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AVAILABLE AND EMERGING TECHNOLOGIES FOR REDUCING GREENHOUSE GAS EMISSIONS FROM THE PULP AND PAPER MANUFACTURING INDUSTRY

Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from the Pulp and Paper Manufacturing Industry

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Acronyms and Abbreviations

AF&PA	American Forest and Paper Association
ANSI	American National Standards Institute
ASB	Aerated stabilization basin
ASD	Adjustable-speed drive
BACT	Best available control technology
BLO	Black liquor oxidation
BLS	Black liquor solids
Btu	British thermal unit(s)
Ca	Calcium
$Ca(OH)_2$	Calcium hydroxide
$CaCO_3$	Calcium carbonate
$CaCO_3MgCO_3$	Dolomite
CaO	Calcium oxide (lime)
CH_4	Methane
CHP	Combined heat and power
CIPEC	Canadian Industry Program for Energy Conservation
ClO_2	Chlorine dioxide
CMP	Chemi-mechanical pulping
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2e	CO_2 equivalent
DCE	Direct contact evaporator
DIP	De-inked pulp
DOC	Degradable organic carbon
DOE	U.S. Department of Energy
E/T	Electric-to-thermal
EnMS	Energy Management Systems
EPA	U.S. Environmental Protection Agency
EPI	Plant Energy Performance Indicator(s)
ESP	Electrostatic precipitator
FGD	Flue gas desulfurization
gal	Gallon(s)
GHG	Greenhouse gas
GWh	Gigawatt-hour(s)
H_2SO_3	Sulfurous acid
HAP	Hazardous air pollutant
HHV	Higher heating value
hp	Horsepower
hr	Hour(s)
HRSG	Heat recovery steam generator
HSO_3^-	Bisulfite
ICFPA	International Council of Forest and Paper Associations
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
kg	Kilogram(s)

kW	Kilowatt(s)
kWe	Killowatt(s)-electric
kWh	Kilowatt-hour(s)
lb	Pound(s)
MC-ASD	Magnetically-coupled adjustable-speed drive
MEE	Multiple-effect evaporator
Mg	Magnesium
min	Minute(s)
MMBtu	Million Btu
MRR	GHG Mandatory Reporting Rule
MSW	Municipal solid waste
$mtCO_2e$	Metric tonne(s) of CO_2 equivalents
MW	Megawatt(s)
MWe	Megawatt(s)-electric
MWh	Megawatt-hour(s)
N_2O	Nitrous oxide
Na	Sodium
Na_2CO_3	Sodium carbonate
Na_2S	Sodium sulfide
Na_2SO_4	Sodium sulfate
NaOH	Sodium hydroxide
NCASI	National Council for Air and Stream Improvement
NCG	Non-condensable gases
NDCE	Nondirect contact evaporator
NESHAP	National emissions standards for hazardous air pollutants
NH_3	Ammonia
NO_X	Nitrogen oxides
NSSC	Neutral sulfite semi-chemical
PCC	Precipitated calcium carbonate
PM	Particulate matter
PRV	Pressure reduction valve
PSD	Prevention of significant deterioration
RCO	Regenerative catalytic oxidizer
RMP	Refiner mechanical pulping
rpm	Revolution(s) per minute
RTOs	Regenerative thermal oxidizer
RTS	Residence time-temperature-speed
SDT	Smelt dissolving tank
SO_2	Sulfur dioxide
SOG	Stripper off gas
STIG	Steam injected gas
TBtu	Trillion Btu
TMP	Thermo-mechanical pulping
TRS	Total reduced sulfur
VOC	Volatile organic compound
WBCSD	World Business Council for Sustainable Development

WRI	World Resources Institute
WWTP	Wastewater treatment plant
yr	Year(s)

I. Introduction

This document is one of several white papers that summarize readily available information on control techniques and measures to mitigate greenhouse gas (GHG) emissions from specific industrial sectors. These white papers are solely intended to provide basic information on GHG control technologies and reduction measures in order to assist States and local air pollution control agencies, tribal authorities, and regulated entities in implementing technologies or measures to reduce GHGs under the Clean Air Act, particularly in permitting under the prevention of significant deterioration (PSD) program and the assessment of best available control technology (BACT). These white papers do not set policy, standards or otherwise establish any binding requirements; such requirements are contained in the applicable EPA regulations and approved state implementation plans.

II. Purpose of this Document

This document provides information on control techniques and measures that are available to mitigate greenhouse gas (GHG) emissions from the pulp and paper manufacturing industry at this time. Because the primary GHG emitted by the pulp and paper manufacturing industry include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), and the control technologies and measures presented here focus on these pollutants. While a large number of available technologies are discussed here, this paper does not necessarily represent all potentially available technologies or measures that that may be considered for any given source for the purposes of reducing its GHG emissions. For example, controls that are applied to other industrial source categories with exhaust streams similar to the pulp and paper manufacturing sector may be available through “technology transfer” or new technologies may be developed for use in this sector.

The information presented in this document does not represent U.S. EPA endorsement of any particular control strategy. As such, it should not be construed as EPA approval of a particular control technology or measure, or of the emissions reductions that could be achieved by a particular unit or source under review.

A. Description of the Pulp and Paper Manufacturing Process

The manufacturing of paper or paperboard can be divided into six main process areas, which are discussed further in the sections below: (1) wood preparation; (2) pulping; (3) bleaching; (4) chemical recovery; (5) pulp drying (non-integrated mills only); and (6) papermaking. Figure 1 below presents a flow diagram of the pulp and paper manufacturing process. Some pulp and paper mills may also include converting operations (e.g., coating, box making, etc.); however, these operations are usually performed at separate facilities.

There are an estimated 386 pulp and/or paper manufacturing facilities in the in the U.S., including:

- 120 mills that carry out chemical wood pulping (kraft, sulfite, soda, or semi-chemical),
- 47 mills that carry out mechanical, groundwood, secondary fiber, and non-wood pulping,

- 102 mills that perform bleaching, and
- 369 mills that manufacture paper or paperboard products. (EPA 2010b)

Some integrated pulp and paper mills perform multiple operations (e.g., chemical pulping, bleaching, and papermaking; pulping and unbleached papermaking; etc.). Non-integrated mills may perform either pulping (with or without bleaching), or papermaking (with or without bleaching).

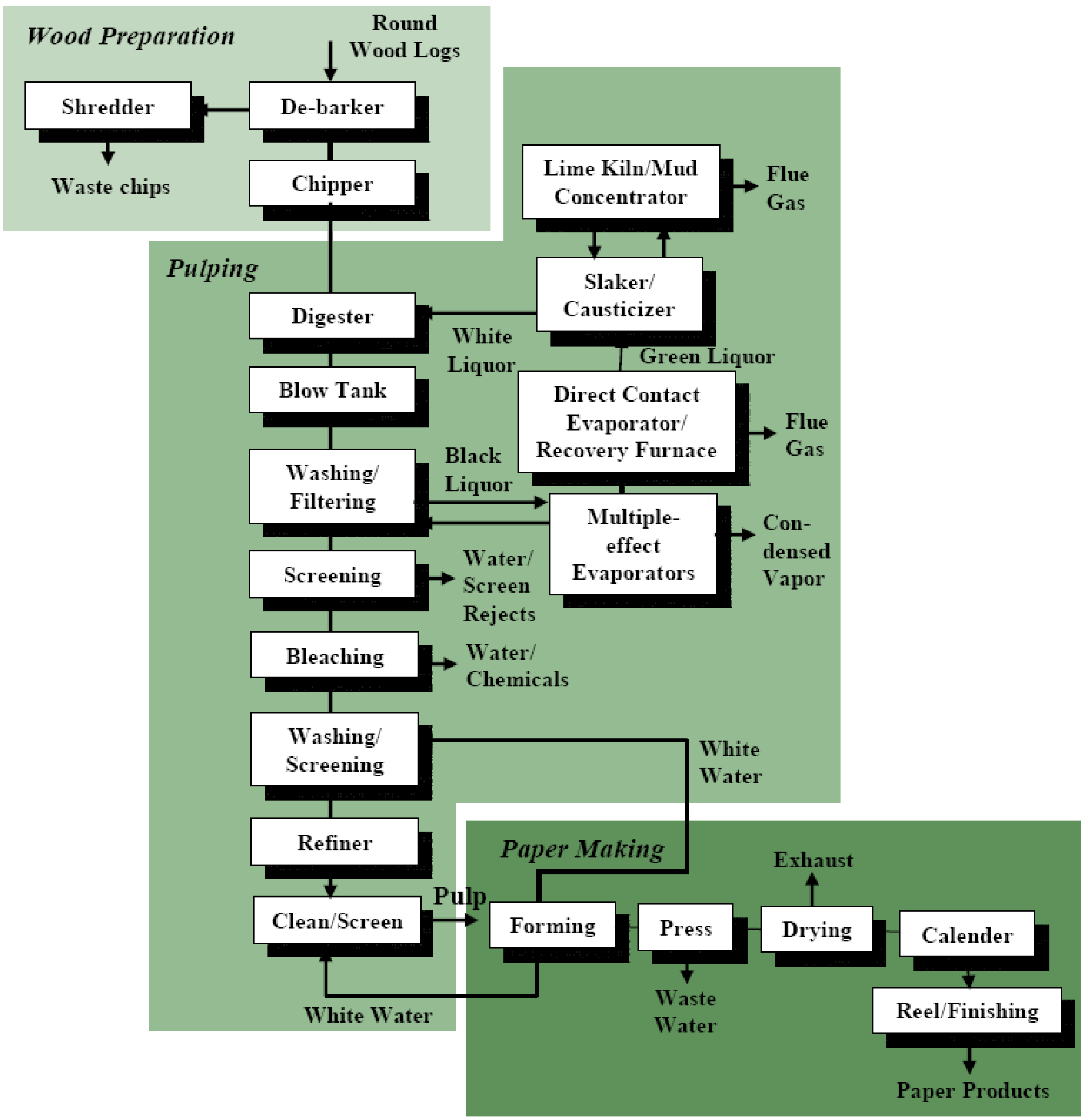

Figure 1. Flow Diagram of the Pulp and Paper Manufacturing Process (Staudt 2010)

1. Wood Preparation

Wood is the primary raw material used to manufacture pulp, although other raw materials can be used. Wood typically enters a pulp and paper mill as logs or chips and is processed in the wood preparation area, referred to as the woodyard. In general, woodyard operations are independent of the type of pulping process. If the wood enters the woodyard as logs, a series of operations converts the logs into a form suitable for pulping, usually wood chips. Logs are transported to the slasher, where they are cut into desired lengths, followed by debarking, chipping, chip screening, and conveyance to storage. The chips produced from logs or purchased chips are usually stored on-site in large storage piles. (EC/R 2005)

2. Pulping

During the pulping process, wood chips are separated into individual cellulose fibers by removing the lignin (the intercellular material that cements the cellulose fibers together) from the wood. There are five main types of pulping processes: (1) chemical; (2) mechanical; (3) semi-chemical; (4) recycle; and (5) other (e.g., dissolving, non-wood). Chemical pulping is the most common pulping process.

Chemical (i.e., kraft, soda, and sulfite) pulping involves “cooking” of raw materials (e.g., wood chips) using aqueous chemical solutions and elevated temperature and pressure to extract pulp fibers. Kraft pulping is by far the most common pulping process used by plants in the U.S. for virgin fiber, accounting for more than 80 percent of total U.S. pulp production.

The kraft pulping process uses an alkaline cooking liquor of sodium hydroxide (NaOH) and sodium sulfide (Na_2S) to digest the wood, while the similar soda process uses only NaOH. This cooking liquor (white liquor) is mixed with the wood chips in a reaction vessel (digester). After the wood chips have been “cooked,” the contents of the digester are discharged under pressure into a blow tank. As the mass of softened, cooked chips impacts on the tangential entry of the blow tank, the chips disintegrate into fibers or “pulp.” The pulp and spent cooking liquor (black liquor) are subsequently separated in a series of brown stock washers. (EPA 2001a, EPA 2008)

The cooking liquor in the sulfite pulping process is an acidic mixture of sulfurous acid (H_2SO_3) and bisulfite ion (HSO_3^-). In preparing sulfite cooking liquors, cooled sulfur dioxide (SO_2) gas is absorbed in water containing one of four chemical bases - magnesium (Mg), ammonia (NH_3), sodium (Na), or calcium (Ca). The sulfite pulping process uses the acid solution in the cooking liquor to degrade the lignin bonds between wood fibers. Sulfite pulps have less color than kraft pulps and can be bleached more easily, but are not as strong. The efficiency and effectiveness of the sulfite process is also dependent on the type of wood furnish and the absence of bark. For these reasons, the use of sulfite pulping has declined in comparison to kraft pulping over time. (EPA 2001a, EPA 2008)

In mechanical pulping (i.e., refiner mechanical pulping [RMP], thermo-mechanical pulping [TMP], chemi-mechanical pulping [CMP]), pulp fibers are separated from the raw materials (e.g., round wood, wood chips) by physical energy such as grinding or shredding, although some mechanical processes use thermal and/or chemical energy to pretreat raw materials. (EPA 2008)

Semi-chemical pulping uses a combination of chemical and mechanical (i.e., grinding) energy to extract pulp fibers. Wood chips first are partially softened in a digester with chemicals, steam, and heat. Once chips are softened, mechanical methods complete the pulping process. The pulp is washed after digestion to remove cooking liquor chemicals and organic compounds dissolved from the wood chips. This virgin pulp is then mixed with 20 to 35 percent recovered fiber (e.g., double-lined kraft clippings) or repulped secondary fiber (e.g., old corrugated containers) to enhance machinability. The chemical portion (e.g., cooking liquors, process equipment) of the pulping process and pulp washing steps are very similar to kraft and sulfite processes. At currently operating mills, the chemical portion of the semi-chemical pulping process uses either a nonsulfur or neutral sulfite semi-chemical (NSSC) process. The nonsulfur process uses either sodium carbonate (Na_2CO_3) only or mixtures of Na_2CO_3 and NaOH for cooking the wood chips, while the NSSC process uses a sodium-based sulfite cooking liquor. (EPA 2001a, EPA 2008)

In the recycle (i.e., secondary fiber) pulping process, pulp fiber from previously manufactured products (e.g., cardboard, office paper) are recovered by hydration and agitation. Secondary fibers include any fibrous material that has undergone a manufacturing process and is being recycled as the raw material for another manufactured product. Secondary fibers have less strength and bonding potential than virgin fibers. The fibrous material is dropped into a large tank, or pulper, and mixed by a rotor. The pulper may contain either hot water or pulping chemicals to promote dissolution of the paper matrix. Debris and impurities are removed by "raggers" (wires that are circulated in the secondary fiber slurry so that debris accumulates on the wire) and "junkers" (bucket elevators that collect heavy debris pulled to the side of the pulper by centrifugal force). (EPA 2001b, EPA 2008)

Dissolving kraft and sulfite pulping processes are used to produce highly bleached and purified wood pulp suitable for conversion into products such as rayon, viscose, acetate, and cellophane. (EPA 2002)

Non-wood pulping is the production of pulp from fiber sources other than trees. Non-wood fibers used for papermaking include straws and grasses (e.g., flax, rice), bagasse (sugar cane), hemp, linen, ramie, kenaf, cotton, and leaf fibers. Pulping of these fibers may be performed by mechanical means at high temperatures or using a modified kraft or soda process. Non-wood fiber pulp production is not common in the U.S. (EPA 2001b)

3. Bleaching

The bleaching process removes color from the pulp (due to residual lignin) by adding chemicals to the pulp in varying combinations, depending on the end use of the product. The same bleaching processes can be used for any of the pulping process categories. The most common bleaching chemicals are chlorine, chlorine dioxide, hydrogen peroxide, oxygen, caustic, and sodium hypochlorite. Concerns over chlorinated compounds such as dioxins, furans, and chloroform have resulted in a shift away from the use of chlorinated compounds in the bleaching process. Bleaching chemicals are added to the pulp in stages in the bleaching towers. Spent bleaching chemicals are removed between each stage in the washers. Washer effluent is collected in the seal tanks and either re-used in other stages as wash water or sent to wastewater treatment. (EC/R 2005)

4. Chemical Recovery

For economic and environmental reasons, chemical and semi-chemical pulp mills employ chemical recovery processes to reclaim spent cooking chemicals from the pulping process. At kraft and soda pulp mills, spent cooking liquor, referred to as “weak black liquor,” from the brown stock washers is routed to the chemical recovery area at kraft and soda pulp mills. The chemical recovery process involves concentrating weak black liquor, combusting organic compounds, reducing inorganic compounds, and reconstituting the cooking liquor. The typical kraft chemical recovery process consists of the general steps described in the following paragraphs. (EPA 2001a, EPA 2008)

Black liquor concentration. Residual weak black liquor from the pulping process is a dilute solution (approximately 12 to 15 percent solids) of wood lignins, organic materials, oxidized inorganic compounds (sodium sulfate [Na_2SO_4], Na_2CO_3), and white liquor (Na_2S and NaOH). The weak black liquor is first directed through a series of multiple-effect evaporators (MEEs) to increase the solids content to about 50 percent to form “strong black liquor.” The strong black liquor from the MEE system is either oxidized in the black liquor oxidation (BLO) system if it is further concentrated in a direct contact evaporator (DCE) or routed directly to a nondirect contact evaporator (NDCE), also called a concentrator. Oxidation of the black liquor prior to evaporation in a DCE reduces emissions of odorous total reduced sulfur (TRS) compounds, which are stripped from the black liquor in the DCE when it contacts hot flue gases from the recovery furnace. The solids content of the black liquor following the final evaporator/ concentrator typically averages 65 to 68 percent. The soda chemical recovery process is similar to the kraft process, except that the soda process does not require BLO systems, since it is a nonsulfur process that does not result in TRS emissions.

Recovery furnace. The concentrated black liquor is then sprayed into the recovery furnace, where organic compounds are combusted, and the Na_2SO_4 is reduced to Na_2S. The black liquor burned in the recovery furnace has a high energy content (5,800 to 6,600 British thermal units per pound [Btu/lb] of dry solids), which is recovered as steam for process requirements, such as cooking wood chips, heating and evaporating black liquor, preheating combustion air, and drying the pulp or paper products. The process steam from the recovery furnace is often supplemented with fossil fuel-fired and/or wood-fired power boilers. Particulate matter (PM) (primarily Na_2SO_4) exiting the furnace with the hot flue gases is collected in an electrostatic precipitator (ESP) and added to the black liquor to be fired in the recovery furnace. Additional makeup Na_2SO_4, or “saltcake,” may also be added to the black liquor prior to firing. Molten inorganic salts, referred to as “smelt,” collect in a char bed at the bottom of the furnace. Smelt is drawn off and dissolved in weak wash water in the smelt dissolving tank (SDT) to form a solution of carbonate salts called "green liquor," which is primarily Na_2S and Na_2CO_3. Green liquor also contains insoluble unburned carbon and inorganic impurities, called dregs, which are removed in a series of clarification tanks.

Causticizing and calcining. Decanted green liquor is transferred to the causticizing area, where the Na_2CO_3 is converted to NaOH by the addition of lime (calcium oxide [CaO]). The green liquor is first transferred to a slaker tank, where CaO from the lime kiln reacts with water to form calcium hydroxide ($Ca(OH)_2$). From the slaker, liquor flows through a series of agitated tanks, referred to as causticizers, that allow the causticizing reaction to go to completion (i.e., $Ca(OH)_2$ reacts with Na_2CO_3 to form NaOH and calcium carbonate [$CaCO_3$]). The causticizing product is then routed to the white liquor clarifier, which removes $CaCO_3$ precipitate, referred to as "lime mud." The lime mud is washed in the mud washer to remove the last traces of sodium. The mud from the mud washer is then dried and calcined in a lime kiln to produce "reburned" lime, which is reintroduced to the slaker. The mud washer filtrate, known as weak wash, is used in the SDT to dissolve recovery furnace smelt. The white liquor (NaOH and Na_2S) from the clarifier is recycled to the digesters in the pulping area of the mill.

5. Pulp Drying/Papermaking

After pulping and bleaching, the pulp is processed into the stock used for papermaking. At non-integrated mills, market pulp is dried, baled, and then shipped off-site to paper mills. At integrated mills, the paper mill uses the pulp manufactured on-site. The processing of pulp at integrated mills includes pulp blending specific to the desired paper product desired, dispersion in water, beating and refining to add density and strength, and addition of any necessary wet additives (to create paper products with special properties or to facilitate the papermaking process). Wet additives include resins and waxes for water repellency; fillers such as clays, silicas, talc, inorganic/organic dyes for coloring; and certain inorganic chemicals (calcium sulfate, zinc sulfide, and titanium dioxide) for improved texture, print quality, opacity, and brightness. (EPA 2002)

The papermaking process is similar for all types of pulp. The pulp is taken from a storage chest, screened and refined (if necessary), and placed into a head box of the paper machine. From the head box, a slurry of pulp is created using water, usually recycled whitewater (drainage from wet pulp stock in pulping and papermaking operations). The pulp slurry is put through a paper machine and then passed through a press section, where the whitewater is drained and the sheet forming process is begun. The paper sheet is then put through a dryer and a series of booths for coating and drying. The finished product then goes through a calender (where the sheet is pressed to reduce thickness and smooth the surface) and is wound onto storage reels. (EPA 2001b, EPA 2002, EC/R 2005)

B. Pulp and Paper GHG Emission Sources

Greenhouse gas emissions from the pulp and paper source category are predominantly CO_2 with smaller amounts of CH_4 and N_2O. The GHG emissions associated with the pulp and paper mill operations can be attributed to: (1) the combustion of on-site fuels; and (2) nonenergy-related emission sources, such as by-product CO_2 emissions from the lime kiln chemical reactions and CH_4 emissions from wastewater treatment. These emissions are emitted directly from the pulp and paper plant site. In addition, indirect emissions of GHG are associated with the off-site generation of steam and electricity that are purchased by or transferred to the mill. Table 1 shows the relative magnitude of nationwide GHG emissions (in million metric tonnes of CO_2 equivalents per year [$mtCO_2e/yr$] and million short tons of CO_2 equivalents per year [ton CO_2e/yr) from stationary sources in the pulp and paper manufacturing sector.

Table 1. Nationwide GHG Emissions from the Pulp and Paper Manufacturing Industry

Emission Source	**Million metric tonnes of CO_2e per year**[1]	**Million short tons of CO_2e per year**
Direct Emissions		
Direct emissions associated with fuel combustion (excluding biomass CO_2)	57.7	63.6
Wastewater treatment plant CH_4 releases	0.4	0.4
Forest products industry landfills[2]	2.2	2.4
Use of carbonate make-up chemicals and flue gas desulfurization chemicals	0.39[3]	0.43[3]
Secondary pulp and paper manufacturing operations (i.e., converting primary products into final products)	2.5	2.8
Direct emissions of CO_2 from biomass fuel combustion (biogenic)[4]	*113*	*125*
Process-related CO_2 including CO_2 emitted from lime kilns (biogenic)[4]	*unavailable*[5]	*unavailable*[5]
Indirect Emissions		
Electricity purchases by pulp and paper mills	25.4	28
Electricity purchases by secondary manufacturing operations (i.e., converting primary products into final products)	8.9	9.8
Steam purchases	unavailable[5]	unavailable[5]

1. Except for make-up chemicals, nationwide $mtCO_2e/yr$ totals are from National Council for Air and Stream Improvement (NCASI) Special Report No. 08-05, *The Greenhouse Gas and Carbon Profile of the U.S. Forest Products Sector*, September 2008; the $mtCO_2e/yr$ values are representative of year 2004.
2. Total includes emissions from wood products industry landfills (but it is expected that pulp and paper landfills are the dominant portion of the total).
3. Nationwide $mtCO_2e/yr$ totals associated with carbonate makeup chemical use are from memorandum from Reid Miner, NCASI, to Becky Nicholson, RTI International, *Calculations Documenting the Greenhouse Gas Emissions from the Pulp and Paper Industry*, May 21, 2008; the $mtCO_2e/yr$ values are representative of years 1995 ($CaCO_3$) and 1999 (Na_2CO_3).
4. Historically, in voluntary GHG reporting, biogenic emissions at pulp and paper mills were considered "other emissions" and were not reported consistently across the industry. EPA's final GHG mandatory reporting rule (MRR) does require reporting of biogenic emissions (40 CFR Part 98).
5. Information on emissions of process-related CO_2 (including CO_2 emitted from lime kilns) and indirect emissions from steam purchases was not available in the literature reviewed. However, this information is required to be reported under subpart AA of EPA's final GHG MRR (40 CFR Part 98).

Secondary manufacturing facilities are not engaged in manufacturing primary pulp or paper products, but instead convert paper products into other products (e.g., paperboard into containers, coated/laminated papers). Some converting operations may operate small fossil fuel-fired package boilers. Direct and indirect emissions from secondary manufacturing operations are included in Table 1 above, along with emissions from primary manufacturing operations.

Table 2 lists the stationary direct GHG emission sources found in the pulp and paper manufacturing industry. GHG emissions associated with mobile sources and machinery are not discussed in this document. Almost all direct GHG emissions from pulp and paper manufacturing are the result of fuel combustion, and CO_2 emissions from stationary fuel combustion represent the majority of GHG emissions from pulp and paper millson-site

Mill projects might also involve indirect emissions of GHG associated with energy consumption by pulp and paper processing equipment, such as new or modified digesters, brownstock washers, bleach plant equipment, paper machines, and various other pulp and paper mill equipment. Emissions related to energy consumption depend on the type and source of the energy (e.g., electrical energy and/or process heat/steam generated on-site or from an outside source).

A number of tools are available to assist with estimating GHG emissions for the pulp and paper industry. Notably, EPA's GHG MRR (40 CFR part 98) contains equations and emission factors for stationary combustion (Subpart C), pulp and paper manufacturing (Subpart AA), industrial landfills (Subpart TT), and industrial wastewater treatment (Subpart II). The calculation procedures in the GHG MRR regulatory text are further described in technical support documents (TSDs) related to each subpart. These GHG MRR subparts and TSDs were compiled considering various GHG inventory and calculation protocols. Additional resources include the *2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories* available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html and industry-specific guidance for the pulp and paper sector entitled *Calculation Tools for Estimating Greenhouse Gas Emissions from Pulp and Paper Mills*, which was developed by the National Council for Air and Stream Improvement (NCASI) for the International Council of Forest and Paper Associations (ICFPA) and accepted by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) (available at http://www.ghgprotocol.org/calculation-tools/pulp-and-paper). It should be noted that these protocols use different emission factors for estimating GHG emissions and are broader in scope than the MRR (e.g., include mobile sources).

Table 2. Direct GHG Emission Sources at Pulp, Paper, and Paperboard Facilities

Emissions Source	Types of pulp and paper mills where emissions sources typically are located	Type of GHG emissions
Fossil fuel- and/or biomass-fired boilers	All types of pulp and paper mills	fossil CO_2, CH_4, N_2O biogenic CO_2, CH_4, N_2O
Thermal oxidizers and regenerative thermal oxidizers (RTOs)	Kraft pulp mills for NCG control and semi-chemical pulp mills (for combustion unit control)	fossil CO_2, CH_4, N_2O
Direct-fired dryers	Gas-fired dryers at some pulp and paper mills	fossil CO_2, CH_4, N_2O
Combustion turbines	All types of pulp and paper mills	fossil CO_2, CH_4, N_2O
Chemical recovery furnaces – kraft & soda	Kraft and soda pulp mills	fossil CO_2, CH_4, N_2O biogenic CO_2, CH_4, N_2O
Chemical recovery furnaces – sulfite	Sulfite pulp mills	fossil CO_2, CH_4, N_2O biogenic CO_2, CH_4, N_2O
Chemical recovery combustion units – stand-alone semi-chemical	Stand-alone semi-chemical pulp mills	fossil CO_2, CH_4, N_2O biogenic CO_2, CH_4, N_2O
Kraft and soda lime kilns	Kraft and soda pulp mills	fossil CO_2, CH_4, N_2O process biogenic CO_2
Makeup chemicals ($CaCO_3$, Na_2CO_3)	Kraft and soda pulp mills	process CO_2
Flue gas desulfurization systems	Mills that operate coal-fired boilers required to limit SO_2 emissions	process CO_2
Anaerobic wastewater treatment	Chemical pulp mills (kraft, mostly)	biogenic CO_2, CH_4
On-site landfills	All types of pulp and paper mills	biogenic CO_2, CH_4

C. Pulp and Paper Energy Use

The pulp and paper manufacturing process is highly energy intensive. Natural gas, fuel oil, biomass-based materials, purchased electricity, and coal are the major energy-related GHG emission sources for U.S. pulp and paper mills. When biomass-derived GHG emissions are not counted, the remaining four energy sources accounted for an estimated 80 percent or more of the industry's energy related GHG emissions in 2002. Thus, a primary option to reduce GHG emissions is to improve energy efficiency. In 2002, the pulp and paper manufacturing industry consumed over 2,200 trillion Btu (TBtu), which accounted for around 14 percent of all fuel consumed by the U.S. manufacturing sector. (Kramer 2009)

Two biomass by-products of the pulp and paper manufacturing process, black liquor and hog fuel (i.e., wood and bark), meet over half of the industry's annual energy requirements. The American Forest and Paper Association (AF&PA) estimates that biomass comprises 64 percent of total fuel use by AF&PA members' pulp and paper facilities. (AF&PA 2008) The use of these by-products as fuels significantly reduces the industry's dependence on purchased fossil fuels and electricity, with the added benefits of reduced raw material costs (i.e., avoided pulping chemical purchases) and reduced waste generation. Natural gas and coal comprise the majority of the remaining fuel used by the industry. (Kramer 2009) Incidental amounts of pulping vent gases and pulping by-products (tall oil and turpentine) are also used, as discussed further in Section II.B.

Steam is the largest end use of energy in the pulp and paper industry, with more than 1,026 TBtu used in 2002. The next largest end use of energy is electricity, with approximately 339 TBtu of electricity (purchased and self-generated) consumed in 2002. Therefore, energy efficiency initiatives that are targeted at reducing steam system losses and improving the efficiency of process steam-using equipment are likely to reduce energy use at pulp and paper mills. (Kramer 2009)

For many of the control techniques listed in this document, CO_2 emission reductions are not explicitly provided. Energy efficiency improvements lead to reduced fuel consumption or reduced electricity demand. Thus, where CO_2 emission reductions are not provided, these reductions can be calculated from the reduction of fuel usage at the boiler or other combustion device. In addition, emission reductions that result from reduced electricity usage can be calculated from the reduced amount of fuel consumed at the power plant (if fuel combustion rather than waste heat is used for this purpose).

II. Control Measures and Energy Efficiency Improvements for Direct GHG Emission Sources

The control measures and energy efficiency options that are currently available for pulp and paper mill processes are listed in Table 3 and discussed in further detail in the sections below.

Table 3. List of Control Measures and Energy Efficiency Options

Boilers	
Burner replacement	Boiler maintenance
Boiler process control	Condensate return
Reduction of flue gas quantities	Minimizing boiler blow down
Reduction of excess air	Blow down steam recovery
Improved boiler insulation	Flue gas heat recovery
Chemical Recovery Furnaces	
Boiler control measures and energy efficiency options (see above)	Recovery furnace deposition monitoring
Black liquor solids concentration	Quaternary air injection
Improved composite tubes for recovery furnaces	
Turbines	
Boiler/steam turbine CHP	Replacement of pressure reducing valves
Simple cycle gas turbine CHP	Steam injected gas turbines
Combined cycle CHP	Regular performance monitoring and maintenance
Natural-Gas Fired Dryers and Thermal Oxidizers	
Energy efficiency measures	Use of thermal oxidizers employing heat recovery (e.g., regenerative or recuperative thermal oxidizers)
Selection of technologies requiring less fuel consumption	Proper design and attention to monitoring and maintenance
Use of existing combustion processes (e.g., power boilers or lime kilns) over a separate thermal oxidizer	
Kraft and Soda Lime Kilns	
Piping of stack gas to adjacent PCC plant	Lime kiln modifications (e.g., high-efficiency filters, higher efficiency refractory insulation brick)
Lime kiln oxygen enrichment	Lime kiln ESP
Makeup Chemicals	
Practices to ensure good chemical recovery rates in the pulping and chemical recovery processes	Addition of Na and Ca in forms that do not contain carbon (e.g., Na_2SO_4, NaOH, CaO)
Flue Gas Desulfurization (FGD) Systems	
Use of sorbents other than carbonates	Use of lower-emitting FGD systems
Wastewater Treatment	
Use of mechanical clarifiers or aerobic biological treatment systems (instead of anaerobic treatment systems)	Minimization of potential for formation of anaerobic zones in wastewater treatment systems (e.g., through placement of aerators where practical)
On-site Landfills	
Dewatering and burning of wastewater treatment plant residuals in on-site boiler	Capture and control of landfill gas by burning it in on-site combustion device (e.g., boilers) for energy recovery and solid waste management

A. Power Boilers, Chemical Recovery Furnaces, and Turbines

The U.S. pulp and paper industry is the largest self-generator of electricity in the U.S. manufacturing sector, with pulp and paper mills using on-site power boilers to generate steam, electricity, and process heat needed for mill processes. Recovery furnaces and other types of chemical recovery combustion units—used at pulp mills primarily to recover pulping process chemicals—also produce steam, electricity, and process heat for the mill. The need to keep up with significant mill demands for process steam and electricity, the high annual operating hours, and the presence of on-site generated fuels (i.e., wood waste and black liquor) has made combined heat and power (CHP) systems an operationally and financially attractive option for many mills around the country.

Major industrial CHP "prime mover" technologies include steam turbines, gas turbines, reciprocating engines, and fuel cells. Of these, steam and gas turbines dominate in U.S. pulp and paper mill applications. Traditional boilers, recovery furnaces, and steam turbine systems are by far the most common, and account for nearly 70 percent of current installed CHP capacity at pulp and paper mills. Around half of these boiler-based systems are fired by on-site fuels (i.e., by black liquor and hog fuel), and the other half are fired by purchased fuels (i.e., by coal, natural gas, and other fuels). These systems generally produce much more steam than electricity and, as a result, do not typically generate enough electricity to meet a mill's total electricity demand.

CHP systems based on natural gas-fired combustion turbines account for around 30 percent of the total installed CHP capacity at pulp and paper mills. Roughly two-thirds of these turbine-based systems use combined cycles, which augment a primary gas turbine system with a secondary, steam-based turbine system for improved power generation. Combustion turbine systems produce more electricity per unit of heat than boiler and steam turbine systems, and can often meet a mill's total electricity demand. From a fuels perspective, around one-third of the current CHP capacity in the U.S. pulp and paper industry is fired by biomass-based energy sources.

1. Control Measures and Energy Efficiency Options for Boilers

Control technologies, energy efficiency measures, and fuel switching options for power boilers are presented in a separate related document of this series titled, *Available and Emerging Technologies for the Control of Greenhouse Gas Emissions from Industrial, Commercial, and Institutional Boilers*. Several energy efficiency measures for boilers presented in that document that could apply most effectively for boilers at pulp and paper mills were also reported in the document *Energy Efficiency Improvement and Cost Saving Opportunities for the Pulp and Paper Industry.* (Kramer 2009)[1] Those boiler energy efficiency measures are listed in Table 3 above and discussed further in the paragraphs below. The boiler energy efficiency measures presented below focus primarily on improved process control, reduced heat loss, and improved heat recovery. Additional energy efficiency measures related to stream distribution systems and

[1] Kramer 2009 provides example costs for various energy efficiency measures. However, it is noted that estimates of initial installation costs, annual operating costs, and total emissions reductions would be specific to the emission source and were not available for inclusion in this document.

reduced electrical consumption that can result in small incremental reductions in boiler demand are discussed in Section III of this document. It is expected that new state-of-the-art boiler designs would incorporate many of the energy efficiency measures discussed below.

Burner replacement. According to a study conducted for the U.S. Department of Energy (DOE), roughly half of the U.S. industrial boiler population (across all sectors) is over 40 years old. Replacing old burners with more efficient modern burners can lead to significant energy savings. Energy and cost savings vary widely based on the condition and efficiency of the burners being replaced. In one example from the pulp and paper industry, replacing circular oil burners with more efficient parallel throat burners with racer type atomizers had a payback period of approximately one year. The U.S. DOE estimates that upgrading burners to more efficient models or replacing worn burners can reduce the boiler fuel use of U.S. pulp and paper mills by around 2.4 percent, with a payback period of around 19 months. (Kramer 2009)

Boiler process control. Flue gas monitors maintain optimum flame temperature and monitor carbon monoxide (CO), oxygen, and smoke. The oxygen content of the exhaust gas is a combination of excess air (which is deliberately introduced to improve safety or reduce emissions) and air infiltration. By combining an oxygen monitor with an intake airflow monitor, it is possible to detect even small leaks. A small 1 percent air infiltration will result in 20 percent higher oxygen readings. A higher CO or smoke content in the exhaust gas is a sign that there is insufficient air to complete fuel burning. Using a combination of CO and oxygen readings, it is possible to optimize the fuel/air mixture for high flame temperature (and thus the best energy efficiency) and lower air pollutant emissions. (Kramer 2009)

Typically, this measure is financially attractive only for relatively large boilers (e.g., 250,000 pounds per hour [lb/hr] of steam), because smaller boilers often will not make up the initial capital cost as easily. Several case studies indicate that the average payback period for this measure is 1.7 years or less. (Kramer 2009)

One case study showed that installing a control system to measure, monitor, and control oxygen and CO levels on coal-fired boilers was estimated to save nearly $475,000 in annual energy costs; at an investment cost of $200,000, the payback period was less than six months. (Kramer 2009) Another estimate suggests capital costs around $0.031 per million Btu (MMBtu) (2008 dollars) for this measure, with a fuel savings of 2.8 percent. (Staudt 2010)

Reduction of flue gas quantities. Often, excessive flue gas results from leaks in the boiler and/or in the flue. These leaks can reduce the heat transferred to the steam and increase pumping requirements. However, such leaks are often easily repaired, saving 2 to 5 percent of the energy formerly used by the boiler. This measure differs from flue gas monitoring in that it consists of a periodic repair based on visual inspection. The savings from this measure and from flue gas monitoring are not cumulative, as they both address the same losses. (Kramer 2009)

Reduction of excess air. Boilers must be fired with excess air to ensure complete combustion and to reduce the presence of CO in the unburned fuel in exhaust gases. When too much excess air is used to burn fuel, energy is wasted because excessive heat is transferred to the air rather than to the steam. Air slightly in excess of the ideal stochiometric fuel-to-air ratio is required for safety and to reduce emissions of nitrogen oxides (NO_X); approximately 15 percent excess air (around 3 percent excess oxygen) is generally adequate. Most industrial boilers already operate at 15 percent excess air or lower; thus, this measure may not be widely applicable. However, if a boiler is using too much excess air, numerous industrial case studies indicate that the payback period for this measure is less than one year. (Kramer 2009)

Examples of improvements to reduce excess air include changing automatic oxygen control set points, periodic tuning of single set point control mechanisms, installing automatic flue gas monitoring and control, fixing broken baffles, and repairing air leaks into the boiler. The U.S. DOE estimates that U.S. pulp and paper plants could reduce boiler fuel use by around 2.3 percent through application of this measure (it was assumed that this measure would be feasible at around one-third of U.S. pulp and paper mills). The estimated average payback period for this measure was 5 months. (Kramer 2009)

One case study showed that combustion tuning of a combination fuel-fired boiler (typically green wood and bark) reduced flue gas oxygen concentrations from the 8 to 12 percent range to the 6 to 7 percent range. The savings in green wood was reported to be around $70,000 per year. Similar benefits were predicted for adjusting the boiler oxygen trim controls on another mill to lower the oxygen levels to between 2.5 and 3 percent; boiler efficiency improvements would save 15,500 MMBtu per year at an annual cost savings of around $118,000. (Kramer 2009)

Improved boiler insulation. New materials insulate better and have a lower heat capacity. Savings ranging from 6 to 26 percent can be achieved if this improved insulation is combined with improved heater circuit controls. This improved control is required to maintain the output temperature range of the old firebrick system. As a result of the ceramic fiber’s lower heat capacity, the output temperature is more vulnerable to temperature fluctuations in the heating elements. The shell losses of a well-maintained boiler should be less than 1 percent. (Kramer 2009)

Boiler maintenance. A simple maintenance program to ensure that all components of a boiler are operating at peak performance can result in substantial fuel savings (6.5 percent) with negligible capital cost investment. (Staudt 2010) In the absence of a good maintenance system, burners and condensate return systems can wear or get out of adjustment. These factors can end up costing a steam system up to 30 percent of initial efficiency over two to three years. On average, the energy savings associated with improved boiler maintenance are estimated at 10 percent. Improved maintenance may also reduce the emissions of criteria air pollutants. (Kramer 2009)

Fouling on the fire side of boiler tubes or scaling on the water side of boilers should also be controlled. Fouling and scaling are more of a problem with coal-fed boilers than natural gas- or oil-fed boilers. (Boilers that burn solid fuels like coal should be checked more often, as they have a higher fouling tendency than liquid fuel boilers do.) Tests reported by the Canadian Industry Program for Energy Conservation (CIPEC) show that a fire side soot layer of 0.03 inches (0.8 millimeters [mm]) reduces heat transfer by 9.5 percent, while a 0.18-inch (4.5-mm) soot layer reduces heat transfer by 69 percent. For water side scaling, 0.04 inches (1 mm) of buildup can increase fuel consumption by 2 percent. (Kramer 2009)

Condensate return. For indirect uses of steam, returning hot condensate to boilers for re-use saves energy and reduces the need for treated boiler feed water. Typically, fresh feed water must be treated to remove solids that might accumulate in the boiler; however, returning condensate to a boiler can substantially reduce the amount of purchased chemical required to accomplish this treatment. The fact that this measure can save substantial energy costs and purchased chemicals costs often makes building a return piping system attractive. The U.S. DOE estimates that this measure can lead to a 1.5 percent reduction in boiler fuel use at U.S. pulp and paper mills, at an average payback period of around 15 months. (Kramer 2009)

In a specific example, the U.S. DOE reports that a large specialty paper plant reduced its boiler makeup water rate from about 35 percent of total steam production to less than 20 percent by returning additional condensate; annual savings were around $300,000 (2004 dollars). (Kramer 2009) Another estimate, provided to the U.S. EPA, indicates a capital cost of $0.292/MMBtu (2008 dollars) and a fuel savings of 13.8 percent for this measure. (Staudt 2010)

Minimizing boiler blow down. Boiler blow down is important for maintaining proper steam system water properties and must be done periodically to minimize boiler deposit formation. However, excessive blow down will waste energy, as well as water and chemicals. The optimum blow down rate depends on a number of factors, including the type of boiler and its water treatment requirements, but typically ranges from 4 to 8 percent of the boiler feed water flow rate. Automatic blow down systems can be installed to optimize blow down rates. Case studies from the pulp and paper industry suggest that automatic blow down systems can have a payback period of just six months. (Kramer 2009)

The U.S. DOE estimates that around 20 percent of U.S. pulp and paper mills could improve blow down practices, which would lead to annual boiler fuel savings of around 1.1 percent. (Kramer 2009)

Blow down steam recovery. Boiler blow down is important for maintaining proper steam system water properties. However, blow down can result in significant thermal losses if the steam is not recovered for beneficial use. Blow down steam is typically low grade, but can be used for space heating and feed water preheating. In addition to energy savings, blow down steam recovery may reduce the potential for corrosion damage in steam system piping. Examples of blow down steam recovery in the pulp and paper industry suggest a payback period of around 12 to 18 months for this measure. (Kramer 2009)

The U.S. DOE estimates that the installation of continuous blow down heat recovery systems is feasible at around 20 percent of U.S. pulp and paper mills and would reduce boiler fuel use by around 1.2 percent. (Kramer 2009)

In one case study, an existing boiler blow down system was modified by installing a plate-and-tube heat exchanger and associated piping to recover energy from the mill's continuous blow downstream from the boiler blow down flash tank. The project resulted in annual energy savings of 14,000 MMBtu, with annual fuel cost savings of over $30,000 (2002 dollars). The period of payback for this project was about six months. In a second case study, a plant-wide assessment estimated that the pursuit of blow down heat recovery (as opposed to the current practice of venting blow down to atmosphere) could save the mill around $370,000 per year (2006 dollars). In a third case study, it was estimated that a significant amount of additional thermal energy could be recovered from the liquid blow down rejected from the flash vessel. If a second stage of blow down energy recovery were installed on the remaining boilers, additional blow down energy recovery savings of $100,000 per year were projected (2006 dollars). (Kramer 2009) Another estimate, provided to the U.S. EPA, indicates a capital cost of $0.061/MMBtu (2008 dollars) and fuel savings of 1.2 percent for this measure. (Staudt 2010)

Flue gas heat recovery. Heat recovery from flue gas is often the best opportunity for heat recovery in steam systems. Heat from flue gas can be used to preheat boiler feed water in an economizer. While this measure is fairly common in large boilers, there is often still room for more heat recovery. The limiting factor for flue gas heat recovery is that one must ensure that the economizer wall temperature does not drop below the dew point of acids contained in the flue gas (such as sulfuric acid in sulfur-containing fossil fuels). Traditionally, this has been done by keeping the flue gases exiting the economizer at a temperature significantly above the acid dew point. In fact, the economizer wall temperature is much more dependent on feed water temperature than on flue gas temperature because of the high heat transfer coefficient of water. As a result, it makes more sense to preheat feed water to close to the acid dew point before it enters the economizer. This approach allows the economizer to be designed so that exiting flue gas is just above the acid dew point. (Kramer 2009)

Typically, one percent of fuel use is saved for every 45°F reduction in exhaust gas temperature. A conventional economizer would result in savings of 2 to 4 percent, while a condensing economizer could result in energy savings of 5 to 8 percent. However, the use of condensing economizers is limited to boilers using clean fuels due to the risk of corrosion. (Kramer 2009)

The U.S. DOE estimates that the installation of boiler feedwater economizers is feasible at around 19 percent of U.S. pulp and paper mills and would reduce boiler fuel use by around 3.5 percent. (Kramer 2009) An estimate for flue gas heat recovery provided to the U.S. EPA indicates a capital cost of $0.054/MMBtu (2008 dollars) and 1.3 percent fuel savings. (Staudt 2010)

2. Control Measures and Energy Efficiency Options for Chemical Recovery Furnaces and Combustion Units

Concentrated spent pulping liquors generated as a byproduct of chemical pulping are burned in chemical recovery furnaces (or other types of chemical recovery combustion units) to produce steam for use in facility processes and to recover chemicals for re-use in the pulping process. Carbon dioxide emissions associated with combustion of spent pulping liquor (e.g., black liquor at kraft mills) in chemical recovery furnaces are biomass-derived CO_2 because the carbon originates from the wood or other cellulosic materials. The carbon in the spent pulping liquor exits the recovery furnace in two forms: (1) as CO_2 emissions from the recovery furnace stack, and (2) as carbonates in the smelt flowing from the bottom of the recovery furnace (which eventually makes its way to the lime kiln). (EPA 2009c)

Fuel switching is generally not an option of significance for recovery furnaces and other chemical recovery combustion units because spent pulping liquor comprises most of the heat input. Small amounts of supplemental fossil fuels (e.g., oil or natural gas) are also fired in the furnace, usually during startup or shutdown conditions. Therefore, chemical recovery furnaces are sources of both biogenic and fossil fuel-based CO_2 (which must be accounted for separately for the federal GHG reporting rule) as well as small amounts of CH_4 and N_2O. (EPA 2009c)

Many of the boiler control technologies and/or energy efficiency measures noted in the previous section for power boilers will also apply for chemical recovery furnaces and combustion units. Additional control technologies, energy efficiency measures, and fuel switching options for power boilers are presented in a separate related document entitled, *Available and Emerging Technologies for the Control of Greenhouse Gas Emissions from Industrial, Commercial, and Institutional Boilers*. Efficiency measures specific to recovery furnaces are summarized in the following sections.

<u>Black liquor solids concentration</u>. Black liquor concentrators are designed to increase the solids content of black liquor prior to combustion in a recovery furnace. Increased solids content means less water must be evaporated in the recovery furnace, which can increase the efficiency of steam generation substantially. There are two primary types in use today: submerged tube concentrators and falling film concentrators. (Kramer 2009)

In a submerged tube concentrator, black liquor is circulated in submerged tubes, where it is heated but not evaporated; the liquor is then flashed to the concentrator vapor space, causing evaporation. One study estimated that, for a 1,000 ton per day pulp mill, increasing the solids content in black liquor from 66 to 80 percent would lead to fuel savings of 30 MMBtu per hour (hr), or about $550,000. Capital costs of the high solids concentrator would include concentrator bodies, piping for liquor and steam supplies, and pumps. (Kramer 2009)

A tube-type falling film evaporator effect operates almost exactly the same way as a more traditional rising film effect, except that the black liquor flow is reversed. The falling film effect is more resistant to fouling because the liquor is flowing faster and the bubbles flow in the opposite direction of the liquor. This resistance to fouling allows the evaporator to produce black liquor with considerably higher solids content (up to 70 percent solids, rather than the traditional 50 percent), thus eliminating the need for a final concentrator. One study estimated a steam savings of 0.76 MMBtu per ton of pulp with this type of concentrator. (Kramer 2009)

According to another study, a 900 ton per day pulp and paper mill which installed a liquor concentrator increased its solids content from 73 to 80 percent and reduced annual energy usage by about 110,000 MMBtu. Cost savings for the mill were about $900,000 per year, with an estimated payback period of 4 years. (Kramer 2009)

<u>Improved composite tubes for recovery furnaces</u>. Recovery furnaces consist of tubes that circulate pressurized water to permit steam generation. These tubes are normally made out of carbon steel, but severe corrosion thinning and occasional tube failure has led to the research and development of more advanced tube alloys, including new weld overlay and co-extruded tubing alloys. Replacing carbon steel tubes in the recovery furnace with these composite alloy tubes allows the use of black liquor with higher dry solids content, which increases the thermal efficiency of the recovery furnace and decreases the number of furnace shutdowns. Improved composite tubes have been installed in more than 18 kraft recovery furnaces in the U.S., leading to a cumulative energy savings of 4.6 TBtu since their commercialization in 1996. (Kramer 2009)

Recovery furnace deposition monitoring. Better control of deposits on heat transfer surfaces in recovery furnaces can lead to higher operating efficiencies, reduced downtime (by avoiding plugging), and more predictable shutdown schedules. A handheld infrared inspection system is currently available that can provide early detection of defective fixtures (tube leaks or damaged soot blower) and slag formation, preventing impact damage and enabling cleaning before deposits harden. The system can reportedly provide clear images in highly particle-laden boiler interiors and enable inspection anywhere in the combustion chamber. As of 2005, 69 units were in use in the U.S., generating 1.4 TBtu in energy savings since their introduction in 2002 (energy savings are attributable to reduced soot blower steam use). (Kramer 2009)

Quaternary air injection. Most recovery furnaces in the U.S. have three stages of air injection but use the third stage in a limited fashion. Fully using the third stage and adding a fourth air injection port can reduce carry over and tube fouling, thereby reducing the frequency of recovery furnace washing, which will lead to energy savings, because boiler shutdowns and reheat can be reduced. One estimate indicated each boiler reheat cycle will consume around 10 MMBtu at a cost of around $50,000. Capital costs for this measure are estimated at $300,000 to $500,000. (Kramer 2009)

3. Energy Efficiency Associated with CHP Systems

The benefits of CHP are significant and well-documented. Pulp and paper mills benefit from improved power quality and reliability, greater energy cost stability, and, possibly, higher revenues from the export of excess electrical power to the grid. CHP systems are significantly more efficient than standard power plants, because they take advantage of waste heat that is usually lost in central power generating systems and also reduce electricity transmission losses. Thus, society also benefits from CHP in the form of reduced grid demand, reduced air pollution, and reduced GHG emissions.

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

Despite the benefits of CHP systems, and their widespread use in the U.S. pulp and paper industry (currently 225 of the 386 mills have some form of CHP system in place, representing approximately 12,000 megawatts (MW) of electric generating capacity (ICF 2010)), much potential for CHP remains. Examples of CHP technology include power boilers and chemical recovery furnaces (e.g., at kraft pulp mills). There are significant remaining opportunities to add CHP capacity, based on evaluation of steam requirements met by boilers and by CHP in the paper industry. In addition, there are opportunities to repower existing CHP plants, making them larger and more efficient. If natural gas is available, existing steam turbine CHP systems can be replaced by newer, more efficient combustion turbines; existing simple cycle combustion turbine

CHP systems can be converted to combined cycle operation by adding steam turbines for additional power.

There are a number of barriers that may account for this untapped potential. These barriers include high capital investment costs, the complexity of the CHP project development process, complexities in permitting, and knowledge barriers related to technology selection, operation, and performance characterization. However, there are a number of resources available to help U.S. pulp and paper mills overcome such barriers. For example, the U.S. EPA's Combined Heat and Power Partnership provides information on CHP technology basics, guidance for streamlining CHP projects, information on federal and state policies and incentives, CHP feasibility assessment tools, and a database of funding resources. The U.S. DOE's CHP Regional Application Centers provides educational assistance and project-specific support in eight different U.S. regions, including project development and screening tools; technical assistance and training; information regarding issues related to permitting, utilities, and siting; and case studies.

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

There are a variety of applications and configurations of CHP systems. As such, CHP systems represent a complex topic. In order to be concise, this section discusses only a few measures related to the efficient application of CHP to pulp and paper mills.

<u>Boiler/steam turbine CHP.</u> The most prevalent form of co-generation in the pulp and paper industry is based on steam turbine generators fed by a mill's power boilers and recovery furnaces. An estimated 199 mills currently employ steam turbine CHP, representing 8,400 MW of generating capacity (ICF 2010) fueled predominantly by black liquor recovery, coal, and wood waste. In these CHP systems, the boilers produce high-pressure steam that runs through back-pressure or extraction steam turbines to produce power and exhaust steam at lower pressure for process use. The electric-to-thermal (E/T) output ratio for this type of CHP system ranges from 0.05 to 0.15; that is, 5 to 15 percent of the energy output from a boiler/steam turbine CHP system is in the form of electricity, and the remaining 85 to 95 percent is steam.

<u>Simple cycle gas turbine CHP.</u> For increased power production, a combustion or gas turbine with a heat recovery steam generator (HRSG) can be used, with the existing boilers providing supplemental or back-up steam when the CHP system is not operating. Gas turbine CHP operating on gaseous fuels such as natural gas or landfill gas offer the advantages of reduced emissions, faster start-up times, low noise, and improved electrical generation efficiency at full loads. Twenty-six mills currently employ this type of CHP system, generating over 1,000 MW of power. Combustion turbine CHP may make economic sense at mills with high electric loads and access to moderately priced natural gas. This type of system has an E/T ratio of 0.45 to 1.05 (much more power is produced per pound of process steam compared to boiler/steam turbine CHP), with the higher E/T ratios coming from larger turbines with higher electric

generating efficiencies. Additional steam can be generated from this type of system through the use of duct burners in the HRSG. This additional steam is generated very efficiently (87 to 90 percent higher heating value [HHV]) because the turbine exhaust which provides the combustion air is effectively preheated to a high temperature level. This type of system is typically used where electric and thermal demands are high and either natural gas or distillate oil is already used for an existing boiler or fuel switching to a gas CHP system makes economic sense.

Combined cycle CHP. Additional power can be produced through the use of a combined cycle CHP system. In combined cycles, the pressure of the steam produced in the gas turbine HRSG is increased, and the steam is run through a back-pressure or extraction steam turbine, producing additional power before being used in the mill processes. Twenty-six mills currently employ this type of CHP system, generating 2,660 MW of power. (ICF 2010) Combined cycle systems can have E/T ratios of around 1.0 to 2.0 and are normally used by larger plants with very high power requirements. An important limitation of combined cycle systems is that part-load operation will reduce overall system efficiency. (Kramer 2009)

In 1999, one pulp and paper initiated a project to install a gas turbine combined cycle system. A key goal of the project was to ensure the financial viability of the mill in the face of sharply rising electricity prices. Prior to the project, the mill generated 20 MW of electrical power based on two boilers fired by hog fuel, sludge, and natural gas. On average, the mill purchased 84 MW of power. At a cost of $75 million, the mill installed a 92 MW gas-fired power plant consisting of two natural gas-fired turbines with HRSGs to provide steam for additional power and process applications. The system allowed the mill to increase the power output of its existing steam turbines, which led to a total generating capacity of 130 MW. The reported availability of the gas turbines was over 95 percent. The mill is now able to sell 20 to 25 MW of excess power on the wholesale market. (Kramer 2009)

Replacement of pressure reduction valves. In many existing paper mill steam systems, high-pressure steam produced by boilers is supplied to the plant steam header and reduced in pressure through a pressure reduction valve (PRV) before being used in the various mills' processes. A PRV does not recover the energy embodied in the pressure drop. However, this energy could be recovered in the form of mechanical or electrical power for beneficial use in a mill. For example, a mechanical steam drive turbine can be used in place of a PRV to replace an electric motor-based drive, such as the drive for boiler feed water pumps. (Kramer 2009)

To generate electrical power, a PRV could be replaced by a small back-pressure steam turbine. Several manufacturers produce and/or sell these turbine sets, such as Turbosteam (previously owned by Trigen) and Dresser-Rand. The potential for application will depend on mill-specific conditions; however, applications of this technology have been commercially demonstrated for various installations. The investments of a typical turbine set are estimated at $600 killowatt-electric (kWe), with operation and maintenance costs at $0.011 per kilowatt-hour (kWh). (Kramer 2009)

In an energy efficiency assessment of one facility, the installation of a steam turbine to replace a PRV was identified as a project that could save 3.1 gigawatt-hours (GWh) of electricity per year. Capital costs for the project were estimated at $604,034, and avoided first year energy expenses were estimated at $163,999. (Kramer 2009)

Steam injected gas (STIG) turbines. Steam injected gas (STIG) turbines are a variation of gas turbine CHP that boost power production and reduce NO_X emissions by injecting steam into the combustion chamber of the turbine. A reported advantage of a STIG turbine is that part-load performance deteriorates at a slower rate with reduced load compared to a combined cycle CHP system. In a combined cycle system, when gas turbine efficiency drops under partial loading, more waste heat is supplied to the steam turbine. While this increases steam turbine electrical output, the overall power efficiency of the combined cycle system is reduced. For mills that experience fluctuations in steam demand, a STIG turbine can improve electrical power generation during the periods of partial turbine loading. (Kramer 2009)

The size of a typical STIG turbine starts around 5 megawatts-electric (MWe), and is currently scaled up to sizes of 125 MW. STIG turbines have been installed at over 50 sites worldwide and are found in various industries and applications, especially in Japan and Europe. Energy savings and payback period will depend on the local circumstances (e.g. thermal demand patterns and power sales conditions). However, no pulp and paper industry case studies could be found. (Kramer 2009)

Performance and Maintenance. Like other critical mill processes, CHP systems require regular performance monitoring and maintenance to ensure that they are operating in the most energy efficient manner possible. (Kramer 2009)

The efficiency of the steam turbine is determined by the inlet steam pressure and temperature as well as the outlet pressure. The higher the ratio of the steam inlet pressure to the steam exit pressure and the higher the steam inlet temperature, the more power it will produce per unit of steam mass flow. As a result, plant operators should make sure that the steam inlet temperature and pressure are as close to the optimum values for a given turbine design as possible. For example, an 18°F decrease in steam inlet temperature will reduce the efficiency of the steam turbine by 1.1 percent. Additionally, operators should also monitor and maintain the outlet pressure of back-pressure turbines, as efficiency losses will occur if this pressure gets too high. Monitoring and maintaining proper feed water and steam chemistry are also critical for avoiding corrosion and erosion problems. (Kramer 2009)

A key variable governing the efficiency of gas turbines is the inlet air temperature. Power and efficiency are increased at low air inlet temperatures, whereas high inlet air temperatures lead to power and efficiency reductions. Power can be restored with inlet air cooling. Options to consider for cooling inlet air include refrigeration cooling (in which a compressor or absorption chiller cools inlet air via a heat exchanger and cooling fluid) and evaporative cooling (which uses a spray of water directly into the inlet air stream). Each cooling option has advantages and drawbacks, however, which should be explored to determine the feasibility of this measure on a site-specific basis. (Kramer 2009)

Gas turbines that operate on a cyclic basis, or above rated capacity for extended periods, will require greater maintenance compared to gas turbines that are steadily operated at the rated load. Reportedly, cycling every hour triples maintenance costs versus a turbine that operates for intervals of 1,000 hours or more. Thus, ensuring consistency in steam demand is also an important operating consideration. (Kramer 2009)

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

- vibration measurements to detect worn bearings, rotors, and damaged blade tips;
- inspection of auxiliaries such as lubricating-oil pumps, coolers, and oil strainers;
- inspection and verification of equipment alignment;
- checking safety devices such as the operation of overspeed controls;
- replacement of filter elements;
- inspection of steam piping supports to check for damage due to torque or vibration;
- for gas turbines, inspection of the combustion path for fuel nozzle cleanliness and wear, along with the integrity of other hot gas path components;
- for steam turbines, dislodging of water solid deposits by applying manual removal techniques, cracking the deposits by shutting the turbine off and allowing it to cool, and washing the turbine with water while it is running. (Kramer 2009)

B. Natural Gas-Fired Dryers and Thermal Oxidizers

Some pulp and paper mills may operate natural gas-fired equipment such as direct-fired dryers or thermal oxidizers. Although steam-heated dryers are more common in the pulp and paper industry, some mills may operate direct-fired dryers to reduce the moisture content of boiler fuel (e.g., wet bark or wastewater treatment residuals) or to dry pulp or paper. Thermal oxidizers or regenerative thermal oxidizers (RTOs) may be used to incinerate process vent gases such as pulp mill non-condensable gases (NCG) or stripper off gas (SOG) to control organic hazardous air pollutant (HAP) or TRS emissions. Semi-chemical pulp mills may also operate RTOs in order to comply with the organic HAP emission limit in the national emissions standards for hazardous air pollutants (NESHAP) for pulp and paper combustion sources.

In general, GHG emissions from fossil-fuel fired equipment can be calculated based on emissions factors and fuel use data (e.g., following the approach in subpart C of the GHG MRR for stationary combustion sources). The GHG emissions associated with combustion of NCG and SOG, and also burning of pulping by-products (e.g., tall oil and turpentine that are sometimes burned as fuel when no beneficial use is available), are biogenic since NCG, SOG, tall oil, and turpentine are derived from wood. The quantity of GHG emissions resulting from combustion NCG, SOG, tall oil, and turpentine is expected to be relatively small because of their infrequent use as fuel (e.g., in boilers and lime kilns) (e.g., less than 0.005 percent of the mill's total GHG emissions). (EPA 2009c)

Approaches for reducing GHG emissions from fossil fuel-fired equipment could include fuel switching or energy efficiency measures. In the case of natural gas-fired equipment, however, fuel switching to a lower carbon fuel is not an option because natural gas emits less CO_2 per amount of heat derived than other gaseous or liquid fuels commonly used in the pulp and paper industry (i.e., fuel oil). Selection of technologies requiring less fuel consumption is also a consideration.

At many pulp mills, pulping vent gases (NCG and SOG) are routed to power boilers and/or lime kilns for destruction. Thermal oxidizers may serve as primary controls (or back-up controls for times when the NCG or SOG stream must be diverted from the boiler or lime kiln). Use of existing combustion processes such as power boilers or lime kilns is preferable over use of a separate thermal oxidizer from both a fuel use and emissions reduction perspective (for GHG and other emissions, such as NO_X or SO_2, which may increase due to RTO use). Thermal oxidizers employing heat recovery (e.g., regenerative or recuperative thermal oxidizers) may also reduce fuel consumption. Catalytic oxidizers and regenerative catalytic oxidizers (RCOs) operate at lower temperatures than do thermal oxidizers or RTOs, but catalytic systems have found limited use in the pulping industry (due in part to the high sulfur content of pulp mill vent gases, which can blind or poison catalytic systems).

Combustion efficiencies of some natural gas-fired combustion devices (e.g., some types of gas-fired dryers) and emission control devices such as RCOs and RTOs can sometimes be relatively low compared to power boilers, allowing a portion of the fuel to exit the combustion device as CH_4 (in highly variable amounts). This condition may exist in combustion devices that operate with low burner temperatures, in situations where the burner is operated at heat input rates below or at the low end of its design operating range, due to catalyst problems, or in devices where the natural gas burners are damaged or poorly maintained. The auto-ignition temperature of natural gas is approximately 1000°F, with greater temperatures (e.g., over 1400°F in thermal systems) required to achieve consistent combustion efficiency. (ICFPA 2005) Such emissions of CH_4 can be mitigated though proper design, and attention to monitoring and maintenance of the combustion device (e.g., to ensure combustion temperatures are maintained and that valves are functioning properly).

C. Kraft and Soda Lime Kilns

Kraft (and soda) pulp mills use lime kilns to regenerate a portion of the chemical cooking solution. The function of the lime kiln is to oxidize lime mud ($CaCO_3$) to reburned lime (CaO), a process known as calcining. The CaO produced in the lime kiln is used in the causticizing reactions that take place in the green liquor slaker and causticizers to produce the NaOH used in the white liquor.

In the kraft (and soda) pulping and chemical recovery process, biomass carbon from the wood is dissolved and either emitted as biomass CO_2 from the recovery furnace or captured in Na_2CO_3 exiting in the smelt from the recovery furnace. In the process of converting the Na_2CO_3 into new pulping chemicals, this biomass carbon (i.e., the carbonate ion) is transferred to $CaCO_3$ in the causticizing process. In the lime kiln, the $CaCO_3$ is converted to CaO (i.e., lime material used in the chemical recovery process) and biomass CO_2 originating from the wood residuals contained in black liquor is released to the atmosphere. Figure 2 contains a simplified representation of the kraft pulping and chemical recovery process. (EPA 2009c, ICFPA 2005)

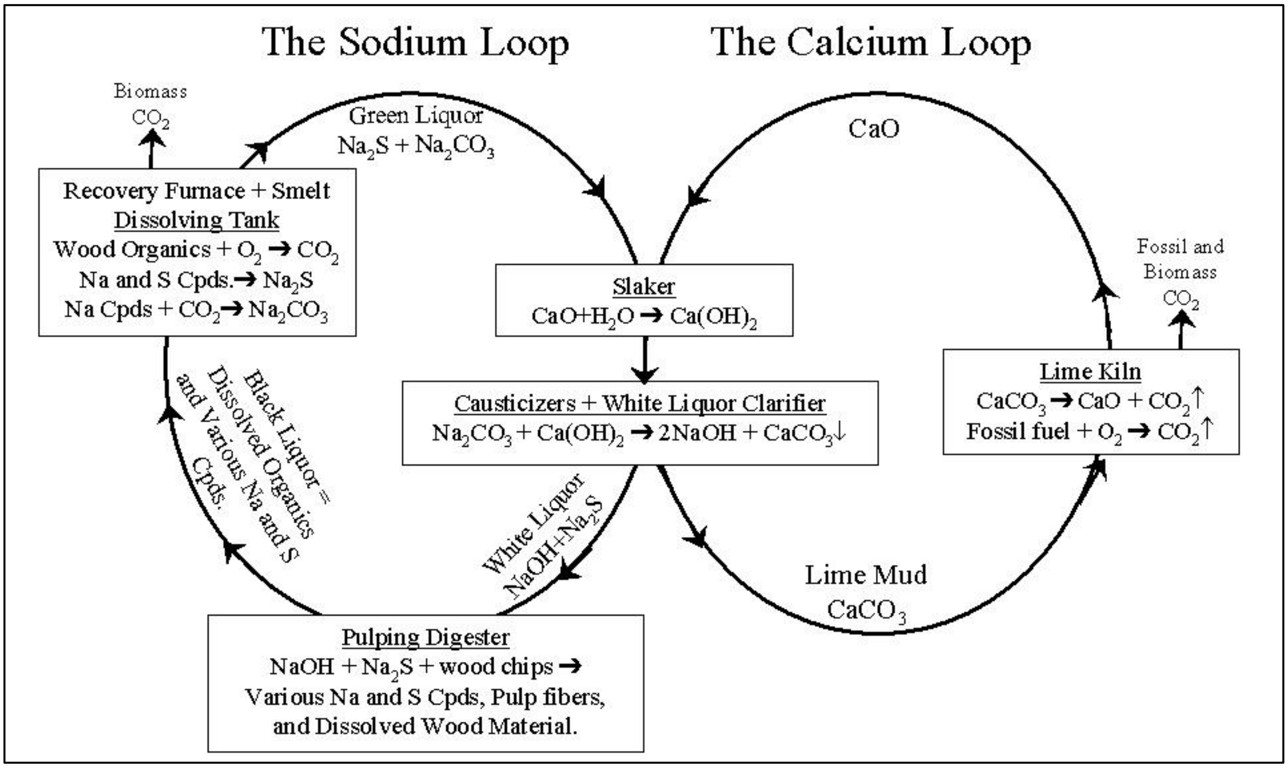

Figure 2. Simplified Representation of the Kraft Pulping and Chemical Recovery System

Unlike lime kilns used at lime production facilities, where CO_2 emissions are entirely fossil in nature, the CO_2 emitted from kraft mill lime kilns originates from two sources: (1) fossil fuels burned in the kiln, and (2) conversion of $CaCO_3$ (or “lime mud”) generated in the recovery process to CaO (lime). As shown above (in Figure 2), the calcium carbonate-derived CO_2 emissions almost exclusively originate from biomass. The lime kiln typically produces about 95 percent of the lime needed for the causticizing reaction. Either make-up lime or limestone is purchased to account for losses. (EPA 2009c)

Several pulp mills pipe stack gas from lime kilns or calciners to adjacent precipitated calcium carbonate (PCC) plants for use as a raw material. PCC is sometimes used as an inorganic filler or coating material in paper and paperboard products.

The EPA is presently unaware of control measures to reduce fossil-related GHG from pulp mill lime kilns other than energy efficiency measures. Some energy efficiency measures are described below.

Lime kiln oxygen enrichment. Oxygen enrichment is an established technology for increasing the efficiency of combustion and has been adopted in various forms by a number of industries with high-temperature combustion processes (e.g., glass manufacturing). According to one study, oxygen enrichment of lime kilns can reduce fuel requirements by around 7 to 12 percent. Reportedly, capital investments for oxygen enrichment are negligible compared to other recausticizing plant upgrades, requiring relatively simple equipment, including feed piping, an injection lance, and controls. Payback periods have been estimated between 1 and 3 years. (Kramer 2009, McCubbin 1996)

Lime kiln modification. Several other modifications are possible to reduce energy consumption in lime kilns. High-efficiency filters can be installed to reduce the water content of the kiln inputs, thereby reducing the required evaporative energy. Higher efficiency refractory insulation brick can be installed to reduce heat losses from the kiln. One estimate indicated that newer high-performance refractory can lead to lime kiln energy savings of up to 5 percent. Heat can also be recovered from the lime and from kiln exhaust gases to pre-heat incoming lime and combustion air. According to one estimate, the energy savings achievable from implementing all of these measures is around 0.47 MMBtu per ton of production. Such improvements may also improve the rate of recovery of lime from green liquor, thereby reducing a mill's requirement for additional purchased lime (Kramer 2009).

Lime kiln electrostatic precipitators. Electrostatic precipitators can replace wet scrubbers on lime kilns and lead to energy and water savings. Electrostatic precipitators can collect kiln dust as a dry material, and return it directly to the kiln feed without unnecessarily loading the lime mud filter. In contrast, wet scrubbers require effluent recycling via the lime mud filter and are significant consumers of water. One estimate indicated that, for every 1 percent reduction in lime mud feed moisture content (through the addition of dry dust), lime kiln energy consumption is reduced by around 46 MMBtu. Another analysis found that increasing mud dryness from 70 to 75 percent would reduce fuel consumption by 0.4 MMBtu per ton of lime. (Kramer 2009)

D. Makeup Chemicals

Makeup chemicals are a source of process-related CO_2 emissions at chemical pulp mills. Over time, small amounts of sodium and calcium are lost from the recovery cycle at kraft and soda facilities. Typically, lost sodium and calcium are replaced using make-up chemicals (e.g., Na_2SO_4, $CaCO_3$, Na_2CO_3) that are added into the recovery loop (e.g., with the spent pulping liquor). When carbonates ($CaCO_3$, Na_2CO_3) are added, the carbon in these make-up chemicals, which can be derived from biomass or mineral sources, is emitted as CO_2 from recovery furnaces and lime kilns. In cases where the carbon is mineral-based, emissions of CO_2 would contribute to GHG emissions. (EPA 2009c)

The EPA has not identified any specific control measures for minimizing emissions associated with makeup chemicals. Practices to ensure good chemical recovery rates in the pulping and chemical recovery process (e.g., at the recovery furnace) would minimize the need for carbonate makeup chemicals. The addition of sodium and calcium in forms that do not contain carbon, such as Na_2SO_4, NaOH, and CaO, would further minimize the need for carbonate makeup chemicals and is a practice employed at many mills. (NCASI 2008b) As of this writing, little data are available on the use and GHG emissions associated with makeup chemical use. However, EPA's GHG MRR will provide this information and may be useful for future benchmarking studies of makeup chemical use (and eventual determination of factors that contribute to reduction in makeup chemical needs).

E. Flue Gas Desulfurization Systems

Limestone ($CaCO_3$) and dolomite ($CaCO_3MgCO_3$) are basic raw materials used by a wide variety of industries, including as a sorbent in flue gas desulfurization (FGD) systems and fluidized bed boilers at electric utility and industrial plants. Wet limestone scrubbers are one type of FGD that use limestone/water slurries to absorb SO_2 from the flue gas. A chemical reaction between the SO_2 gas and crushed limestone releases CO_2 as a by-product. A few coal-fired boilers at pulp and paper mills incorporate such FGD systems. (ICFPA 2005) The EPA's GHG MRR for Stationary Combustion (Subpart C) contains an equation for calculating CO_2 emissions from sorbent use (for fluidized bed boilers that use sorbent injection and units equipped with flue gas desulfurization systems). (40 CFR Part 98, subpart C)

Methods for reducing SO_2 from coal-fired boilers include use of low-sulfur coal or a variety of FGD systems. Some types of FGD systems use sorbents other than carbonates, and, therefore, do not add CO_2 to the boiler stack emissions. The impact of different types of SO_2 controls on coal-fired electric generating unit CO_2 emissions is discussed in a separate document related to this one, *Available and Emerging Technologies for Control of Greenhouse Gas Emissions from Coal-Fired Electric Generating Units*.

F. Anaerobic Wastewater Treatment

The pulp and paper industry is among the largest industrial process water users in the U.S. Many pulp and paper mills operate wastewater treatment systems that can be a source of CH_4 emissions if operated under anaerobic conditions. Wastewater treatment also produces CO_2 that is considered to be biogenic. Emissions of N_2O from wastewater treatment are considered to be negligible. (ICFPA 2005)

The EPA's threshold analysis for the proposed GHG MRR suggested that less than about 3 percent of pulp and paper wastewater treatment systems would trigger the proposed 25,000 $mtCO_2e$ threshold (equivalent to 27,600 tons CO_2e), with only one system triggering a threshold of 100,000 $mtCO_2e$. (EPA 2009b)

NCASI studies have confirmed that mechanical clarifiers and aerobic biological treatment systems with high intensity mixing (such as activated sludge treatment systems) do not generate significant amounts of CH_4. Anaerobic treatment systems are known to generate CH_4, but there are very few biological treatment systems in the U.S. forest products industry designed for anaerobic decomposition of organic matter. There are, however, operations that can contain zones that become anaerobic, including aerated stabilization basins (ASBs), primary settling basins, and post-aeration basins. (NCASI 2008a) One way to minimize CH_4 emissions from such systems would be to minimize the potential for formation of anaerobic zones in the wastewater treatment system (e.g., though placement of aerators where practical).

Though uncommon in the pulp and paper industry, some industrial treatment systems are covered and designed for anaerobic wastewater treatment or digestion of sludge. The CH_4 released from these systems can be collected and burned.

G. On-site Landfills

Many pulp and paper mills use on-site landfills to dispose of wastewater treatment plant (WWTP) residuals, combustion ash residues, and other inorganic solid wastes (e.g., lime slaker grits, green liquor dregs from the causticizing process). According to NCASI 2008a, wastewater treatment residuals and ash constitute the vast majority of the solid residuals landfilled. Ash is essentially inert, so only WWTP residuals are considered to produce GHG emissions through degradation. NCASI and others have documented that residuals collected in primary treatment alone degrade in landfills very slowly or not at all, probably because of a lack of essential nutrients (particularly phosphorus and nitrogen) to support anaerobic biological activity. (NCASI 2008a)

After being placed in a landfill, waste is initially decomposed by aerobic bacteria. After the oxygen has been depleted, the remaining waste is available for consumption by anaerobic bacteria, which break down organic matter into substances such as cellulose, amino acids, and sugars. These substances are further broken down through fermentation into gases and short-chain organic compounds that form the substrates for the growth of methanogenic bacteria. These CH_4-producing anaerobic bacteria convert the fermentation products into stabilized organic materials and biogas. (EPA 2009a)

Methane generation from a given landfill is a function of several factors, including: (1) the total amount of waste disposed of in the landfill each year (annual waste acceptance rate); (2) the age of the landfill (or the total quantity of waste in-place); (3) the characteristics of the waste (i.e., composition and organic content of waste); and (4) the climatic conditions (temperature and soil moisture content – wet soils promote anaerobic degradation). The amount of CH_4 emitted is dependent on the amount of CH_4 generated less the amount of CH_4 that is recovered (and either flared or used for energy purposes) and the amount of CH_4 oxidized near the landfill surface prior to being released into the atmosphere. (EPA 2009a)

ICFPA 2005 includes a "screening" emission factor for CH_4 of 3,500 kilograms (kg) CO_2e/dry metric ton solid waste (3.86 tons CO_2e/dry short ton solid waste). This "screening" emission factor conservatively assumes that 50 percent of landfilled waste is degradable organic carbon, 50 percent of the degradable organic carbon degrades to gas, 50 percent of the carbon in the gas is contained in CH_4, none of the CH_4 is oxidized in the landfill cover or captured, and all is released in the same year that the waste is landfilled. More refined methods of estimating landfill CH_4 emissions will normally yield lower estimates of emissions. Subpart TT to EPA's GHG MRR (and the associated technical support document) contains the methods for calculating CH_4 emissions from industrial landfills, based on the quantity of waste disposed in the landfill, the fraction of degradable organic carbon (DOC) in the waste, the fraction of DOC dissimilated, the fraction by volume of CH_4 in the landfill gas, the decay rate of the waste, and the years when the waste was disposed and the emissions are calculated.

Control measures to reduce GHG emissions from pulp and paper landfills could include: (1) dewatering and burning the WWTP residuals in an on-site boiler, or (2) capture and control of landfill gas by burning it in an on-site combustion device. The practice of burning WWTP residuals in boilers for energy recovery and solid waste management has become more common in recent years, particularly as technologies for dewatering this material have advanced. Pulp and paper mill WWTP residuals are comprised predominantly of wood fiber, considered to be biomass material. Pulp mill WWTP residuals are usually co-fired fired in small amounts relative to other boiler fuels (e.g., less than 10 percent of boiler heat input).

Industrial waste landfills are not subject to federal standards. New source performance standards and emission guidelines require some municipal solid waste (MSW) landfills to capture and control landfill gas. Nevertheless, landfills could potentially be capped with low permeability cover material and the landfill gases collected and burned for their energy content. It is expected that landfill gas-to-energy projects would only be cost-effective for larger landfills in the pulp and paper industry. Cost data for landfill gas-to-energy projects at pulp and paper mills are unavailable because, as of this writing, we are unaware of any landfill gas collection systems installed at U.S. pulp and paper industry landfills.

III. Additional Energy Efficiency Improvements

This section discusses general energy efficiency measures that could be employed by energy-using equipment at pulp and paper mills (e.g., equipment that uses electricity, steam heat, or heat recovered from another process) other than processes that directly emit GHG. Examples of such equipment include raw material handling systems, digesters, stock washers, screens, evaporators, bleaching equipment, paper machines, and various other types of pulp and paper process equipment.

If the necessary process energy is generated at the mill site, the application of energy efficiency measures can reduce electrical or steam demand from on-site power boilers, combustion turbines, or recovery furnaces, resulting in a reduction in GHG emissions at the mill site. If the energy required by the process is not self-generated by the mill, then energy efficiency measures could result in a reduction of purchased electricity (or in some cases a reduction in purchased/imported steam), with a corresponding reduction in indirect GHG emissions at the off-site location where the energy is generated.

The energy efficiency measures presented in this document are summarized from an October 2009 ENERGY STAR® report, *Energy Efficiency Improvement and Cost Saving Opportunities for the Pulp and Paper Industry*, developed by Ernest Orlando Lawrence Berkeley National Laboratory (Kramer 2009). Please note that the energy efficiency measures discussed here are not universally applicable to all mills. Applicability of energy reducing measures depends on the pulping process, equipment configurations, desired product characteristics, or various other factors. Also, there are likely other energy efficiency measures not discussed here that individual mills might identify, which could be applied on a site-specific basis.

A. Energy Efficiency Improvements in Steam Systems

Steam is used in a number of important applications throughout the typical pulp and paper mill, but by far most significantly in the cooking, bleaching, evaporation, and drying processes. Over 80 percent of the energy consumed by the industry is in the form of boiler fuel. According to a recent study by the U.S. DOE, the U.S. pulp and paper industry could reduce its fuel use by 12.5 percent, and save 278 TBtu, by implementing best practice steam system improvement opportunities. Energy efficiency improvements to steam systems, therefore, represent the most significant opportunities for energy savings in pulp and paper mills. (Kramer 2009)

Two primary sources of steam in pulp and paper mill operations are recovery furnaces and power boilers. As discussed previously, recovery furnaces are fired with black liquor to recover pulping chemicals and produce steam for mill process heating applications, and often for co-generation of on-site electricity. Power boilers can be fired with multiple fuels and operate at high pressures for co-generation of both electrical power and steam. Whatever the use or the source of the steam, efficiency improvements in steam generation, distribution, and end-use are possible. (Kramer 2009)

Steam distribution systems are often quite extensive and can be major contributors to energy losses within a typical pulp and paper mill. Energy efficiency improvements to steam distribution systems are primarily focused on reducing heat losses throughout the system and recovering useful heat from the system wherever feasible. The following measures describe a number of key opportunities for saving energy in industrial steam distribution systems.

Steam distribution controls. Steam demand can be interrupted due to changing operating procedures at steam-using processes (e.g., paper machines or turbines), or due to operational failures (e.g., a sheet breakage). This can lead to the dumping of excess steam or additional fuel use for back-up boilers. Modern control systems have been deployed to better manage a steam system, reducing the need for back-up steam capacity or the need to dump steam. (Kramer 2009)

In one example, a second-generation control system was implemented for a steam system, which consisted of three paper machines, two natural gas-fired gas turbine-based CHP units, one steam turbine, and a steam accumulator. The system is a model-based predictive control system to manage steam loads better. The system resulted in a 95 percent reduction of steam venting and a 70 percent reduction in fuel use for back-up steam generation, with a payback period of less than 6 months. (Kramer 2009)

Improved insulation. Using more insulating material or using the best insulation material for the application can save energy in steam distribution systems. Crucial factors in choosing insulating material include low thermal conductivity, dimensional stability under temperature change, resistance to water absorption, and resistance to combustion. Other characteristics of insulating material may also be important depending on the application, such as tolerance of large temperature variations, tolerance of system vibrations, and adequate compressive strength where the insulation is load-bearing. (Kramer 2009)

Removable insulating pads are commonly used in industrial facilities for insulating flanges, valves, expansion joints exchangers, pumps, turbines, tanks and other surfaces. Insulating pads can be easily removed for periodic inspection or maintenance and replaced as needed. Insulating pads also contain built-in acoustical barriers to help control noise. Reported estimates indicate that the installation of removable insulation on valves, pipes, and fittings can reduce steam system energy use by 1 to 3 percent. (Kramer 2009)

Case studies from the U.S. pulp and paper industry indicate that the payback period for improved insulation is typically less than one year. At one mill, 1,500 feet of saturated steam lines to the dryer were not insulated, leading to significant losses of energy and process steam temperature and pressure. The addition of insulation reduced this heat loss and maintained the process temperature throughout the lines. In addition to adding insulation, the mill also replaced 70 steam traps, which resulted in a 10 percent increase in condensate return. Total energy savings amounted to about 63,000 MMBtu at a cost savings of over $138,000. With implementation costs of $69,280, the payback period was six months. (Kramer 2009)

At another mill, it was estimated that the repair of insulation could lead to annual energy savings of $80,000 at a repair cost of around $25,000. The payback period for insulation repair was around four months. (Kramer 2009)

Insulation maintenance. It is often found that after heat distribution systems have undergone some form of repair, the insulation is not replaced. In addition, some types of insulation can become brittle or rot over time. As a result, a regular inspection and maintenance system for insulation can also save energy. (Kramer 2009)

One estimate indicates that (as of 2002) roughly half of U.S. pulp and paper mills could significantly benefit from insulation improvements and installation and that these mills could reduce their boiler fuel use anywhere from 3 to 10 percent if such improvements were pursued. (Kramer 2009)

As part of an energy use and energy efficiency opportunities case study of 10 different pulp and paper mills in Illinois, it was shown that installing or improving insulation on pipes and valves could save (on average) over 3,600 MMBtu and over $12,000 per year. (Kramer 2009)

Steam trap improvement. Using modern thermostatic element steam traps can reduce energy use while also improving reliability. The main efficiency advantages offered by these traps are that they open when the temperature is very close to that of saturated steam (within 4°F or 2°C), purge non-condensable gases after each opening, and are open on startup to allow a fast steam system warm-up. These traps also have the advantage of being highly reliable and useable for a wide variety of steam pressures. (Kramer 2009)

A new steam trap design is the venturi orifice steam trap, which is better suited for varying loads than traditional mechanical steam traps. One mill in Europe changed 25 steam traps to the new type on a coating battery, which resulted in energy costs savings of nearly $200,000, with a payback period of 2.5 months. Other projects saved 11 percent on steam demand in preheater and end corrugator rolls (10 steam traps), and a 30 percent on a flute machine. (Kramer 2009)

Steam trap maintenance. A simple program of checking steam traps to ensure that they are operating properly can save significant amounts of energy for very little money. In the absence of a steam trap maintenance program, it is common to find up to 15 to 20 percent of steam traps malfunctioning in a steam distribution system. Annual failure rates are estimated at 10 percent or more. Energy savings for a regular system of steam trap checks and follow-up maintenance are conservatively estimated at 10 percent. Several industrial case studies suggest that investments for repair or replacement steam traps are very low, resulting in a payback period of only a few months or less. (Kramer 2009)

At one mill, opportunities were found for repairing failed steam traps that could save the mill about $31,000 in fuel use and about $3,900 in water use annually. The annual energy savings were estimated at 1,262 MMBtu of natural gas and 12,168 MMBtu of other fuels. The estimated costs to implement this measure were between roughly $7,400 and $12,400, which implies a payback period of well under a year. (Kramer 2009) Another estimate suggests a capital cost of $0.092/MMBtu (2008 dollars) to implement this measure, with a fuel savings of 9.2 percent. (Staudt 2010)

Steam trap monitoring. Attaching automated monitors to steam traps in conjunction with a maintenance program can save even more energy without significant added cost. This measure is an improvement over steam trap maintenance alone, because it gives quicker notice of steam trap failure and can detect when a steam trap is not performing at peak efficiency. Employing steam trap monitoring has been estimated to provide an additional 5 percent in energy savings compared to steam trap maintenance alone, at a payback period of around one year. Systems that are able to implement steam trap maintenance are also likely to be able to implement automatic monitoring. (Kramer 2009)

Leak repair. As with steam traps, steam distribution piping networks often have leaks that can go undetected without a program of regular inspection and maintenance. Reported estimates indicate that repairing leaks in U.S. pulp and paper mill steam distribution systems could lead to fuel savings of around 2 percent. Case studies of U.S. pulp and paper mills suggest a payback period for this measure of less than one year. (Kramer 2009)

One mill found opportunities for repairing steam leaks around paper machines that could result in annual fuel and water cost savings of about $20,000, with a payback period of around 1 to 1.5 years. (Kramer 2009) Another estimate indicates capital costs of $0.023/MMBtu (2008 dollars) to implement this measure, with a fuel savings of 2.8 percent. (Staudt 2010)

Flash steam recovery. When a steam trap purges condensate from a pressurized steam distribution system to ambient pressure, flash steam is produced. As with flash steam produced by boiler blow down, steam trap flash steam can be recovered and used for low-grade facility applications, such as space heating or feed water preheating. (Kramer 2009)

The potential for this measure is site-dependent, as its cost effectiveness depends on whether or not areas where low-grade heat is useful are located close to steam traps. Where feasible, this measure can be easy to implement and can save considerable energy. In an example from the food industry, an analysis of a U.S.-based food processing facility predicted that the installation of a flash steam recovery system used for feed water preheating would save the plant around $29,000 in fuel costs annually, at a payback period of less than 1.8 years. Based on the reduction in boiler fuel use, it was further estimated that the plant's carbon emissions would be reduced by 173 ton/yr. (Kramer 2009)

B. Energy Efficiency Improvements in Raw Material Preparation

1. Debarking

Cradle debarker. Using a cradle debarker over other debarking methods can reduce energy consumption by up to 33 percent. Cradle debarkers also inflict less damage to the logs. The U.S. DOE reported that a cradle debarker can reduce costs by $30/ton of wood. (Kramer 2009)

Use secondary heat in debarking. When logs need to be defrosted prior to debarking, waste heat from the plant can be used to replace steam. Recovering waste heat for this operation can save $150,000 (2001 dollars) in energy costs. Capital investments were estimated to be $110,000. (Kramer 2009)

2. Chip Handling, Screening, and Conditioning

Replace pneumatic chip conveyor with belt conveyor. Belt conveyors are typically more energy efficient than pneumatic conveyors. One study performed in 2001 indicated that a belt conveyor operating at 1 kWh/ton could replace an 18.2 kWh/ton pneumatic conveyor, resulting in a savings of 17,200 kWh/day, or $210,000/yr in electricity costs. However, the installation and maintenance costs of belt conveyors can be significant. (Kramer 2009)

Automatic chip handling and thickness screening. Automatic chip handling and thickness screening can reduce steam consumption in the digester and evaporator. Some studies suggest that digester yield can be increased by 5 to 10 percent, although this is somewhat offset by the raw material screened out. The return on investment may be 15 to 20 percent. (Kramer 2009)

Bar-type chip screens. Bar-type chip screens typically have lower energy consumption than other types of screens, even though capital costs are approximately the same. Energy savings were estimated to be 0.33 MMBtu/ton chemical pulp due to yield increases, and operating and maintenance costs were estimated to be reduced by $0.70/ton pulp (1998 dollars). (Kramer 2009)

Chip conditioning. Chip conditioners improve the delignification process. Energy savings from replacing chip slicers were estimated to be 0.19 MMBtu/ton chemical pulp, and savings from reduced operating and maintenance costs were estimated to be $0.40/ton chemical pulp (1998 dollars). (Kramer 2009)

C. Energy Efficiency Improvements in Chemical Pulping

1. Digesters (Chip Cooking)

Use of pulping aids. Chemical pulping aids added to the pulping process can increase pulp yields and reduce energy consumption. Viability of this measure will depend on the cost of the chemical pulping aids versus the fiber savings. A study of one pulping aid estimated that energy savings of 125,000 Btu/ton of processed wood chips may be realized. Other benefits include an increase in yield of 2 to 5 percent per ton of wood, reduced pulp rejects, reduced use of bleaching chemicals, and reduced sulfur-based emissions. Another study of a different pulping aid indicated an energy savings of 8 to 10 percent and yield increases of 4 to 6 percent. (Kramer 2009)

Continuous digester control systems. Control systems to optimize the digester can reduce production losses, operating costs, and environmental impacts while increasing paper quality and quantity. Initial implementation of one computer model resulted in a 1 percent energy savings for the pulping process. (Kramer 2009)

Batch digester modification. The use of indirect heating and cold blow can reduce energy consumption in batch digesters. Indirect heating involves withdrawing cooking liquor from the digester and pumping it through an external heat exchanger. Energy savings were estimated to be 3 MMBtu/ton, although maintaining the heat exchanger will increase overall maintenance costs. Cold blow systems displace hot spent pulping liquor from the digester using brownstock washer filtrate. Heat can be recovered from the spent liquor for heating subsequent cooks, which reduces steam consumption. One study estimated the energy savings to be $2 million/yr for a 1,000 ton/day mill. However, capital costs for this system can be high. (Kramer 2009)

Digester blow/flash heat recovery. Heat can be recovered from steam produced when the hot pulp and cooking liquor are reduced to atmospheric pressure at the end of the cooking cycle. For example, the black liquor that is flashed in stages from continuous digesters can be used in chip steaming. An audit at one facility showed that installing new heat exchangers and other piping improvements to improve blow heat recovery could save 940,000 MMBtu of fuel, 705,000 MMBtu of natural gas, and $2.35 million (2003 dollars) annually, with a payback period of about one year. At another mill, the addition of a digester heat recovery system was expected to reduce natural gas usage by 130,000 MMBtu/yr and save $280,000/yr. (Kramer 2009)

2. Pulp Washing

Optimize dilution factor. Organic solids and spent cooking chemicals can be washed from the pulp with brownstock, resulting in a higher level of chemical recovery, while minimizing dilution of black liquor. Optimizing the dilution factor control will lower the average amount of water that must be evaporated from weak black liquor, thereby reducing steam consumption in the evaporators. The dilution factor can be optimized by controlling shower water flow on the last washing stage to an optimum level that can be determined by considering the cost of steam, the cost of bleaching chemicals, the impact on effluent quality, and other process variables. At one plant, it was estimated that these improvements could reduce water usage by 200 gallons per minute (gal/min) and reduce natural gas usage by 310,000 MMBtu/yr, resulting in costs savings of $580,000/yr. (Kramer 2009)

Improved brownstock washing. Replacing conventional vacuum pressure units with pressure diffusion or wash presses for brownstock washing can reduce the electricity and steam consumption and reduce bleaching chemical usage. Estimated steam savings may be as much as 9,500 Btu/ton of production, and electricity savings may be about 12 kWh/ton of production. (Kramer 2009)

3. Bleaching

Heat recovery from bleach plant effluent. Heat exchangers can be used to recover the large amount of heat in the bleach plant effluent. An audit at one facility showed that the heat from the bleach plant effluent could be used to generate hot water for the paper machine. Energy savings were estimated to be 890,000 MMBtu/yr, with annual cost savings of $2.4 million (2003 dollars). After a capital investment of $1.6 million, the estimated payback period was 0.7 years. (Kramer 2009)

Chlorine dioxide (ClO_2) heat exchange. Although solutions of ClO_2 are normally chilled to maximize ClO_2 concentration, preheating the solution prior to entering the mixer will reduce steam demand in the bleach plant. An audit at one mill identified a way to preheat the solution that reduced costs by $61,000/yr (2003 dollars) for fuel, electricity, and steam savings. The capital costs were estimated to be $124,000 for a payback period of about two years. (Kramer 2009)

D. Energy Efficiency Improvements in Mechanical Pulping

1. Mechanical Pulping

Refiner improvements. Refiners are used in mechanical pulping to rub or grind the wood fibers apart. Several improvements are possible within the refiner section of a mill, which can reduce electricity consumption in mechanical pulping. For example, a newsprint mill implemented a refiner control strategy to minimize variations in the freeness of ultra-high-yield sulfite pulps and saved 51.3 kWh per ton of production due to reduced motor load. Another option in refining is the switch to conical refiners rather than disk refiners. By decreasing the consistency of pulping to about 30 percent from 50 percent, a 7 to 15 percent electricity savings may be possible in TMP and RMP processes. One study estimated an electricity savings potential of 11 percent due to such mechanical refining improvements, at a capital cost of around $7.7/ton (2000 dollars) of pulp production. (Kramer 2009)

Thermopulping. Thermopulping is a variation of the TMP process, whereby pulp from the primary stage refiner is subjected to a high-temperature treatment for a short time in a thermo-mixer and in the subsequent secondary refiner. The higher operating pressures in the secondary refiner reduce the volumetric flow of generated steam. Published estimates suggest that thermopulping can reduce specific energy consumption compared to TMP by up to 20 percent. (Kramer 2009)

Heat recovery in TMP. A vast amount of steam is produced as a by-product of thermo-mechanical pulping. This low-pressure steam is often contaminated, but most of the energy can be reclaimed for use in other mill processes through heat recovery equipment. Heat recovery options include: (1) mechanical vapor recompression for integrated mills, where the clean steam generated can be used in the paper machine dryer section, (2) direct-contact heat exchangers for generating hot water for use in paper machines and as boiler makeup water and clean process steam, (3) reboilers for producing clean process steam, and (4) other devices such as thermo vapor recompression and cyclotherm plus heat pump systems. One study estimated that typical heat recovery systems for pressurized refiners can generate 1.1 to 1.9 tons of clean steam at dryer can pressure per ton of pulp. Payback periods vary widely depending on capital costs, but can be as low as a few months. Average installation costs have been estimated to be $21/ton of pulp (2000 dollars), with significant increases in operations and maintenance costs. (Kramer 2009)

Pressurized groundwood. In a pressurized groundwood system, grinding takes place under compressed air pressure where water temperature is high (more than 95ºC), thereby allowing for higher grinding temperatures without steam flashing. The higher temperature promotes softening of the lignin, which improves fiber separation and reduces specific energy consumption. The technical literature claims around 20 to 36 percent saving in electricity compared with atmospheric mechanical pulping processes. (Kramer 2009)

2. Repulping of Market Pulp

Continuous repulping. The repulping process for purchased market pulp involves blending the dried pulp feedstock with water in a large tank to produce fibrous slurry. Typically this is done as a batch process, but converting to a continuous process can lead to energy savings due to improved process efficiency. One study estimated that energy savings of up to 40 percent are possible, in the form of reduced pulping motor power requirements. If the existing repulper can be retrofitted, capital costs are estimated around $100,000 (2006 dollars). (Kramer 2009)

Efficient repulping rotors. Newer repulper rotor designs have been optimized for power consumption. Reportedly, replacing an existing rotor with a new rotor that is optimized for efficiency can reduce rotor motor consumption by 10 to 30 percent. Payback periods for this measure have been estimated at 1 to 2 years. One mill installed and tested a new 500–horsepower (hp) high-efficiency repulper rotor. Reportedly, the high-efficiency rotor reduced repulping electricity consumption by 23 percent. Another mill tested a new high-capacity, aerodynamic, variable-speed pulping rotor. The new rotor reduced electricity consumption by more than 50 percent. Projected annual energy savings amounted to around 3.6 GWh, or about $193,000 in electricity costs (2006 dollars). (Kramer 2009)

3. Secondary (Recovered) Fiber Processing

Increased use of recycled pulp. Statistics from the AF&PA indicated that, in 2009, a record-high 63.4 percent of the paper used in the U.S. was recovered for recycling. (AF&PA 2010). The production of recycled pulps consumes, on average, significantly less energy than that required to produce mechanical or chemical wood pulps. One study estimates that costs for the construction of recycled pulp processing capacity in the U.S. is around $485 per ton of pulp; however, depending on the price of waste paper versus virgin pulp, this may result in up to $73.9 per ton of pulp in operations and maintenance cost savings. However, recycled pulp produces sludge that can present a disposal difficulty. (Kramer 2009) In addition, there are limitations to the amount of recycled fiber that can be used for a given product (e.g., due to the shorter fibers of the recycled pulp, difficulty achieving the same brightness as virgin fiber, etc.).

Drum pulpers. Drum pulpers are applicable to mills that generate pulp from recovered paper and paperboard products. The more gentle mechanical action of drum depulpers allows contaminants to remain intact while the paper is defibered. Drum pulpers have lower energy requirements than conventional mechanical pulpers, can use less water, and reduce fiber shortening. However, when drum pulpers are used in brown fiber applications, the rapid wetting of furnish and the incomplete removal of bailing wire can reportedly cause problems. One analysis suggested that replacing a vat type batch pulper with a continuous drum pulper in de-inking operations can reduce specific pulping energy by over 25 percent. (Kramer 2009)

Heat recovery from de-inking effluent. De-inking effluents are often discharged at elevated temperatures and represent a possible source of low-grade heat recovery. The installation of heat exchangers in the effluent circuit can recover some of this heat for other beneficial uses, such as facility water heating. A study at one mill that had combined effluent streams at approximately 120°F with a flow rate of 600 gal/min showed that a heat exchanger could generate warm filtered shower water for the mill's paper machines, which would offset some of the mill's steam demand. Annual boiler fuel savings of 37,000 MMBtu were estimated, which would lead to annual cost savings of $125,000 (2004 dollars). Capital costs were estimated at $375,000, with a payback period of about 3 years. (Kramer 2009)

Fractionation of recycled fiber. One mill tested the potential of separating the long fibers and short fibers in a deinking line. This enables a simplification of the deinking line, with a capital reduction of 13 to 22 percent compared to traditional de-inked pulp (DIP) lines, a reduction in electricity consumption of 11 to 13 percent, and thermal energy reductions of 40 percent. (Kramer 2009)

Residence time-temperature-speed (RTS) pulping. In RTS (short-residence time, elevated-temperature, high-speed) pulping, energy consumption is reduced by increasing the rotational speed of the primary refiner. Temperatures of approximately 165°C are used, resulting in a reduction in specific energy consumption, with no loss of pulp quality. Published estimates for the energy savings achievable with RTS pulping vary. One study estimated that RTS pulp can be produced with approximately 15 percent lower specific energy requirements than pulp produced with a traditional refining system. Another study suggested that the specific energy of RTS pulping is around 20 percent lower than TMP processes. Yet another study estimated that the effect of increasing rotational speed on TMP refiners will reduce energy use by anywhere from 15 to 30 percent, depending on plate type and refiner mode. (Kramer 2009)

E. Energy Efficiency Improvements in Papermaking

1. Paper Machines – Forming and Pressing Sections

Shoe (extended nip) press**.** After paper is formed, it is pressed to remove as much water as possible. Normally, pressing occurs between two felt liners pressed between two rotating cylinders. Extended nip presses use a large concave shoe instead of one of the rotating cylinders. The additional pressing area adds dwell time in the nip and allows for greater water extraction (about 5 to 7 percent more water removal) to a level of 35 to 50 percent dryness. Greater water extraction leads to decreased energy requirements in the dryer, which leads to reductions in steam demand. Furthermore, reduced dryer loads allow plants to increase capacity up to 25 percent in cases where production is dryer limited. Published estimates for the steam savings achievable through the installation of extended nip presses range from 2 to 15 percent, depending on product and plant configuration. Capital costs have been estimated at $38/ton of paper, and additional maintenance costs have been estimated at $2.24/ton of paper. (Kramer 2009)

Paper machine vacuum system optimization. Vacuum pumps and a vacuum system exist on every paper machine. There is approximately the same horsepower associated with the vacuum system as is used to drive the entire paper machine. However, inefficiencies within the vacuum system increase the electrical and/or steam energy requirements of water removal, and, therefore, represent an important energy efficiency improvement opportunity. For example, following an audit of 14 paper machines owned by a Canadian manufacturer, a potential of 3.5 MW of electrical power demand could be saved following system modifications, operational changes, and even removal of some vacuum pumps. Cost to achieve the first MW of savings was considered negligible, with minor piping or operational changes. Total annual cost savings were approximately $400,000/year (2009 dollars). (Kramer 2009)

Gap forming**.** Gap formers are an alternative to the Fourdrinier paper machine. The forming sections are very short, and the formation takes place in a fraction of the time it takes for a Fourdrinier machine (Martin et al. 2000). Coupling the former with a press section rebuild or an improvement in the drying capacity may increase production capacity by as much as 30 percent. Nevertheless, retrofitting a gap former may increase retention losses. Energy savings from gap formers come from reduced electricity consumption. Published estimates for electricity savings are around 40 kWh/ton of paper. Based on one study, the cost to install a gap former, including the head box, is approximately $75,750/inch of width (1996 dollars), as opposed to $30,750 for a Fourdrinier with a head box. (Kramer 2009)

2. Paper Machines – Drying Section

Advanced dryer controls**.** One study of dryer control software indicated savings of 4,500 pounds of steam per hour, which were estimated to lead to $360,000 in annual energy cost savings (2006 dollars). The payback period was estimated at under 3 years based on energy savings alone (i.e., no consideration of productivity benefits). Another study showed an annual savings of $263,000 (2005 dollars) due to reduced energy consumption, lower maintenance cost, and higher production. The reported payback period was seven months. (Kramer 2009)

Reduced air requirements**.** Air-to-air heat recovery systems on existing machines recover only about 15 percent of the energy contained in the hood exhaust air. This percentage could be increased to 60 to 70 percent for most installations with proper maintenance and extensions of the systems. Paper machines with enclosed hoods require about one-half the amount of air per ton of water evaporated compared to paper machines with canopy hoods. Enclosing the paper machine reduces thermal energy demands since a smaller volume of air is heated. Electricity requirements in the exhaust fan are also reduced. Published estimates suggest steam savings of 0.72 MMBtu/ton of paper and electricity savings of 6.3 kWh/ton of paper by installing a closed hood and an optimized ventilation system. Investment costs and operation and maintenance costs have been reported at $9.5/ton paper and $0.07/ton paper, respectively (2000 dollars). (Kramer 2009)

Optimizing pocket ventilation temperature**.** Mill operators often monitor the operating air temperature of pocket ventilation systems, but when such systems operate at greater air temperatures than the minimum required for proper operation, energy can be wasted. One estimate stated that decreasing the temperature of the pocket ventilation system to between 180 and 195°F decreased the overall use of steam by about 1,000 to 2,000 lb/hr in a typical mill. Paybacks are immediate since this measure involves improved operations and control rather than capital investments. (Kramer 2009)

Waste heat recovery**.** In the paper drying process, several opportunities exist to recover thermal energy from steam and waste heat. One mill replaced the dryers with stationary siphons in their paper machine and was able to achieve energy savings of 0.85 MMBtu/ton due to improved drying efficiency, with an operation cost savings of $25,000 ($0.045/ton) (1998 dollars). A second system used mechanical vapor recompression in a pilot facility to re-use superheated steam into the drying process. Steam savings for this approach were up to 4.7 MMBtu/ton (50 percent), with additional electricity consumption of 160 kWh/ton. A third system noted in the literature was the use of heat pump systems to recover waste heat in the drying section. One study estimated steam energy savings of around 0.4 MMBtu/ton of paper are achievable through paper machine heat recovery, with installation costs of around $18 per ton of paper. However, the installation of heat recovery systems will lead to more maintenance since heat exchangers require periodic cleaning. (Kramer 2009)

Heat can also be recovered from the ventilation air of the drying section and used for heating of the facilities. For example, a mill-wide energy assessment found that the recovery of paper machine vent heat could be used for heating the plant in winter months. The estimated annual cost savings were about $1,000,000. With investment costs of about $1,500,000, the payback period was estimated at only 1.5 years (2002 dollars). (Kramer 2009)

For direct-fired air dryer hoods, which are mainly used on tissue and toweling machines, several opportunities for waste heat recovery exist. Hood exhaust air can be recovered and used to preheat the air entering the combustion chamber, thereby reducing hood fuel demand. A cascade system can be employed, which uses the hood exhaust air to feed the supply fan of the wet section, which will reduce the fuel demand for wet section burners. Lastly, an economizer can be installed to reclaim heat from hood exhaust air and use it to heat fresh water for high-pressure showers of the paper machine felt and wires. (Kramer 2009)

<u>CondeBelt drying</u>. In CondeBelt drying, the paper is dried in a drying chamber by contact with a continuous hot steel band, heated by either steam or hot gas. The water from the paper is evaporated by the heat from this metal band. This drying technique has the potential to completely replace the drying section of a conventional paper machine, with a drying rate 5 to 15 times higher than conventional steam drying. However, CondeBelt drying is not suited for high basis weight papers and has seen limited application in the U.S. to date (although it is operating in mills in Europe and Korea). Capital costs are considered to be high, although the size of the drying area can be reduced. One study estimated savings of 15 percent in steam consumption (1.5 MMBtu/ton of paper) and a slight reduction in electricity consumption (20 kWh/ton of paper), with investment costs of $28/ton paper (1998 dollars) for retrofit installations. (Kramer 2009)

<u>Air impingement drying</u>. Air impingement drying leads to less steam use and slightly higher electricity use. This technology is mostly applicable to coating drying but is also gaining acceptance for general paper drying in place of traditional steam cylinders. Published estimates suggest that impingement drying can lead to steam savings of 10 to 40 percent compared to conventional gas-fired or infrared drying technologies, but with an increased electricity use of up to 5 percent. (Kramer 2009)

F. Energy Efficiency Improvements in Facility Operations

1. Energy Monitoring and Control Systems

Computerized/automated controls systems can be used to maintain operating conditions in the process at optimum levels. Many pulp and paper mills currently use modern process control systems, but those that do not could see energy and cost savings around 5 percent or more for many applications after installing these types of controls. (Kramer 2009)

2. High-Efficiency Motors

Motor-driven systems are by far the most significant consumer of electrical energy in a typical U.S. pulp and paper mill. Motor-driven systems accounted for around 90 percent of all the electricity used by the industry. Due to the high use of motors at a pulp and paper facility, a systems approach to energy efficiency should be considered. Such an approach should look for energy efficiency opportunities for all motor systems (motors, drives, pumps, fans, compressors, controls). An evaluation of energy supply and energy demand should be performed to optimize overall performance. A systems approach includes a motor management plan that considers at least the following factors (Kramer 2009):

- Motor management plan
- Strategic motor selection
- Maintenance
- Proper size
- Adjustable speed drives
- Power factor correction
- Minimize voltage unbalances

At one pulp and paper mill, energy efficient motors were an important part of a strategy to reduce electricity costs. By replacing its electric motors with premium-efficiency motors, the company was able to reduce its consumption of electricity per ton of paper by 35 percent. (Kramer 2009)

Motor management plans and other efficiency improvements can be implemented at existing facilities and should be considered in the design of new construction.

3. Pumps

Pumps account for a significant share of motor-driven system electricity use in the U.S. pulp and paper industry. Pumps are used to pressurize and circulate water, process chemicals, and pulping slurries as part of the pulp and paper making process. Energy costs and operation and maintenance costs are the most important components in the lifetime costs of a pump system. Therefore, optimization of the design of a new pumping system should focus on optimizing the lifecycle costs. Kramer 2009 listed the following factors that should be considered regarding pump system improvements:

- Pump system maintenance
- Pump system monitoring
- Pump demand reduction
- Controls
- High-efficiency pumps
- Properly sized pumps
- Use of multiple pumps for variable loads
- Adjustable-speed drives
- Impeller trimming
- Avoiding throttling valves
- Replacement of belt drives
- Proper pipe sizing
- Precision castings, surface coatings, or polishing
- Sealings
- Curtailing leaking through clearance reduction

Optimization of the design of a pumping system has been shown to result in large reductions in energy use and lifetime costs of a complete pumping system, up to 10 to 17 percent in energy savings. (Kramer 2009)

At one mill, an over-sized pump was replaced with one of proper size, resulting in an energy savings of 2,450 megawatt-hours per year (MWh/yr). With an investment cost of $123,500, the payback period was 17 months. (Kramer 2009)

4. High-Efficiency Fans

Fan technology has improved greatly since many older plants were constructed. Basic fan system improvements could save the U.S. pulp and paper industry around 1,100 GWh of electricity per year. (Kramer 2009)

5. Optimization of Compressed Air Systems

Compressed air systems provide compressed air that is used throughout the mill. Although the total energy used by compressed air systems is small compared to the facility as a whole, there are opportunities for efficiency improvements that will save energy. Efficiency improvements are primarily obtained by implementing a comprehensive maintenance plan for the compressed air systems. Kramer 2009 listed the following elements of a proper maintenance plan:

- Ongoing filter inspection and maintenance
- Keep compressor motors properly lubricated and cleaned
- Inspect fans and water pumps
- Inspect drain traps

- Maintain the coolers
- Check belts for wear
- Replace air lubricant separators as recommended
- Check water cooling systems
- Minimize compressed air leaks throughout the system
- Check applications requiring compressed air for excessive pressure, duration, or volume.

In addition to the maintenance plan, reducing leaks in the system can reduce energy consumption by 20 percent. Reducing the air inlet temperature will reduce energy usage, and routing the air intake to outside the building can have a payback period in 2 to 5 years. Control systems can reduce energy consumption by as much as 12 percent. Properly sized pipes can reduce energy consumption by 3 percent. Since as much as 93 percent of the electrical energy used by air compressor systems is lost as heat, recovery of this heat can be used for space heating, water heating, and similar applications. (Kramer 2009)

Air compressor system maintenance plans and other efficiency improvements can be implemented at existing facilities and should be considered in the design of new construction.

6. Lighting System Efficiency Improvements

Similar to air compressor systems, the energy used for lighting at pulp and paper mills represent a small portion of the overall energy usage. However, there are opportunities for cost-effective energy efficiency improvements. Automated lighting controls that shut off lights when not needed may have payback periods of less than two years. Replacing T-12 lights with T-8 lights can reduce energy use by half, as can replacing mercury lights with metal halide or high-pressure sodium lights. Substituting electronic ballasts for magnetic ballasts can reduce energy consumption by 12 to 25 percent. (Kramer 2009)

Lighting system improvements can be implemented at existing facilities and should be considered in the design of new construction.

7. Process Integration Pinch Analysis

Process integration can be an effective systems optimization approach to improve the energy efficiency of complex industrial facilities. Process integration is an analytical approach that can be used to optimize the selection and/or modification of processing steps, and of interconnections and interactions within the process, with the goal of minimizing resource use. Developed in the early 1970s, process integration is now an established methodology for improving the energy efficiency of continuous industrial processes. Pinch analysis is one of the most widely used process integration techniques. (Kramer 2009)

Pinch analysis takes a systematic approach to identifying and correcting the performance-limiting constraint (or pinch) in any manufacturing process system. It was developed originally in response to the “energy crisis” and the need to reduce steam and fuel consumption in oil refineries and chemical plants by optimizing the design of heat exchanger networks. Since then, the pinch analysis approach has been extended to resource conservation in general, whether the resource is capital, time, labor, electrical power, water, or a specific chemical species such as hydrogen. (Kramer 2009)

The critical innovation in applying pinch analysis was the development of "composite curves" for heating and cooling, which represent the overall thermal energy demand and availability profiles for the process as a whole. When these two curves are drawn on a temperature-enthalpy graph, they reveal the location of the process pinch (the point of closest temperature approach), and the minimum thermodynamic heating and cooling requirements. These are called the energy targets. The pinch analysis methodology involves first identifying the targets and then following a systematic procedure for designing heat exchanger networks to achieve these targets. The optimum approach temperature at the pinch is determined by balancing capital and energy tradeoffs to achieve the desired payback. The procedure applies equally well to new designs and retrofits of existing plants. (Kramer 2009)

Energy savings potential using pinch analysis far exceeds that from well-known conventional techniques such as heat recovery from boiler flue gas, insulation, and steam trap management. For example, one estimate indicates that pinch analyses can lead to energy savings of 10 to 35 percent in the pulp and paper industry. (Kramer 2009)

Since the U.S. pulp and paper industry relies heavily on water, pinch analyses that are aimed at optimizing both energy and water use are ideal. Several case studies of the successful application of pinch analysis by pulp and paper companies are discussed below. (Kramer 2009)

At one pulp and paper mill, a process integration analysis of the mill's energy and water systems identified several heat recovery and wastewater reduction options. Pinch analysis was used to develop "hot" and "cold" composite curves for the entire mill. In addition to identifying all thermodynamically possible synergies between hot and cold systems, the pinch analysis also pinpointed inappropriate heat exchanges and ways to improve mill heat recovery. A total of 12 projects were deemed feasible from this analysis, which were estimated to lead to a 15 percent reduction in the mill's total fuel use. Additional benefits included the reduction in mill effluent. The payback period of these improvements was estimated at only ten months. (Kramer 2009)

At another pulp mill, a process integration study identified water and energy efficiency opportunities that focused on feed water preheating measures and cooling tower hot water streams displacement. Five priority projects were identified that would reduce energy consumption, while also reducing the use of fresh water by 10 percent. Capital expenditures for these projects were estimated at around $1.8 million, but the return on investment is expected to take only a little over one year. (Kramer 2009)

A third company also identified significant energy savings opportunities by using pinch analysis. Three heat recovery projects were identified that could reduce annual costs by about $4.8 million and annual natural gas use by 1,845,000 MMBtu. The overall payback period for these projects was estimated to be less than one year. At one of the company's mills, a pinch analysis identified eight projects that could offer significant savings. It was estimated that annual steam savings of 718,972 MMBtu and annual natural gas savings of 10,483 MMBtu would be possible, with an overall payback period of around 2.75 years. (Kramer 2009)

G. *Emerging Energy Efficiency Technologies*

1. Raw Material Preparation

Microwaving logs. By microwaving logs, the lignin in the wood can be softened, leading to lower energy requirements in the TMP process. Test results suggested that high-power microwave cooking of commercial black spruce for TMP could lead to energy savings of 15 percent, with the added benefit of improved pulp quality. A tradeoff is that, with microwaving, more bleaching may be required to receive the desired paper quality; however, increased bleaching costs may be justified by the energy and quality improvements. Initial estimates of capital costs for 20-kilowatt (kW) and 50-kW systems range from $7.5 to $12.5 million (2002 dollars). (Kramer 2009)

Biotreatment. The treatment of wood chips with a fungus or enzymes can soften the bonds in wood, resulting in less energy use in pulping processes. The results of a pilot project in which the biopulping process for treating wood chips prior to mechanical pulping were scaled up to a 50-ton, semi-commercial scale. The economic advantages of biomechanical pulping derive from several effects, including significantly improved strength properties and significantly reduced refiner energy requirements (about 33 percent less energy use for refining). (Kramer 2009)

The physical process begins after the pulpwood has been chipped and screened for oversize chips. At this point, the chips are briefly heated to 100ºC to kill off anything that might compete with the lignin-degrading fungus. The chips are then air-cooled, and the fungus and the nutrients are added. The treated chips are placed in a pile for the next 1 to 4 weeks: climatic and seasonal factors are very important for the effectiveness of the treatment. The fact that up to four weeks worth of chips must be stored may be a problem for mill sites with space constraints. This technology is reportedly ready for commercial deployment, but no data could be found on the extent to which this technology has been adopted by U.S. pulp and paper mills. (Kramer 2009)

2. Chemical Pulping

Black liquor gasification. Kraft mills combust black liquor in so-called Tomlinson recovery furnaces to recover pulping chemicals and generate process steam and on-site electricity (via a steam turbine). The efficiency of such furnaces is typically low, around 65 to 70 percent. An alternative to using a recovery furnace is an emerging process known as black liquor gasification. Black liquor gasification refers to the process of creating a clean synthesis gas (syngas) from black liquor by converting its biomass content into a gaseous energy carrier. The syngas can be used in boilers or in combined cycle processes to generate on-site electricity and process steam. (Kramer 2009)

Black liquor gasifiers may be applied as an incremental addition in chemical recovery capacity in situations where the recovery furnace is a process bottleneck. There is also increasing interest in using gasifiers in combined cycle power systems as replacements for

Tomlinson recovery furnace systems, to provide fuel for lime kilns, and even for transport fuels such as Fischer-Tropsch liquids or hydrogen. (Kramer 2009)

The black liquor gasification process may be implemented through one of two systems. Both high- and low-temperature mill-scale gasification systems are able to produce syngas and assist in recovering pulping chemicals. Both systems have the capacity to create similar end products (i.e., syngas and pulping chemicals) but differ from each other and from the Tomlinson recovery process in the resulting gasified black liquor chemical compositions. Low-temperature gasification tends to produce a sulfur-lean smelt and results in approximately 90 percent of the total sulfur components leaving in the syngas when compared to the Tomlinson recovery furnace. High-temperature gasification has a similar affect on sulfur loss but the effect is not as pronounced. (Kramer 2009)

The potential advantages of black liquor gasification are the greater end-use flexibility offered by a gaseous fuel, reduced air pollutant content, and higher electricity-to-heat ratios in combined cycle systems than standard recovery furnace steam turbine systems. The secondary fuel source will offer the opportunity to eliminate the dependency of grid purchased power and produce additional power to sell back. Also, gasification is expected to reduce emissions of SO_2, NO_X, CO, volatile organic compounds (VOCs), PM, CH_4, HAP, and TRS and wastes (i.e., water, solids, and coal use) generally associated with power production. (Kramer 2009)

Some potential disadvantages of gasification combined cycle systems include higher lime kiln and causticizer loads (and associated fuel inputs) compared to Tomlinson systems, the overall installation cost, and the steam demand to operate (and associated fuel inputs). The sulfur loss that occurs in black liquor gasification subsequently increases the amount of Na_2CO_3 in the smelt. This higher concentration of Na_2CO_3 requires additional lime kiln and causticizer loads to convert the Na_2CO_3 back to NaOH needed for pulping. The additional causticizing capacity directly contributes to the installation cost, due to the need to improve or replace the current lime kiln. Additionally, since combined cycle systems generate electrical power more efficiently than steam turbine-based systems, more fuel is required in the gasification combined cycle system than in the Tomlinson boiler system to meet the same level of facility steam demand. However, this additional fuel use also results in more available electricity for facility use or export to the grid. (Kramer 2009)

At least one study (Larson 2003) has comprehensively analyzed the potential for black liquor gasification accompanied by combined cycle electricity generation at pulp and paper mills in the U.S. The study analyzed the various tradeoffs of different gasification and Tomlinson boiler co-generation systems under different assumptions. The study results suggest that, on a thermodynamic basis, high-efficiency Tomlinson boiler systems would be more efficient at generating steam and power than low-temperature mill-scale gasification systems. However, the study results also suggested that high-temperature mill-scale gasification systems would be more efficient than high-efficiency Tomlinson boiler systems. The study estimated total installed capital costs (including causticizing area upgrades) for a 6 million pound of black liquor solids per day (lb BLS/day) gasification unit to be \$234 million for a low-temperature system and \$194 million for a high-temperature system (2002 dollars). (Larson 2003)

<u>Directed green liquor utilization pulping.</u> This technology is based on the use of green liquor for pretreatment of wood chips prior to pulping. Green liquor is naturally rich in

hydrosulfide ions, which can accelerate pulping. The use of green liquor in this manner has been demonstrated in pulp mills in Finland and can reportedly increase pulp yields, produce higher fiber strength, reduce digester alkali demand by as much as 50 percent, offload the lime kiln by up to 30 percent, provide higher pulp bleachability, and reduce energy use by up to 25 percent. As of 2006, this technology was being demonstrated at a mill in the U.S. and was expected to be commercialized shortly. (Kramer 2009)

Biomass gasification. Biomass (wood) gasification systems for generating power at pulp mills are also under development. Biomass gasification would produce a syngas fuel from the gasification of wood residuals. This biogenic syngas could then be used to replace the fossil fuels currently being burned in lime kilns, power boilers, or other combustion devices.

3. Pulp Washing

Steam cycle washer for unbleached pulp. According to the U.S. DOE, current U.S. pulp washing equipment has an average age of 45 years. Thus, significant energy saving opportunities may exist with the development and adoption of new, more efficient pulp washing technologies. The U.S. DOE is sponsoring the development of a new steam cycle washer that is designed to de-water and wash wood pulp using counter-current washing, steam, and high-differential pressure. Reportedly, the technology uses 70 to 75 percent less water than conventional washers because it allows the pulp mat to be washed at a high consistency of 28 to 32 percent. This results in less energy consumption, up to a 21 percent decrease in electrical power consumption and up to a 40 percent decrease in fuel use for unbleached pulp production. This technology is currently undergoing demonstration and commercialization. (Kramer 2009)

4. Secondary Fiber Processing

Electrohydraulic contaminant removal. Adhesive materials on secondary fiber feedstock can significantly degrade the quality of recycled paper products. A demonstration project sponsored by the U.S. DOE indicated that a new contaminant removal technology that is based on the principle of electrohydraulic discharge may remove such contaminants effectively and in an energy efficient manner. The technology uses the discharge of sparks in cleaning and screening processes to enhance the removal efficiency of adhesive materials in screening and cleaning and to increase the efficiency of flotation deinking. Trials have been run at several mills. One study reported that improved adhesive material removal, flotation, and clarification were observed that could lead to direct energy use reductions of 10 to 15 percent in contaminant removal and cleaning equipment. (Kramer 2009)

5. Papermaking

Laser-ultrasonic web stiffness sensor. A laser-ultrasonic sensor has been developed which measures a paper's bending stiffness and shear strength as it speeds through a production web. The laser-ultrasonic sensor measures these important mechanical properties in real time, which can allow paper manufacturers to optimize the amount of raw material used to make paper by running closer to specifications. Reportedly, this could save approximately $200 million in energy costs and $330 million in fiber costs each year in the U.S.

The technology has been proven in a full-scale mill trial, and is currently being evaluated in a larger pilot study. At the mill scale, it is estimated that implementation of this technology could lead to a 2 percent decrease in basis weight due to the ability of running closer to specification. Furthermore, the portion of off-grade paper that must be recycled could be reduced by 1 percent (which avoids the additional energy necessary to reprocess the recycled fiber in the mill). In total, mill-scale energy savings of 3 percent have been estimated. (Kramer 2009)

Advanced fibrous fillers. Mineral fillers are commonly used to replace wood fibers in the production of paper products, but filler loading is currently limited to roughly 15 to 20 percent due to paper strength and quality requirements. New inorganic fibrous fillers have been developed that could raise the filler loading limit to up to 50 percent, while maintaining paper strength and quality in many products. Reportedly, the use of fillers could reduce energy consumption by 25 percent and costs by $10 to $50 per ton of paper produced (2006 dollars). Energy savings are attributable to avoided wood pulp production and reduced drying energy due to an increase in the percentage of press solids in the sheet. Mill-scale production trials of this technology are underway. (Kramer 2009)

Lateral corrugators. The lateral corrugator holds promise for reducing the fiber use and energy consumption associated with the manufacture of corrugated boxes. The lateral corrugator is designed to increase the compression strength of corrugated containers by aligning the corrugated flutes with the orientation of the linerboard fibers (i.e., the paper machine direction). This change reportedly increases the compressive strength of corrugated boxes by up to 30 percent and may allow manufacturers to use 15 percent less fiber to produce boxes with the same strength. Significant energy savings should be possible due to the reductions in raw materials preparation, pulping, and paperboard making energy attributable to reduced fiber input. (Kramer 2009)

6. Paper Machines – Drying Section

Impulse drying. Impulse drying may lower the moisture content of the paper web entering the drying section by up to 38 percent, thereby significantly lowering the energy required in the paper machine's drying stage. Impulse drying involves pressing the paper between one very hot rotating roll (150 to 500°C) and a static concave press with a very short contact time. The pressure is about 10 times higher than that in press and CondeBelt drying. Potentially, energy savings can be significant. One estimate placed the potential savings in drying steam consumption at 50 to 75 percent. Another description of impulse drying claims energy savings of about 18 to 20 percent or 2 MMBtu/ton of paper. Electricity requirements do increase, however, by 5 to 10 percent. Other reported benefits of this technology include reduced capital costs, increased machine productivity, improved strength, reduced fiber use, and increased recycled fiber content allowed for any given paper strength. However, current results from pilot operations show limited energy efficiency improvements when compared to state-of-the-art efficient paper machines. (Kramer 2009)

Gas-fired paper dryer. The gas-fired dryer system uses small dimples or cavities for combustion in a cylinder dryer, which can replace current steam dryers whose productivity is limited by drying capacity. The technology significantly raises drum temperatures (to over 600°F), thereby increasing drying rates, which can reportedly reduce energy use and increase the throughput of the paper machine by an estimated 10 to 20 percent. A key contributor to increased efficiency is the fact that diffusion firing allows high levels of heat recovery to preheat combustion air. (Kramer 2009)

Multi-port dryer. A new multi-port cylinder dryer has been developed that can reportedly increase paper production rates by 50 percent relative to conventional dryers and by 20 percent relative to dryers fitted with so-called "spoiler bars." Conventional steam-filled drying cylinders develop condensate on the inside of the drum, which is a major thermal barrier. The new multi-port cylinder dryer uses smaller-sized ports located in close proximity to the inside surface of the cylinder dryer, which improves heat transfer by significantly minimizing the condensate layer thickness and increasing the surface temperature of the dryer shell. This technology is reportedly being designed for retrofit applications and is projected to cost only 20 percent as much as the installation of a new dryer cylinder. The multi-port dryer is currently undergoing pilot demonstration. (Kramer 2009)

7. Facility Operations - Motors

Magnetically-coupled adjustable-speed drives. Magnetically-coupled adjustable-speed drives (MC-ASDs) are a new type of ASD, in which the physical connection between the motor and the driven load is replaced with a gap of air. Torque is generated by the interaction of rare-earth magnets on one side of the drive with induced magnetic fields on the other side. The amount of torque transferred is controlled by varying the air gap distance between the rotating plates in the assembly. Compared to existing ASDs, MC-ASDs have several advantages, including: (1) a greater tolerance for motor misalignment; (2) little impact on power quality; (3) the ability to be used with regular duty motors (instead of inverters); (4) expected lower long-term maintenance costs; and (5) extended motor and equipment lives, due to elimination of vibration and wear on equipment. (Kramer 2009)

One mill opted to install MC-ASDs to reduce wasted energy in the pumping of TMP whitewater to its pulping process and de-inking system. The old constant-speed pump ran at full capacity during normal operations, which resulted in cavitation and excessive vibration, leading to maintenance problems. Further, a bypass valve was used to maintain constant pressure in the system when there was no demand for TMP whitewater, which led to significant energy waste. The MC-ASD was installed in this application instead of an ASD due to its lower installation and infrastructure costs. The coupling allowed the mill to vary the speed of its pump motor to maintain the required pressure but with an energy demand that was around 60 percent lower than the former constant-speed, bypass-valve based system. Annual energy costs were reduced by around $19,000 (2002 dollars), cavitation was eliminated, and pump vibration was dramatically reduced. (Kramer 2009)

In a similar case study, a MC-ASD was installed in a pumping application at a mill. The mill had 100–hp, 1175–revolutions per minute (rpm) motors operated in parallel running vertical shaft pumps to move wastewater from the main pump station to a clarifier. These two pumps ran constantly to meet a maximum flow rate of 7,000 gal/min; however, the average demand was only 4,800 gal/min, which meant that 2,200 gal/min was passed through an energy wasting bypass valve. The MC-ASDs were installed on the two pumps as a lower-cost alternative compared to ASDs. The MC-ASDs allowed the mill to maintain its 4,800 gal/min flow, while reducing electricity demand from 142 to 62 kW, a savings of 56 percent. Reportedly, the couplings also eliminated damaging vibration and water hammer, resulting in equipment and maintenance cost savings of approximately $15,000 per year (2002 dollars). (Kramer 2009)

IV. Energy Programs and Management Systems

Industrial energy efficiency can be greatly enhanced by effective management of the energy use of operations and processes. EPA's ENERGY STAR Program works with hundreds of U.S. manufacturers and has seen that companies and sites with stronger energy management programs gain greater improvements in energy efficiency than those that lack procedures and management practices focused on continuous improvement of energy performance. Energy management practices and system elements can be considered as part of work practice requirements established under permitting conditions.

Energy Management Systems (EnMS) provide a framework managing energy and promote continuous improvement. The EnMS provides the structure for an energy program and its energy team. EnMS establish assessment, planning, and evaluation procedures which are critical for actually realizing and sustaining the potential energy efficiency gains of new technologies or operational changes.

Energy management systems promote continuous improvement of energy efficiency through:

- Organizational practices and policies,
- Team development
- Planning and evaluation,
- Tracking and measurement,
- Communication and employee engagement, and
- Evaluation and corrective measures.

For nearly 10 years, the EPA's ENERGY STAR Program has promoted an energy management system approach. This approach, outlined in the graphic below, outlines the basic steps followed by most energy management systems approaches.

In recent years, interest in energy management system approaches has been growing. There are many reasons for the greater interest. These include recognition that a lack of management commitment is an important barrier to increasing energy efficiency. Further, lack of an effective energy team and program result in low implementation rates for new technologies or recommendations from energy assessments. Poor energy management practices that fail to monitor performance do not ensure that new technologies and operating procedures will achieve their potential to improve efficiency.

Approaches to implementing energy management systems vary. EPA's ENERGY STAR Guidelines for Energy Management are available for public use on the web and provide extensive guidance (see: www.energystar.gov/guidelines). Alternatively, energy management *standards* are available for purchase from American National Standards Institute (ANSI), ANSI MSE 2001:200 and in the future from International Organization for Standardization (ISO), ISO 50001. See Figure 3.

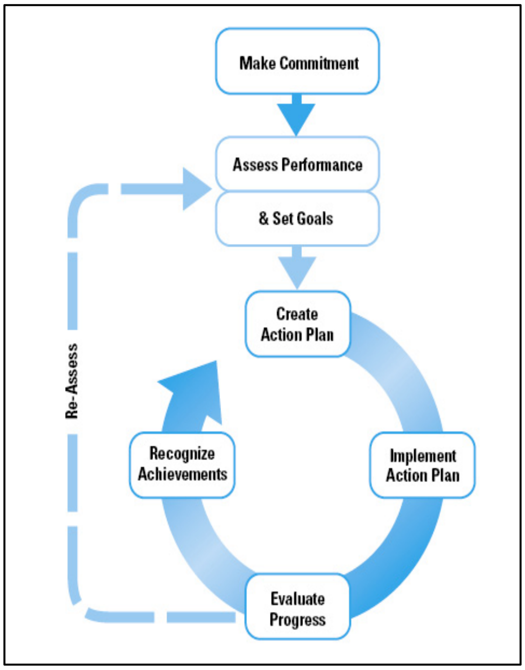

Figure 3 - ENERGY STAR Guidelines for Energy Management
(www.energystar.gov/guidelines)

While energy management systems can help organizations achieve greater savings through a focus on continuous improvement, they do not guarantee energy savings or CO_2 reductions alone. Combined with effective plant energy benchmarking and appropriate plant improvements, energy management systems can help achieve greater savings.

There are a variety of factors to consider when contemplating requiring certification to an Energy Management Standard established by a standards body such as ANSI or ISO. First, energy management system standards are designed to be flexible. A user of the standard is able to define the scope and boundaries of the energy management system so that single production lines, single processes, a plant, or a corporation could be certified. Beyond scope, achieving certification for the first time is not based on efficiency or savings (although re-certifications at a later time could be). Finally, cost is an important factor in the standardized approach. Internal personnel time commitments, external auditor, and registry costs are expensive.

From a historical perspective, few companies have pursued certification according to the ANSI energy management standards to date. One reason for this is that the elements of an energy management system can be applied without having to achieve certification, which adds additional costs. The ENERGY STAR Guidelines and associated resources are widely used and adopted partly because they are available in the public domain and do not involve certification.

Overall, a systems approach to energy management is an effective strategy for encouraging energy efficiency in a facility or corporation. The focus of energy management efforts are shifted from a "projects" to a "program" approach. There are multiple pathways available with a wide range of associated costs (ENERGY STAR energy management resources are public, while the standardized approaches are costly). The effectiveness of an energy management system is linked directly to the system's scope, goals, and measurement and tracking. Benchmarks are the most effective measure for demonstrating the system's achievements.

A. Sector-Specific Plant Energy Performance Benchmarks

Plant energy benchmarking is the process of comparing the energy performance of one site against itself over time or against the range of performance of the industry. Plant energy benchmarking is typically done at a whole-facility or site level in order to capture the synergies of different technologies, operating practices, and operating conditions.

Benchmarking enables companies to set informed and competitive goals for plant energy improvement. Benchmarking also helps companies prioritize where to make investment to improve performance of poor performers, while learning from the approaches used by top performers.

When benchmarking is conducted across an industrial sector, a benchmark can be established that defines best-in-class energy performance. The EPA's ENERGY STAR Program has developed benchmarking tools that establish best-in-class for specific industrial sectors. These tools, known as Plant Energy Performance Indicators (EPI) are established for specific industrial sectors and available for free at www.energystar.gov/industrybenchmarkingtools. Using several basic plant-specific inputs, the EPIs calculate a plant's energy performance, providing a score from 0 to 100. EPA defines the average plant within the industry nationally at the score of 50; energy-efficient plants score 75 or better. ENERGY STAR offers recognition for sites that score in the top quartile of energy efficiency for their sector using the EPI.

As of July 2010, ENERGY STAR had developed two EPIs for the pulp and paper sector. These include a Pulp Mill EPI and an integrated Pulp and Paper Mill EPI. The integrated Pulp and Paper Mill EPI is applicable to mills that manufacture products in specific product categories. EPA is evaluating the development of further EPIs for other mill configurations, such as recycled fiber mills, tissue mills, etc.

B. Industry Energy Efficiency Initiatives

The U.S. EPA's ENERGY STAR Program (www.energystar.gov/industry) and U.S. DOE's Industrial Technology Program (www.energy.gov/energyefficiency) have lead industry specific energy efficiency initiatives over the years. These programs have helped to create guidebooks of energy efficient technologies, profiles of industry energy use, and studies of future technologies. Some states have also lead sector-specific energy efficiency initiatives. Resources from these programs can help to identify technologies that may help reduce CO_2 emissions.

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