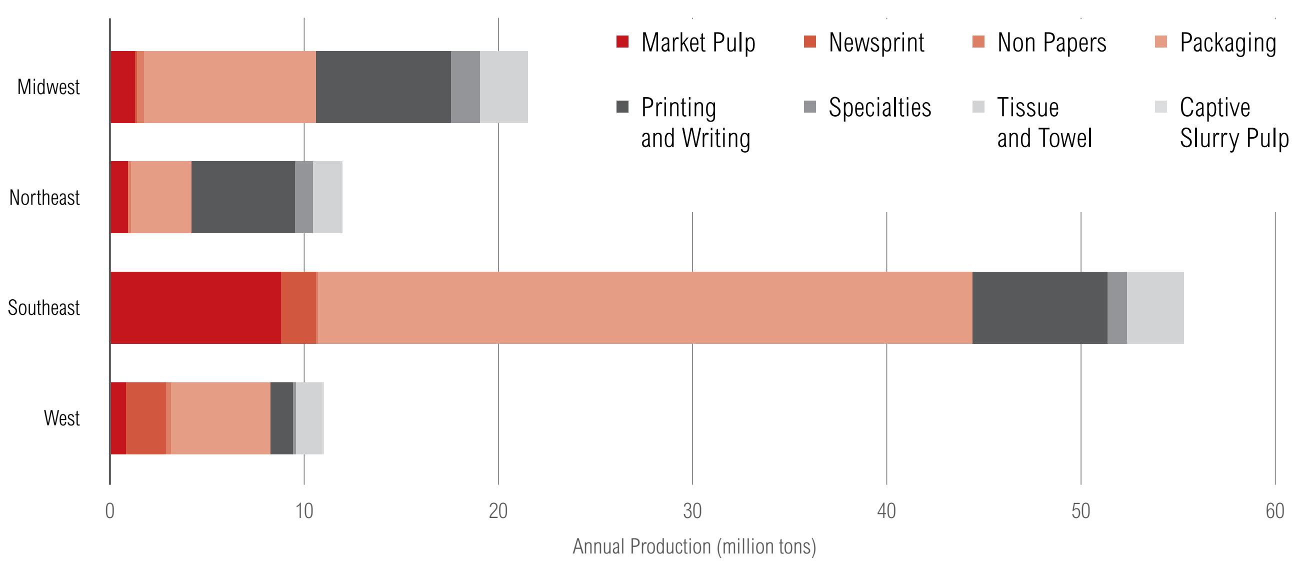
Product categories vary among mills and data sources. However, product mix influences regional differences in aggregate energy use and intensity. Figure 18 shows average energy intensity of U.S. paper production by product category. Tissue, coated freesheet, and printing and writing paper all have a higher average intensity of production than newsprint or pulp (Jacobs et al. 2006).

In 2010 the Midwest had a higher share of paper-only mills than other regions of the U.S. While the share of production by process influences regional pulp and paper sector energy and resource use, it does not affect the energy efficiency assessment results presented in this report, as they are based on integrated and pulp-only process-specific tools.

In 2010, Wisconsin had as many integrated mills as the rest of the Midwest in aggregate. While Minnesota accounted for 10 percent of mills located in the Midwest, the state accounted for 25 percent of Midwest integrated mills. Table 8 shows that nearly 75 percent of Midwest mills were located in Wisconsin, Michigan, and Ohio.

From a pulping process perspective, recycling is energy efficient.[82] Figure 19 illustrates the lower average energy use per ton of pulp production for recycling facilities than chemical or mechanical pulping units. The lower-than-national-average Midwest share of integrated mill production in 2010 was echoed by a higher-than-national-average share of recycled pulp production. In 2010 the Midwest had twice the average national share of recycled pulp production.

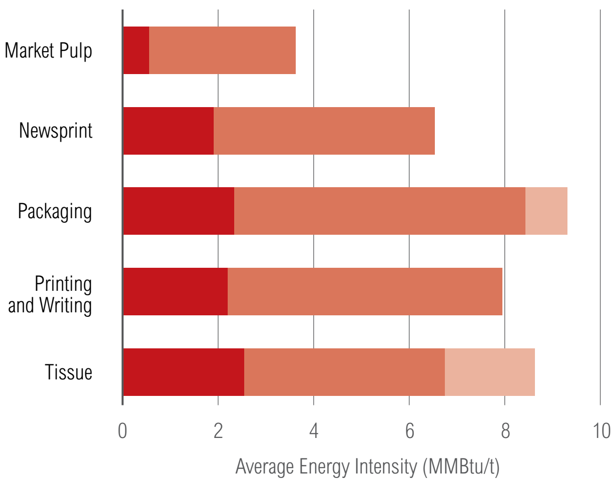
Figure 17 | **Annual Production of Selected Grades of Pulp and Paper, 2010**



Source: Fisher International 2013.

Notes: The scope of these production data vary from production data included earlier in the report; these data are for inter-regional comparison.

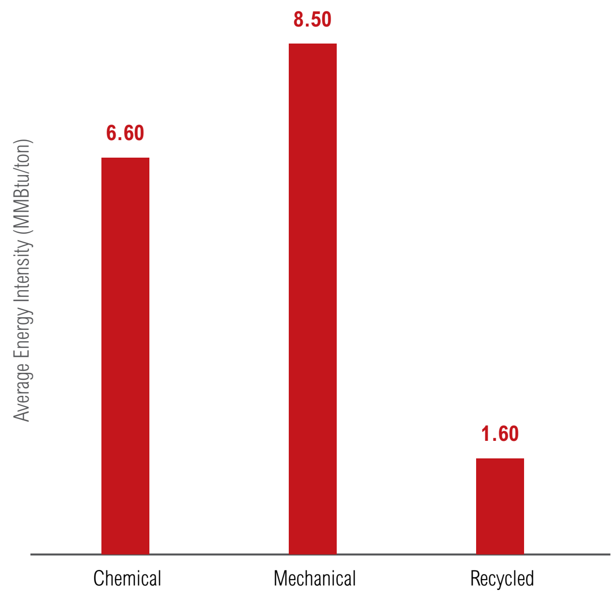
Figure 18 | **Midwest Average Energy Intensity by Mill Type, 2010**



Source: Jacobs et al. 2006.

Note: The data in this figure are in end-use terms.

Figure 19 | **Midwest Average Energy Intensity of Pulp Production by Process, 2010**



Source: Fisher 2012.

Table 8 | **Distribution of Mill Type by State, 2010**

STATE	PULP	PAPER	INTEGRATED	TOTAL
Illinois	0	6	0	**6**
Indiana	0	4	0	**4**
Iowa	0	2	0	**2**
Kansas	0	1	0	**1**
Michigan	1	13	3	**17**
Minnesota	1	3	5	**9**
Missouri	0	2	0	**2**
Ohio	2	12	2	**16**
Wisconsin	1	25	10	**36**

Source: Fisher International 2013.

APPENDIX II. METHODS AND ASSUMPTIONS

Cost Curve Data and Assumptions

The cost curve presented in this report is based on the LBL pulp and paper sector cost curve, with the cost numbers adjusted for inflation (Xu, Sathaye, and Kramer 2012). The LBL cost curve uses a cost of conserved energy approach summarized in the following equations:

EQUATION 1

$$CCE_i = \frac{\Delta I_i \cdot q + \Delta M_i}{\Delta E_i}$$

EQUATION 2

$$q = \frac{d}{(1 - (1 + d)^{-n})}$$

Where:

CCE_i = Cost of conserved energy for energy efficiency measure i (or sustainability option i), in \$/GJ

ΔI_i = Change in capital cost associated with measure i (or option i) (\$)

q = Capital recovery factor (yr-1), see Equation (2)

ΔM_i = Annual change in monetizable non-energy costs and benefits from O&M changes associated with option i (\$/yr)

ΔE_i = Annual energy savings associated with option i (GJ/yr)

d = Discount rate

n = Lifetime of the mitigation option (years)

The LBL cost curve analysis assumes a high discount rate of 30 percent, thereby generating high annualized cost estimates for energy efficiency improvement options. The rationale behind the high discount rate is that it simulates impediments associated with market failures and indirect costs. For the purposes of this study, we updated the LBL cost data to 2010 values using inflation data from the Bureau of Labor Statistics.

WRI Pulp & Paper Manufacturing GHG Emissions Calculation

This project used version 1.3 of the NCASI/WRI pulp and paper manufacturing GHG emissions tool to calculate direct, indirect, and biomass CO_2 emissions from pulp and paper mills. It can be used to estimate emissions attributed to purchased electricity and steam, as well as on-site generation. Depending on the data provided by the user, the tool has the capacity to determine the direct emissions from fuel combustion, mobile and transportation, waste management, CHP allocation, and make-up chemicals. The scope of indirect emissions covers steam and power imports, transportation and mobile sources, and waste management. In addition, the tool offers the ability to calculate CO_2 imports to each mill, CO_2 exports to precipitated calcium carbonate (PCC) plants, and combustion-related releases of biomass-derived CO_2.

For this report, the tool was used to calculate 2010 mill-specific CO_2 emissions from direct stationary combustion, indirect steam and power imports, and the combustion of biomass (i.e., woodwaste, pulping liquor, and tires). To calculate the CO_2 emissions associated with each, values for two key variables—energy usage and emissions factors—were necessary. Fisher supplied data for this study on the type and amount of fuel, steam, and electricity consumed either on-site or imported by each pulp and paper mill in the Midwest. The emissions factors involve complicated calculations that are dependent on a variety of detailed variables.

Specific to direct stationary fuel consumption, default values for the emissions factor are provided for numerous fuel sources in the tool, and are derived from the revised 2006 IPCC Guidelines for National Greenhouse Gases (IPCC 2006), EIA (U.S. DOE/EIA 2007, or NCASI (NCASI 1981, 2004). The number of coal and natural gas subfuels with default emissions factors provided in the tool is extensive, and is beyond the limited description of "coal" and "gas" provided in the Fisher data. Therefore, the emissions factor used for coal in this study was an average of the emissions factor for the seven variations of bituminous coal and four variations of sub-bituminous coal, resulting in an emissions factor of 95.1 kg CO_2/GJ (LHV). While emissions factors for the six variations of natural gas fuel types are provided in the tool, each of the six had the same CO_2 emissions factor of 56.1 kg CO_2/GJ (LHV). The detail of data provided by Fisher with respect to the consumption of distillate fuel was described as either No. 2 or No. 6 oil, and the default CO_2 emissions factor provided in the NCASI/WRI tool for each was used. Although sludge was provided as a fuel source in a limited number of mills, emissions from sludge digestion systems are particular to CH4 and the waste management portion of the NCASI/WRI tool. Therefore, sludge was not accounted for when estimating the CO_2 emissions attributed to each mill. Furthermore, the tool provided default CO_2 emissions factor values for solid biomass (112 kg CO_2/GJ (LHV)), black liquor (95.3 kg CO_2/GJ (LHV)), and tires and tire derived fuel (85.9 kg CO_2/GJ (LHV)). The emissions factors associated with each of the three were used to calculate the CO_2 emissions attributable to the fuel sources—woodwaste, pulping liquor, and tires— provided within the Fisher data, respectively. The emissions factor for purchased steam used in this study was from the U.S. Department of Energy's voluntary greenhouse gas reporting program (88.18 kg CO_2/MMBtu).

To determine the emissions factor for imported electricity with respect to CO_2 emissions (kg CO_2/MWh) in the year 2010, the U.S. Energy Information Administration's (EIA) total electric power industry's estimated CO_2 emissions were used for each of the twelve Midwestern states considered in this report. The cumulative CO_2 emissions from each state's electric power industry in 2010 were then divided by each state's respective total electric power industry generation for that year. The result produced a state-specific emissions factor that was used to calculate the CO_2 emissions attributable to electricity purchased by each mill within their respective state.

The total CO_2 emissions attributable to each pulp and paper mill within the twelve Midwestern states were determined by aggregating the direct stationary fuel consumption (scope 1), indirect imported electricity and steam (scope 2), and on-site biomass combustion.[83] The emissions intensity (EI) of each mill was then discernible through dividing a mill's cumulative annual emissions by the amount of annual production in the year 2010. The EIs were aggregated by state and the Midwest, establishing a weighted average EI that yielded a state and regional level comparison of pulp and paper mill emissions intensities.

APPENDIX III. PULP AND PAPER ENERGY COST DATA

Reported pulp and paper mill energy prices vary by state and data source. Figure 20 illustrates the range of reported state, regional, and national-level energy prices.

Data from MECS, State Energy Data System (SEDS), and Fisher provide varying scopes of estimated average total energy prices within the Midwest. MECS data is specific to the pulp and paper sector at the three-digit (322) and six-digit (i.e., 322110, 322121, 322122, and 322130) NAICS code, and its geographical scope is the regional and national level. The four-digit NAICS code subsector of the paper industry—NAICS 3222—accounted for more than 52 percent of the paper sector's value of product shipments in the year 2010 (U.S. Census Bureau 2013), but data pertaining to that subsector's estimated average energy price was not provided. In addition, comprehensive 2010 MECS data was not available at the time of this report, making 2006 MECS data the most recent available data. Since the majority of data used throughout this report was relevant to pulp, paper, and integrated mills, MECS six-digit NAICS codes 322110 (pulp mills) and 322121 (paper mills, except Newsprint) data for average total prices of purchased energy were considered when establishing a baseline average energy price for the Midwest (Table 9).

The SEDS data has state-level total energy price estimates as recent as the year 2010 (Table 9). The SEDS estimated price data has a scope limited to the sector level (i.e., industrial, residential, commercial, and transportation).

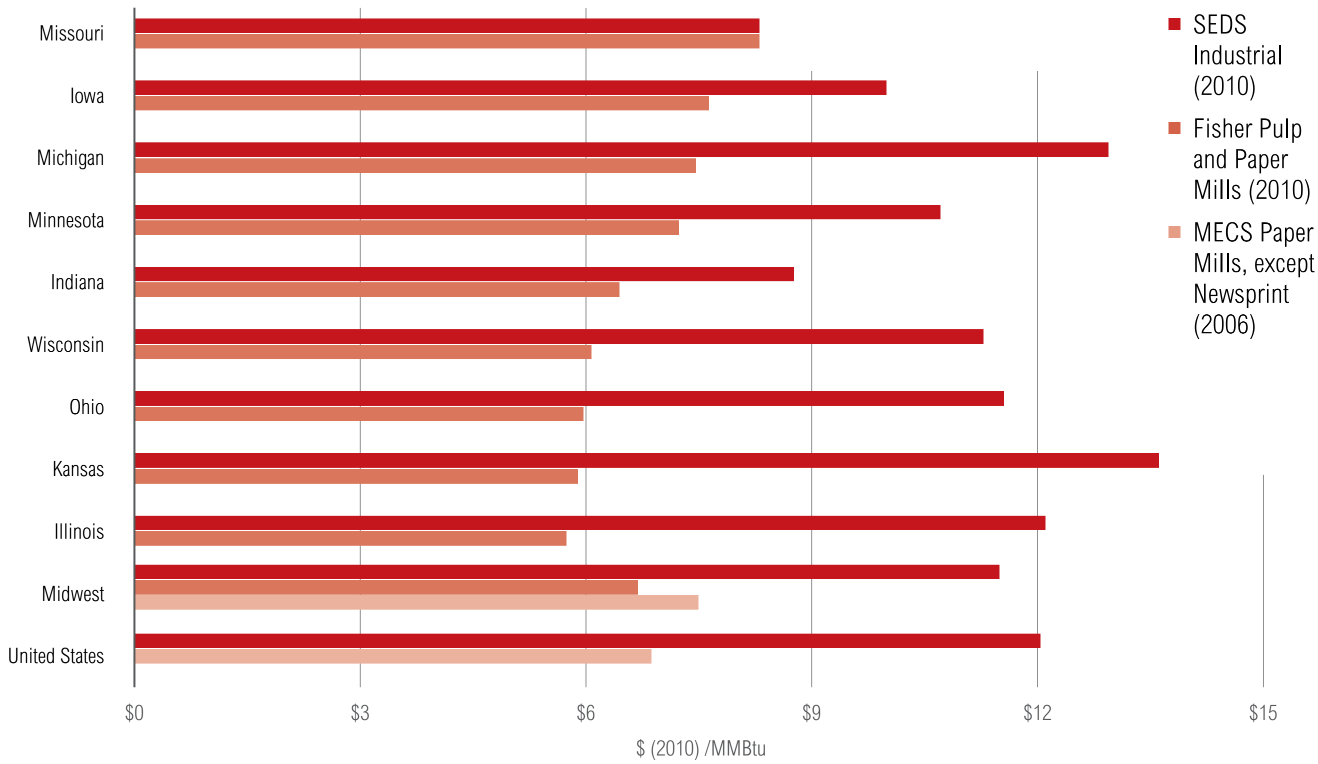
Fisher offers mill-specific average energy price data for pulp, paper, and integrated mills. From the ninety-three pulp, paper, and integrated mills within the Midwest, the $6.69/MMBtu weighted average total energy price for 2010 from the Fisher data was used as the baseline energy price for the Midwest pulp and paper sector throughout this study. It is useful to note that energy markets have changed substantially since 2010—for example, average U.S. industrial natural gas prices declined from $6.93 per thousand cubic feet (tcf) in January 2010 to $3.01/tcf in May 2012 before rebounding to $4.54/tcf in February 2013 (U.S. DOE/EIA 2013b).

Table 9 | **Midwest Estimated Average Purchased Energy Prices ($/MMBtu)**

REGION	MECS NAICS 322 PULP AND PAPER MILLS (2010)	FISHER PULP AND PAPER MILLS (2010)	SEDS (2010)
Midwest Region	$7.91	$6.69	$11.41

Sources: Fisher International 2013; U.S. DOE 2009b; U.S. DOE/EIA 2013a.

Figure 20 | **Midwest State and Regional Average Pulp and Paper Sector Purchased Energy Prices**



Sources: Fisher International 2013; U.S. DOE 2009b; U.S. DOE/EIA 2013a.

APPENDIX IV. ADDITIONAL RESOURCES FOR PULP AND PAPER ENERGY EFFICIENCY POLICY AND TECHNOLOGY INFORMATION

This appendix provides additional resources with further information on pulp and paper sector technologies and policies.

- American Forest and Paper Association (AF&PA). 2012. "2012 AF&PA Sustainability Report" Available online: http://www.afandpa.org/docs/default-source/default-document-library/2012-af-amp-pa-sustainability-report.pdf
- Confederation of Indian Industry. 2008. "National Best Practices Manual: Pulp & Paper Industry" Available online: http://www.greenbusinesscentre.com/site/mmbase/attachments/239196/Pulp_Paper-vol1.pdf
- Focus on Energy. 2005. "Pulp and Paper Energy Best Practice Guidebook" Available online: http://www.focusonenergy.com/sites/default/files/pulpandpaper_guidebook.pdf
- Institute for Industrial Productivity. 2013. Industrial Efficiency Technology Database. Available online: http://www.ietd.iipnetwork.org/content/pulp-and-paper#technology-resources
- International Energy Agency (IEA). 2009. "Energy Technology Transitions for Industry," Available online: http://www.iea.org/publications/freepublications/publication/industry2009.pdf
- Jacobs and the Institute of Paper Science and Technology (IPST) at Georgia Institute of Technology. 2006. "The Pulp & Paper Industry: Energy Bandwidth Study" Report prepared for the American Institute for Chemical Engineers. Available online: https://www1.eere.energy.gov/manufacturing/resources/forest/pdfs/doe_bandwidth.pdf
- Natural Resources Canada. 2008. "Benchmarking Energy Use in Canadian Pulp and Paper Mills" Available online: http://oee.nrcan.gc.ca/sites/oee.nrcan.gc.ca/files/pdf/industrial/technical-info/benchmarking/pulp-paper/pdf/benchmark-pulp-paper-e.pdf

APPENDIX V. KEY PULP AND PAPER ENERGY EFFICIENCY TECHNOLOGIES

This appendix provides information on key energy efficiency technologies to supplement the technology descriptions in Section 3 above.

Cradle Debarking | In this wood preparation process logs are loaded into a long trough containing a series of horizontal and vertical conveyor chains, oriented at an angle supportive to the path of the logs. Chains lift and drop the logs as they move along the trough, loosening and removing bark (Kramer et al. 2009).

Belt Conveyors | During the wood preparation process, belt (mechanical) conveyors are typically significantly more energy efficient at transporting wood chips within a mill than pneumatic conveyors (Kramer et al. 2009).

Bar-type chip screens | Due to different design than the majority of the installed disc and V-type screens, the maintenance costs of bar-screens are lower than conventional screens while the lifetime is longer (Kramer et al. 2009).

Batch digester modification | In this chemical pulping process there are several options to reduce energy consumption in batch digesters, such as the use of cold blow systems and indirect heating (Kramer et al. 2009).

Thermopulping | A variation of the TMP process in mechanical pulping where pulp from the initial and subsequent refiner is subjected to a high temperature treatment for a brief time in a thermomixer (Kramer et al. 2009).

Pressurized groundwood | A process in mechanical pulping where grinding takes place under compressed air pressure and high water temperatures that allow for higher grinding temperatures, softening the lignin and improving fiber separation while reducing energy consumption (Kramer et al. 2009).

RTS pulping | A process in mechanical pulping where energy consumption is reduced by increasing the rotational speed of the primary refiner, leading to reduced residence time, smaller plate gaps, and higher refining intensity (Kramer et al. 2009).

Drum pulpers | A process in recycled pulping where a rotating, inclined drum with baffles mixes recovered fiber sources, water, and de-inking chemicals. (Kramer et al. 2009)

Heat recovery from de-inking effluent | Typically in recycled fiber pulping mills, high temperature discharged de-inking effluents offer a source of low-grade heat recovery (Kramer et al. 2009).

GLOSSARY AND ABBREVIATIONS

ADT	Air dried ton (measurement unit; often in reference to pulp production).
AF&PA	American Forest & Paper Association.
AMO	Advanced Manufacturing Office.
ASM	American Survey of Manufacturers.
Bleaching	A process used to brighten pulp prior to being used in the papermaking process. In chemical pulping, the small amount of remaining lignin is removed for a more permanent change in pulp brightness.
Blow Tank	Receives pulp discharged from a digester and reduces pressure at this point in the papermaking process to atmospheric pressure.
Boiler MACT	The final Boiler Maximum Achievable Control Technology rule, which regulatesindustrial, commercial, and institutional boiler emissions, was published by the Environmental Protection Agency in the *Federal Register* January 31, 2013.
Btu	The British thermal unit (sometimes BTU) is a traditional unit of energy equal to about 1055 joules. It is approximately the amount of energy needed to heat 1 pound (0.454 kg) of water, which is exactly one-tenth of a UK gallon or about 0.1198 US gallons, from 39°F to 40°F (3.8°C to 4.4°C).
CAIR	On March 10, 2005, EPA issued the Clean Air Interstate Rule, which will permanently cap emissions of sulfur dioxide (SO2) and nitrogen oxides (NOx) in the eastern United States. CAIR was designed to achieve large reductions of SO2 and/or NOx emissions across 28 eastern states and the District of Columbia. The first compliance phase for CAIR's replacement, the Cross-State Air Pollution Rule (CSAPR), was scheduled to go into effect in January 2012. In December 2011, the Court of Appeals stayed the rule, leaving CAIR in effect until a court ruling on CSAPR.
CEAC	Clean Energy Assessment Center.
CHP	Combined heat and power; for more information, see Section 3.2.
Condebelt-Drying	This process is papermaking dries the paper in a drying chamber by contact with a continuous hot steel band which is heated either by steam or hot gas. The water from the band is evaporated due to the heat from the band.
CSAPR	On July 6, 2011, the US Environmental Protection Agency (EPA) finalized the Cross-State Air Pollution Rule. The rule requires states to improve air quality by reducing power plant emissions that contribute to ozone and/or fine particle pollution in other states. The first compliance phase for CSAPR was scheduled to go into effect in January 2012. In December 2011, the Court of Appeals stayed the rule, leaving CAIR in effect until a court ruling on CSAPR.
Digester	Used to soften and cook wood chips into pulp using steam, chemicals, and heat.
DOE	Department of Energy.
EE	Energy Efficiency.
EERS	Energy Efficiency Resource Standard.
EIA	Energy Information Administration. An independent statistical agency of the U.S. Department of Energy.
EPA	Environmental Protection Agency.
ESA	Energy Savings Assessment.
FoE	Focus on Energy.
FRP	Flambeau River Papers.
GDP	Gross domestic product. The total value of goods and services produced by labor and property located in a given country.
IA	Iowa.
IAC	Industrial Assessment Center.
IL	Illinois.
IN	Indiana.
ITP	Industrial Technologies Program.
KS	Kansas.
kWh	A kilowatt hour is a unit of energy equivalent to 3.6 megajoules; it is the amount of energy converted if work is performed at a rate of one thousand watts for one hour. The kilowatt hour is commonly used as a billing unit for electricity delivered to consumers by electric utilities.
LBNL	Lawrence Berkley National Laboratory.
MACT	Maximum Achievable Control Technology.
MDT	Machine dried ton (measurement unit; often in reference to paper production)
MECS	Manufacturing Energy Consumption Survey.
MEP	Manufacturing Extensive Partnership.

MI	Michigan.
MMBtu	Million British thermal units.
MN	Minnesota.
MO	Missouri.
MW	A megawatt is equivalent to one million (106) watts. A watt is a unit of power or energy conversion equivalent to one joule per second.
MWh	A megawatt hour is a unit of energy equivalent to 1,000 kWh.
NAICS	The North American Industry Classification System (NAICS) is the standard used by federal statistical agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the US business economy. The NAICS was developed under the auspices of the Office of Management and Budget (OMB) and adopted in 1997 to replace the Standard Industrial Classification (SIC) system; the current system was updated in 2007.
ND	North Dakota.
NE	Nebraska.
OAR	Office of Air and Radiation.
OBES	Output-based emissions standards, otherwise known as output-based environmental regulations (OBR), encourage energy efficiency and clean energy supply such as combined heat and power (CHP) by relating emissions to the productive output of the energy-consuming process. The goal of OBES is to encourage the use of fuel conversion efficiency as an air pollution control measure.
OECD	Organisation for Economic Co-operation and Development. The OECD was established in 1960 and in 2013 included 34 member countries.
Quad	An energy unit equivalent to 1015 Btu; total U.S. energy use has recently been a bit less than 100 Quads. 1 Quad of energy is equivalent to 1,000 trillion Btu.
RES	Renewable Energy Standard.
ROI	Return on Investment.
Screening	Scanning of pulp to remove oversized contaminants.
SD	South Dakota.
SEDS	State Energy Data System.
Steam Trap Maintenance	Maintenance of an automatic valve that allows condensate, air, and other non-condensable gases to be discharged from the steam system while holding or trapping the steam in the system.
TMP	Thermo-mechanical pulp mill.
TRI	Toxics release inventory. The TRI is a public database that contains detailed information on nearly 650 chemicals and chemical categories that 23,000 industrial and other facilities manage through disposal or other releases, recycling, energy recovery, or treatment. Facilities report annually. The TRIwas created by the Environmental Protection Agency under the 1986f the Emergency Planning and Community Right-to-Know Act. See < http://www.epa.gov/tri>.
Washing	Diffusing water through the pulp during the pulping process, washing is a necessary process to remove chemicals and other impurities from the pulp.
WHR	Waste Heat Recovery.
WI	Wisconsin.

REFERENCES

Aden, N. 2012. “Energy efficiency as a compliance pathway for industry environmental regulation in the United States.”*Proceedings of the European Council for an Energy Efficient Economy Industry 2012 Summer Study*: 295–303.

Allcott, H., and M. Greenstone. 2012. “Is There an Energy Efficiency Gap.” *Journal of Economic Perspective* 26 (1): 3–28.

American Council for an Energy-Efficient Economy (ACEEE). 2012. “State Energy Efficiency Resource Standards (EERS).” Policy Brief. Available online at: <http://aceee.org/files/pdf/policy-brief/state-eers-summary-0912.pdf>.

American Forest and Paper Association (AF&PA). 2010. “2010 AF&PA Sustainability Report.” Available online at: <http://www.afandpa.org/sustainability/>.

American Forest and Paper Association (AF&PA). 2012. “2012 Sustainability Report.” Available online at: <http://www.afandpa.org/sustainability/>.

Australia Prime Minister's Taskforce on Manufacturing. 2012. “Smarter Manufacturing for a Smarter Australia.” Available online at: <http://www.innovation.gov.au/Industry/Manufacturing/Taskforce/Pages/default.aspx>.

Boston Consulting Group (BCG). 2012. “More Than a Third of Large Manufacturers Are Considering Reshoring from China to the U.S.” Available online at: <http://www.bcg.com/media/PressReleaseDetails.aspx?id=tcm:12-104216>.

Boyd, G.A, and Y.F. Guo. 2012. “Development of ENERGY STAR® Energy Performance Indicators for Pulp, Paper, and Paperboard Mills.” EPA ENERGY STAR Technical Document. Available online at: <http://www.energystar.gov/index.cfm?c=in_focus.bus_pulppaper_focus>.

Bradbury, J.A. 2010. “EPA, the Clean Air Act, and U.S. Manufacturing.” World Resources Institute Factsheet. Available at: <http://www.wri.org/stories/2010/11/epa-clean-air-act-and-us-manufacturing>.

Bradbury, J., and N. Aden. 2012. “Midwest Manufacturing Snapshot: Energy Use and Efficiency Policies.” WRI Working Paper. Available online at: <http://pdf.wri.org/working_papers/midwest_manufacturing_snapshot/midwest_manufacturing_snapshot.pdf>.

Brown, M. A. 2001. “Market Failures and Barriers as a Basis for Clean Energy Policies." *Energy Policy* 29 (14): 1197–1207.

Brown, M.A., R. Jackson, M. Cox, R. Cortes, B. Deitchman, and M.V. Lapsa. 2011. “Making Industry Part of the Climate Solution: Policy Options to Promote Energy Efficiency.” Oak Ridge National Laboratory (ORNL) Report 2010/78. Available online at: <http://info.ornl.gov/sites/publications/Files/Pub23821.pdf>.

Brueske, S., R. Sabouni, C. Zach, and H. Andres. 2012. “U.S. Manufacturing Energy Use and Greenhouse Gas Emissions Analysis.” ORNL Report ORNL/TM-2012/504. Available online at: <http://info.ornl.gov/sites/publications/files/Pub39685.pdf>.

Bureau of Labor Statistics. 2012. “Inflation Calculator.” Available online at: <http://www.bls.gov/data/inflation_calculator.htm>.

Carney, M. 2013. “Dutch Disease.” Bank of Canada published speech. Available online at: <http://www.bankofcanada.ca/wp-content/uploads/2012/09/remarks-070912.pdf>.

Chittum, A. 2011. “Follow the Leaders: Improving Large Customer Self-Direct Programs.” American Council for an Energy Efficient Economy (ACEEE) Research Report IE112. Available online at: <http://www.aceee.org/research-report/ie112>.

Chittum, A. 2012. “Coal Retirements and the CHP Investment Opportunity.”American Council for an Energy Efficient Economy (ACEEE) Research Report IE123. Available online at: <http://www.aceee.org/research-report/ie123>.

Chittum, A., and S. Nowak. 2012. “Money Well Spent: 2010 Industrial Energy Efficiency Program Spending.” ACEEE Report IE121. Available at: http://www.aceee.org/research-report/ie121.

Coito, F., E. Worrell, F. Rafael, and M. Rufo. 2005. “California Industrial Energy Efficiency Potential.” Lawrence Berkley National Laboratory (LBNL). In *Proceedings of the American Council on Energy Efficient Economy 2005 Summer Study on Energy Efficiency in Industry*. Available online at: <http://ies.lbl.gov/iespubs/59956.pdf>.

Davidsdottir, B., and M. Ruth. 2004. “Capital vintage and climate change policies: the case of U.S. pulp and paper.” *Environmental Science and Policy* 7(2004): 221–233.

DeWahl, K., K. Larson, J. Baker, A.J. Van den Berghe, M. Jost, P. Pagel, and C. McComas. 2010. “Energy Conservation Market Analysis: A Study to Identify Energy Conservation Opportunities for Minnesota’s Manufactures.” University of Minnesota Technical Assistance Program (MnTAP). Available online at: <http://www.mntap.umn.edu/resources/reports/DOC/MnTAP_IndustrialE2Analysis.pdf>.

Dietsch, N., J. Brown, J. Bryson, R. DeYoung and J. Miller. 2012. "The Opportunity for Energy Efficiency with Clean Air Regulations." American Council for an Energy-Efficient Economy 2012 Summer Study Proceedings. Available online at: <http://www.aceee.org/files/proceedings/2012/data/papers/0193-000272.pdf>.

East Bay Municipal Utility District (EBMUD). 2008. “Watersmart Guidebook: A Water-Use Efficiency Plan Review Guide for New Businesses.” Available online at: <http://www.ebmud.com/sites/default/files/pdfs/WaterSmart-Guidebook.pdf>.

Energy Center of Wisconsin. 2009. “A Review and Analysis of Existing Studies of the Energy Efficiency Resource Potential in the Midwest.” Available online at: <http://www.midwesterngovernors.org/Energy/EEResourcePotential.pdf>.

Environmental Paper Network (EPN). 2007. “The State of the Paper Industry: Monitoring the Indicators of Environmental Performance.” Available online at: <http://www.greenpressinitiative.org/documents/StateOfPaperInd.pdf>.

Ericsson, K., L.I. Nilsson, and M. Nilsson. 2011. “New energy strategies in the Swedish pulp and paper industry—the role of national and EU climate and energy policies,” *Energy Policy* 39: 1439–1449. Available online at: <http://ac.els-cdn.com/S030142151000916X/1-s2.0-S030142151000916X-main.pdf?_tid=f17461b6-4481-11e2-b2b6-00000aacb35d&acdnat=1355333746_ead2da7a09c633801c61715ed5e82571>.

Ericsson, P., M. Lazarus, J. Adair, J. Brant, E. Levitt, H. Hermann, T. Larson, B. Ross, and A. Wheeless. 2010. “Issues and Options for Benchmarking Industrial GHG Emissions.” White Paper for the Washington State Department of Ecology. Available online at: <http://sei-us.org/Publications_PDF/SEI-BenchmarkingWAWhitePaper-10.pdf>.

Fisher International, Inc. 2013. FisherSolve™ Platform. Available online at: <http://www.fisheri.com/>.

Hedman, B. 2010. “Effect of a 30 Percent Investment Tax Credit on the Economic Market Potential for Combined Heat and Power.” Available online at: <http://www.uschpa.org/files/public/USCHPA%20WADE_ITC_Report_FINAL%20v4.pdf>.

Heilmayr, R., and J.A. Bradbury. 2011. “Effective, efficient or equitable: Using allowance allocations to mitigate emissions leakage.” *Climate Policy* 11(4): 1113–1130.

Huntington, H.G. 2011. “The Policy Implications of Energy-Efficiency Cost Curves.” *The Energy Journal* 32: 7–21.

ICF International. 2010. “Combined Heat and Power Installation Database.”
Available online at: <http://www.eea-inc.com/chpdata/>.

International Energy Agency (IEA). 2007. “Tracking Industrial Energy Efficiency and CO_2 Emissions.” Available online at: <http://www.iea.org/publications/freepublications/publication/tracking_emissions.pdf>.

International Energy Agency (IEA). 2010. “Energy Technologies Perspectives 2010: Scenarios and Strategies to 2050.” Available online at: <http://www.iea.org/techno/etp/index.asp>.

International Energy Agency (IEA). 2012a. *World Energy Outlook 2012*. Paris: IEA. Available online at: <http://www.worldenergyoutlook.org/>.

International Energy Agency (IEA). 2012b. “Spreading the Net: The multiple benefits of energy efficiency improvements” Paris: IEA. Available online at: <www.iea.org/publications/insights/ee_improvements.pdf>.

International Paper (IP). 2011. Available online at: <http://www.internationalpaper.com/documents/EN/Sustainability/IP_Sustainability_Re.pdf>.

Intergovernmental Panel on Climate Change (IPCC), Task Force on National Greenhouse Gas Inventory. 2006. “Guidelines for National Greenhouse Gas Inventories.” Volume 2: Energy, chapter 2. Available online at: <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html>.

Jacobs and the Institute of Paper Science and Technology (IPST) at Georgia Institute of Technology. 2006. “The Pulp & Paper Industry: Energy Bandwidth Study.” Report prepared for the American Institute for Chemical Engineers. Available online at: <http://www1.eere.energy.gov/manufacturing/industries_technologies/forest/pdfs/doe_bandwidth.pdf>.

Jaffe, B., and R.N. Stavins. 1994. “The Energy-Efficiency Gap.” *Energy Policy* 22 (10): 804–810. Available online at: <http://www.hks.harvard.edu/fs/rstavins/Papers/The%20Energy%20Efficiency%20Gap.pdf>.

Kowalczyk, I. 2013.“Barriers to the Expansion of Electrical Cogeneration by the Wood Products Industry in the United States.” *Journal of Sustainable Forestry* 32 (1-2): 159–174.

Kramer, K.J., E. Masanet, T. Xu, and E. Worrell. 2009. “Energy Efficiency Improvement and Cost Saving Opportunities for the Pulp and Paper Industry: An ENERGY STAR Guide for Energy and Plant Managers.” Lawrence Berkley National Laboratory (LBNL). Available online at: <http://www.energystar.gov/ia/business/industry/downloads/Pulp_and_Paper_Energy_Guide.pdf>.

Laitner J.A., S. Nadel, R.N. Elliott, H. Sachs, and A. Khan. 2012. “The Long-Term Energy Efficiency Potential: What the Evidence Suggests.” American Council for an Energy Efficient Economy Research Report E121. Available online at: <http://www.aceee.org/research-report/e121>.

Larsen, J., T. Damassa, and R. Levinson. 2007. “Charting the Midwest: An Inventory and Analysis of Greenhouse Gas Emissions in America's Heartland.” WRI Report. Available online at: <http://www.wri.org/publication/charting-the-midwest>.

Lindmark, M., A. Bergquist, and F. Andersson. 2011. “Energy transition, carbon dioxide reduction, and output growth in the Swedish pulp and paper industry: 1973-2006.” *Energy Policy* 39(2011): 5449–5456.

Litz, F., N. Bianco, M.B. Gerrard, and G. Wannier. 2011. “What’s Ahead for Power Plants & Industry? Using the Clean Air Act to Reduce GHGs, Building on Regional Programs.” World Resources Institute Working Paper. Available online at: <http://www.wri.org/publication/whats-ahead-for-power-plants-and-industry>.

Livingston, J., S. Mason, and J.W. Rowe. 2009. “Embracing the Future: The Midwest and a New National Energy Policy.” Chicago Council on Foreign Affairs. Report of the Task Force on National Energy Policy and Midwestern Regional Competitiveness. Available online at: <http://www.thechicagocouncil.org/UserFiles/File/Task%20Force%20Reports/09%20Energy%20Task%20Force%20-%20Full%20Report.pdf>.

McKinsey & Company. 2009. “Unlocking Energy Efficiency in the U.S. Economy.” Available online at: <http://www.mckinsey.com/client_service/electric_power_and_natural_gas/latest_thinking/~/media/204463A4D27A419BA8D05A6C280A97DC.ashx>.

National Academy of Sciences (NAS). 2010. “Real Prospects for Energy Efficiency in the United States.” Available online at: <http://www.nap.edu/catalog.php?record_id=12621>.

National Council for Air and Stream Improvement, Inc. (NCASI). 1981. “A study of the kraft process lime kiln total gaseous non-methane organic emissions.” Technical Bulletin No. 358. Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc.

National Council for Air and Stream Improvement, Inc. (NCASI). 2004. “Calculation Tools for Estimating Greenhouse Gas Emissions from Pulp and Paper Mills, Version 1.1.” Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc.

National Council for Air and Stream Improvement, Inc. (NCASI). 2008. “Calculation Tools for Estimating Greenhouse Gas Emissions from Pulp and Paper Mills, Version 1.1.” Revisions to version 1.1 to generate version 1.3. Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc.

National Renewable Energy Lab (NREL). 2009. “2008 Industrial Technologies Market Report.”Available online at: <http://www.nrel.gov/docs/fy09osti/46024.pdf>.

National Research Council (NRC), 2010. “Advancing the Science of Climate Change.” Available online at: <http://www.nap.edu/catalog.php?record_id=12782>.

Nowak, S., M. Kushler, M. Sciortino, D. York, and P. Witte. 2011. “Energy Efficiency Resource Standards: State and Utility Strategies for Higher Energy Savings.” American Council for an Energy Efficient Economy Research Report U113. Available online at: <http://www.aceee.org/research-report/u113>.

Oda, J., K. Akimoto, T. Tomoda, M. Nagashima, K. Wada, and F. Sano. 2012. “International Comparisons of Energy Efficiency in Power, Steel and Cement Industries.” *Energy Policy* 44: 118–129.

Reed, G.M. 1995. “Realization of a Dream: Charles H. Herty and the South's First Newsprint Mill.” *Forest & Conservation History* 39 (1): 4–16.

Schnepf, R., and B.D. Yacobucci. 2012. “Renewable Fuel Standard (RFS): Overview and Issues.” Congressional Research Service Report 7-5700. Available online at: <http://www.fas.org/sgp/crs/misc/R40155.pdf>.

Shipley, A., A. Hampson, B. Hedman, P. Garland, and P. Bautista. 2008. “Combined Heat and Power: Effective Strategies for a Sustainable Future.” Oak Ridge National Laboratory (ORNL) Report 2008/224. Available online at: <http://info.ornl.gov/sites/publications/files/Pub13655.pdf>.

Stockholm Environment Institute (SEI). 2010. “Issues and Options for Benchmarking Industrial GHG Emissions.” SEI White Paper. Available online at: <http://sei-us.org/publications/id/320>.

Tanaka, K. 2011. “Review of policies and measures for energy efficiency in industry sector.” *Energy Policy* 39 (2011): 6532–6550.

Toivanen, H. 2012. “Waves of Technological Innovation: The Evolution of the U.S. Pulp and Paper Industry, 1860–2000.” In *The Evolution of the Global Paper Industry 1800–2050: A Comparative Analysis*, edited by J.-A. Lamberg et al. *World Forests* 17: 49–80. Available at: <DOI 10.1007/978-94-007-5431-7_3>.

United Nations Food and Agriculture Organization Statistical Database (UN FAOSTAT). 2013. International Pulp and Paper Production Data. Available online at: <http://faostat.fao.org>.

U.S. Census Bureau. 2008. “Pollution Abatement Costs and Expenditures: 2005, MA200(05).” Washington, DC: U.S. Government Printing Office. Available online at: <http://www.census.gov/prod/2008pubs/ma200-05.pdf>.

U.S. Census Bureau. 2008. *Economic Census*. Available online at: <http://factfinder2.census.gov/faces/nav/jsf/pages/index.xhtml>.

U.S. Census Bureau. 2013. *American Survey of Manufacturers* (ASM). Available online at: <http://www.census.gov/manufacturing/asm/>.

U.S. Council of Industrial Boiler Owners (U.S. CIBO). 2003. “Energy Efficiency & Industrial Boiler Efficiency: An Industry Perspective.” Available online at: <http://cibo.org/pubs/whitepaper1.pdf>.

U.S. Department of Commerce. 2012. *Global Patterns of U.S. Merchandise Trade*. Available online at: <http://tse.export.gov/TSE/TSEhome.aspx>.

U.S. Department of Energy, Energy Information Administration (U.S. DOE/EIA). 2012. “*Annual Energy Outlook*.” Published annually from 2000 to 2011. Available online at: <http://www.eia.gov/forecasts/aeo/archive.cfm>.

U.S. Department of Energy, Energy Efficiency and Renewable Energy, Industrial Technologies Program (U.S. DOE/EERE/ITP). 2005a. “Energy and Environmental Profile of the U.S. Pulp and Paper Industry.” Available online at: <http://www1.eere.energy.gov/manufacturing/resources/forest/pdfs/pulppaper_profile.pdf>.

U.S. Department of Energy (U.S. DOE). 2005b.“Forest Products Industry of the Future: Fiscal Year 2004 Annual Report.”

U.S. Department of Energy, Energy Information Administration (U.S. DOE/EIA). 2007. “Instructions for Form EIA-1605, Voluntary Reporting of Greenhouse Gases.” Available online at: <http://www.eia.doe.gov/oiaf/1605/pdf/EIA1605_Instructions_10-23-07.pdf>.

U.S. Department of Energy, Energy Efficiency and Renewable Energy, Industrial Technologies Program (U.S. DOE/EERE/ITP). 2009a. “Flambeau River Papers Makes a Comeback with a Revised Energy Strategy.” Available online at: <http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/case_study_flambeau.pdf>.

U.S. Department of Energy, U.S., Energy Information Administration (U.S. DOE/EIA). 2009b. *Manufacturing Energy Consumption Survey (MECS) 2006*. Available online at: <http://www.eia.gov/emeu/mecs/mecs2006/2006tables.html>.

U.S. Department of Energy, Energy Information Administration (U.S. DOE/EIA). 2010. "Form EIA-1605: Voluntary Reporting of Greenhouse Gases, Appendix N, Emission Factors for Steam and Chilled/Hot Water." Available online at: <http://www.eia.gov/oiaf/1605/pdf/Appendix%20N_20110128.pdf>.

U.S. Department of Energy, Energy Information Administration (U.S. DOE/EIA). 2012a. "Annual Energy Outlook 2012: with Projections to 2035." Available online at: <http://www.eia.gov/forecasts/archive/aeo12/sector_industrial.cfm>.

U.S. Department of Energy, Energy Information Administration (U.S. DOE/EIA). 2012b. "Annual Energy Review 2011." Available online at: <http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf>.

U.S. Department of Energy, Energy Information Administration (U.S. DOE/EIA). 2012c. "State Energy Data System." Available online at: <http://www.eia.gov/state/seds/seds-datacomplete.cfm#data>.

U.S. Department of Energy, Energy Information Administration (U.S. DOE/EIA). 2013a. "Manufacturing Energy Consumption Survey (MECS) 2010." Available online at: <http://www.eia.gov/consumption/manufacturing/data/2010/>.

U.S. Department of Energy, Energy Information Administration (U.S. DOE/EIA) 2013b. United States Natural Gas Industrial Price. Available online at: <http://www.eia.gov/dnav/ng/hist/n3035us3m.htm>.

U.S. Environmental Protection Agency (U.S. EPA). 2004. "Output-Based Regulations: A Handbook for Air Regulators." Available online at: <http://www.epa.gov/chp/documents/obr_final_9105.pdf>.

U.S. Environmental Protection Agency (U.S. EPA). 2007. "Energy Trends in Selected Manufacturing Sectors: Opportunities and Challenges for Environmentally Preferable Energy Outcomes." Available online at: <http://www.epa.gov/sectors/pdf/energy/report.pdf>.

U.S. Environmental Protection Agency, Combined Heat and Power Partnership (U.S. EPA/CHPP). 2009. "Energy Portfolio Standards and the Promotion of Combined Heat and Power." Available online at: <http://www.epa.gov/chp/documents/eps_and_promotion.pdf>.

U.S. Environmental Protection Agency (U.S. EPA). 2010. "Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from the Pulp and Paper Manufacturing Industry." Available online at: <http://www.epa.gov/nsr/ghgdocs/pulpandpaper.pdf>.

U.S. Environmental Protection Agency (U.S. EPA) 2011. Deferral for CO_2 Emissions from Bioenergy and Other Biogenic Sources under the Prevention of Significant Deterioration (PSD) and Title V Programs Summary of Public Comments and Responses. Available at: <http://www.epa.gov/nsr/documents/RTC_6-30_final_comb.pdf>.

U.S. Environmental Protection Agency (U.S. EPA). 2012a. "Boiler Emissions Database (version 8).mdb." (ICR database.) Available online at: <http://www.epa.gov/ttn/atw/boiler/boilerpg.html#TECH>.

U.S. Environmental Protection Agency (U.S. EPA). 2012b. "GHG Inventory tool." Available online at: <http://ghgdata.epa.gov/ghgp/main.do>.

U.S. Environmental Protection Agency (U.S. EPA). 2012c. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2010." Available online at: <http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2012-Main-Text.pdf>.

U.S. Environmental Protection Agency (U.S. EPA). 2012d. "Toxic Release Inventory (TRI) Explorer tool." Available online at: <http://iaspub.epa.gov/triexplorer/tri_release.chemical>.

U.S. Global Change Research Program (USGCRP). 2013. *Third National Climate Assessment Report*. Available online at: <http://www.globalchange.gov/what-we-do/assessment/draft-report-information/public-review>.

Venugopal, S., A. Sauer, and K. Loughlin. 2011."How U.S. Federal Climate Policy Could Affect Chemicals' Credit Risk."Available online at: <http://www.wri.org/publication/how-us-federal-climate-policy-could-affect-chemicals-credit-risk>.

Wisconsin Focus on Energy (WFoE). 2005. "Pulp and Paper Energy Best Practice Guidebook." Available online at: <http://www.focusonenergy.com/files/Document_Management_System/Business_Programs/pulpandpaper_guidebook.pdf>.

Worrell, E., L. Price., and N. Martin. 1999. "Energy Efficiency and Carbon Dioxide Emissions Reduction Opportunities in the US Iron and Steel Sector." Lawrence Berkley National Laboratory (LBNL). Available online at: <http://ies.lbl.gov/iespubs/41724.pdf>.

Xu, T.F., J. Sathaye, and K.J. Kramer. 2012. "Bottom-up Representation of Industrial Energy Efficiency Technologies in Integrated Assessment Models for the U.S. Pulp and Paper Sector." Lawrence Berkley National Laboratory (LBNL) Report 5801E.

Xu, T.F., J. Sathaye, and K.J. Kramer. 2013 (in press). "Sustainability Options in Pulp and Paper Making: Costs of Conserved Energy and Carbon Reduction in the U.S." In *Sustainable Cities and Society* Available at: <DOI: 10.1016/j.scs.2013.01.006>.

ENDNOTES

1. The almanac is available online at: <http://www.wri.org/project/midwest-almanac#about>.

2. See, for example: <http://insights.wri.org/news/2012/08/white-houses-industrial-energy-efficiency-plan-will-boost-manufacturing-curb-emissions>.

3. To view the bill in its entirety, see: <http://www.gpo.gov/fdsys/pkg/BILLS-112s1000is/pdf/BILLS-112s1000is.pdf>.

4. The scope of paper trade is here defined by international Harmonized System code 48 (paper, paperboard).

5. Fisher International is a private pulp and paper consulting company that collected the facility-level data used in this report's energy efficiency benchmarking analysis. For more information, see: <http://www.fisheri.com/>.

6. Fifteen states (AL, AR, FL, GA, KY, LA, MD, MS, NC, OK, SC, TN, TX, VA, and WV) comprise the South U.S. Census region.

7. In this case, energy intensity is defined as total energy consumed per unit of value-added.

8. Electricity intensity was determined by dividing the sum of the quantity of electricity purchased for heat and power and generated electricity by the value added (U.S. Census Bureau 2013).

9. Wisconsin, Michigan, and Ohio were responsible for 47 percent, 22 percent, and 16 percent respectively of the total paper sector's toxin releases within the Midwest in 2010.

10. According to U.S. Census data (2005, the most recent available survey), the pulp and paper sector reported spending \$2.4 billion on capital expenditures and on the operations of pollution prevention equipment (see Table 1).Those expenditures combined accounted for more than 1.4 percent of the sector's total value of shipments in that year (\$163 billion)—a greater portion than other sectors. For data, see: U.S. Census Bureau 2008 at: <http://www.census.gov/prod/2008pubs/ma200-05.pdf>.

11. According to the National Renewable Energy Laboratory (NREL), rising energy costs and other challenges caused 232 pulp and paper mills to close between the year 2000 and 2009, resulting in more than 180,000 workers losing their jobs.

12. Note that for kraft mills more steam energy may be used in the evaporator area.

13. The intensity analysis in this report focuses on purchased energy rather than total energy. Data for purchased energy are clearly defined, widely available, and can be inputted into the ENERGY STAR EPI tool used in this report. Other analysis based on total energy use (including non-purchased combustion of wood byproducts) yields differing results.

14. EPI tools are publicly distributed online. A copy of the integrated pulp and paper mill EPI tool can be downloaded at <http://www.energystar.gov/ia/business/industry/downloads/Integrated_Paper_Mill_EPI_v1.xls?a763-30d2>.

15. This analysis is based on mill-level purchased energy use and production as noted. Correspondence with AF&PA and the National Council for Air and Stream Improvement (NCASI) indicates that other analysis may show Midwest mills to be comparable or in some cases more efficient than the U.S. average. Individual mills are encouraged to download the EPI tool to perform their own assessment.

16. The lack of facility-specific information regarding currently installed technologies prevents us from estimating the upfront investment costs that would be necessary for underperforming mills to achieve U.S. average or ENERGY STAR levels of performance. As a result, we are not able to estimate the net cost savings associated with achieving these benchmarks.

17. According to emissions data reported to the EPA registry (EPA 2012b) (http://www.epa.gov/ghgreporting/ghgdata/datasets.html), energy-related CO_2 emissions accounted for roughly 99 percent of U.S. pulp and paper sector greenhouse gas emissions (measured in terms of CO_2 equivalent over a 100-year time horizon). The remaining GHG emissions source categories are nitrous oxide and methane.

18. See: <http://www.ncasi.org/support/downloads/Detail.aspx?id=3>.

19. This difference is due to the high portion of electricity use among Minnesota mills, which drives up indirect CO_2 emissions. Over a longer time frame, decarbonization of the electricity system can substantially reduce pulp and paper mills indirect greenhouse gas emissions, particularly in states such as Minnesota with high electricity use.

20. Inclusion of biomass combustion would increase total Midwest pulp and paper mill CO_2 emissions by nearly 50 percent. EPA is in the process of developing biogenic accounting factors for calculating carbon emissions related to biomass combustion; see: <http://yosemite.epa.gov/sab/sabproduct.nsf/0/57B7A4F1987D7F7385257A87007977F6/$File/EPA-SAB-12-011-unsigned.pdf>.

21. See: <http://www.gpo.gov/fdsys/pkg/FR-2011-07-20/pdf/2011-17256.pdf>.

22. See: <http://dsireusa.org/incentives/incentive.cfm?Incentive_Code=MD05R>.

23. Depending on how biogenic emissions are counted, fuel switching from fossil fuels to biomass would further reduce paper sector emissions.

24. It should be noted that the Boiler MACT rules are designed to reduce hazardous air pollutants and not to address greenhouse gas emissions.

25. Xu,Sathaye, and Kramer (2012) present cost curves for saved energy and carbon reduction for the U.S. pulp and paper industry in 1994 and 2006. This report adapts the 2006 saved energy cost curve, which assumes a 30 percent discount rate.

26. These percentage savings estimates are based on national-level data reported in Xu, Sathaye, and Kramer (2012).

27. Energy and fuel prices fluctuate: average U.S. industrial natural gas prices varied from $3 to $7 per thousand cubic feet between 2010 and 2012. See: <http://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm>.

28. This is a simplified method to estimate cost-effective energy savings, as some measures will only be operated with a single type of energy (e.g., electricity).

29. See http://paperrecycles.org/stat_pages/recovery_rate.html for annual data.

30. American Forest & Paper Association, private communication, March 8, 2013.

31. A biorefinery is defined as a facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass.

32. For references, see case study descriptions in:<http://rrbconference.org/bestanden/downloads/322.pdf>.

33. U.S. Department of Energy, Integrated Biorefinery Platform. See: <http://www1.eere.energy.gov/biomass/integrated_biorefineries.html>.

34. Lindmark et al.(2011). The article also notes that fiscal and R&D policies for industry are most effective when coordinated with longer-term capital investment and structural cycles.

35. See: <http://eippcb.jrc.es/reference/BREF/ppm_bref_1201.pdf>.

36. See: <http://ec.europa.eu/clima/policies/roadmap/documentation_en.htm> and <http://www.cepi.org/node/12760>.

37. The AEO number includes industrial-owned generators not always classified as combined heat and power, such as standby generators (U.S. DOE 2012a). For reference, the CHP installation database estimates total U.S. pulp and paper CHP capacity at more than 12 GW.

38. See: <http://www.whitehouse.gov/the-press-office/2012/08/30/executive-order-accelerating-investment-industrial-energy-efficiency>.

39. See: <http://www1.eere.energy.gov/manufacturing/distributedenergy/boilermact.html>.

40. These are pulp and paper sector efficiency projects for which WRI was able to gather quantitative information; other recent sector projects may have achieved significant efficiency savings.

41. The information presented here updates case study information originally published by U.S. DOE (2009a). “Flambeau River Papers Makes a Comeback with a Revised Energy Strategy.” See: <http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/case_study_flambeau.pdf>.

42. Presentation provided by Randy Stoeckel, Flambeau River Papers Vice President of Operations (August 31, 2012).

43. Now known as the Advanced Manufacturing Office (AMO).

44. Presentation provided by Randy Stoeckel, Flambeau River Papers Vice President of Operations (August 31, 2012).

45. Presentation provided by Randy Stoeckel, Flambeau River Papers Vice President of Operations (August 31, 2012).

46. Flambeau River Papers. See: <http://flambeauriverpapers.com/environment/> (September 2012).

47. Presentation provided by Randy Stoeckel, Flambeau River Papers Vice President of Operations (August 31, 2012).

48. Presentation provided by Randy Stoeckel, Flambeau River Papers Vice President of Operations (August 31, 2012).

49. Presentation provided by Randy Stoeckel, Flambeau River Papers Vice President of Operations (August 31, 2012).

50. Bill Granzin, Flambeau River Papers Energy Manager, private correspondence, September 27, 2012.

51. U.S. DOE (2009a); Presentation provided by Randy Stoeckel, Flambeau River Papers Vice President of Operations (August 31, 2012). Other data sources suggest varying trends of FRP paper production from 2005–11.

52. Bill Granzin, Flambeau River Papers Energy Manager, private correspondence, September 27, 2012.

53. Presentation provided by Randy Stoeckel, Flambeau River Papers Vice President of Operations (August 31, 2012).

54. Presentation provided by Randy Stoeckel, Flambeau River Papers Vice President of Operations (August 31, 2012).

55. Presentation provided by Randy Stoeckel, Flambeau River Papers Vice President of Operations (August 31, 2012).

56. U.S. DOE (2009a). Per correspondence with the Wisconsin Economic Development Corporation, loans between Flambeau River Papers, LLC and the Wisconsin Economic Development Corporation were current as of February 7, 2013.

57. Annual Manufacturers Survey, U.S. Paper Manufacturing number of paid employees, 2006 – 2009.

58. Correspondence with Randy Stoeckel (September 17, 2012). As part of its recovery, FRP attributes 8 percent of its recovered workforce to the reinstatement of its maintenance and electrical apprenticeship programs.

59. U.S. DOE (2009a); Presentation provided by Randy Stoeckel, Flambeau River Papers Vice President of Operations (August 31, 2012). Other data sources suggest varying trends of FRP paper production from 2005–11.

60. Information in this section is from public sources and written communication with Weyerhaeuser staff.

61. Percent reduced of water usage and waste sent to landfills was with respect to 2010 levels.

62. From direct and indirect emissions using a 2010 baseline.

63. From purchased energy.

64. See: <http://www1.eere.energy.gov/manufacturing/tech_deployment/betterplants/partners.html>.

65. See: <http://www1.eere.energy.gov/energymanagement/>

66. See: <http://www.whitehouse.gov/the-press-office/2012/08/30/executive-order-accelerating-investment-industrial-energy-efficiency> (September 2012); see also <http://insights.wri.org/news/2012/08/white-houses-industrial-energy-efficiency-plan-will-boost-manufacturing-curb-emissions>.

67. For more information, see: <http://www.epa.gov/climatechange/endangerment/>.

68. For information on U.S. CHP capacity, see: <http://insights.wri.org/news/2012/08/white-houses-industrial-energy-efficiency-plan-will-boost-manufacturing-curb-emissions>.

69. Earlier in the year the Council of Development Finance Agencies (CDFA) proposed the American Manufacturing Bond Finance Act to facilitate energy efficiency investment. Although Congress has not adopted the American Manufacturing Bond Finance Act, the economic and energy impacts of energy efficiency investment were specifically highlighted as topics to be covered in the American Energy Manufacturing Technical Corrections Act (H.R. 6582) study.

70. Previous analysis indicates that permitting requirements are not expected to yield significant GHG emissions reductions beyond business-as-usual projections (Litz et al. 2010).

71. See: <http://epa.gov/carbonpollutionstandard/pdfs/20120327proposal.pdf>.

72. The most recently published version of EPA's Boiler MACT rule would promote energy efficiency through a number of provisions, including alternative output-based emissions limits, facility energy assessments and annual boiler tune-ups, and compliance credit for efficiency measures implemented across the facility to reduce energy demand met by boilers.

73. U.S. EPA (2012a). See: <http://www.epa.gov/ttn/atw/boiler/boilerpg.html#TECH>. Previous analysis indicates that permitting requirements are not expected to yield significant GHG emissions reductions beyond business-as-usual projections (Litz et al., 2010). Among U.S. major source facilities, 86 percent of boilers are used for industrial activity, compared to 8 percemt for institutional and 6 percent for commercial enterprises. EPA ICR database- "Boiler Emissions Database (version 8).mdb" (U.S. EPA 2012a).

74. The EPA ICR database is a consistent and publicly available data source; however, it is continuously updated and subject to revision. In his January 2013 presentation, John Cuttica indicated that there were fifty-five paper sector coal and oil-fired boilers in the Midwest that would be affected by Boiler MACT. See: <http://www.midwestcleanenergy.org/events/PDF/MEEA_Cuttica2013Jan30.pdf>.

75. Among the nine paper-producing states of the Midwest, three states (Illinois, Ohio, and Wisconsin) have established utility public benefit funds whereby funding collected by utilities is transferred to a central or statewide entity that administers energy efficiency programs. See: <http://www.dsireusa.org/summarytables/rrpee.cfm>.

76. The Ohio Pilot Program will facilitate cost-effective compliance with Boiler MACT standards by providing site-specific technical and cost information to affected facilities, and by assisting interested facilities in CHP implementation.< http://www1.eere.energy.gov/manufacturing/distributedenergy/boilermact.html> (September, 2012).

77. See: <http://www.focusonenergy.com/> (September 2012).

78. This taxonomy is developed by Tanaka (2011).

79. Ericsson et al. (2010). While a carbon tax would apply to actual emissions, tax rebates could work in a way that is similar to allowance allocations.

80. Australia Prime Minister's Taskforce on Manufacturing. 2012.

81. For U.S. total 2011 GHG emissions by sector (with electricity-related emissions allocated by end use), see U.S. EPA (2013) pp. 2–23, Table 2-14 (http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2013-Chapter-2-Trends.pdf).

82. These data do not include energy embodied in pulp mill inputs. While pulp and paper can be recycled a number of times and thereby reduce energy and materials requirements, increased recycling can have adverse impacts on sector employment levels.

83. CO_2 emissions from biomass combustion are considered additional information by the EPA. Although the CO_2 generated when biomass fuels are burned is considered "additional" in the EPA's GHG emissions inventory, this information is a valuable measurement due to the fact that many pulp and paper mills generate more than half of their energy needs from biomass fuels recovered from the industry's waste and process streams.

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