ENERGY BEST PRACTICES GUIDE | DECEMBER 2022

PULP & PAPER

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Pulp & Paper Industry Energy Best Practices Guide

FOCUS ON ENERGY®, Wisconsin utilities' statewide program for energy efficiency and renewable energy, helps eligible residents and businesses save energy and money while protecting the environment. Focus on Energy information, resources and financial incentives help to implement energy efficiency, emerging technologies, and renewable energy projects that otherwise would not be completed.

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Introduction

This guide is one of a series of guides developed to highlight industrial energy-efficiency best practices in common industrial sectors. The Focus on Energy Pulp & Paper Best Practices Guide provides guidance on establishing energy management best practices as well as proven energy saving strategies and emerging technologies for various aspects of pulp and paper operations.

The information provided in the guide was identified and screened through visits to pulp and paper manufacturing sites. This guide will be updated as new best practices and emerging technologies are identified and screened for applicability. If you have an energy-related best practice for this industry sector that you believe should be included in this guide, please reach out to Focus on Energy at 800.762.7077.

Are you a world class energy user?

World-class energy users have:

1. Benchmarked energy consumption in their plant.
2. Defined quantifiable, affordable energy-reduction goals.
3. Established a multi-year plan to meet their energy-reduction goals.
4. Established a site energy champion who is identifiable, enthusiastic, and technically sound.
5. Assigned a cross functional team to implement the energy management plan.
6. Key energy metrics identified and displayed.
7. Reporting, feedback, and renewal processes.
8. Obtained firm commitments from their facility managers for improvements in energy efficiency and demand reduction.
9. Performed regular process energy audits as part of their sustainability strategy.
10. Utilized available energy-reduction incentives to achieve faster project payback.

Background

Paper mills in the United States had total revenue of $58.2 billion in 2020 with profits of $10.7 billion. Pulp, paper and paperboard mills account for 95% of energy use in the U.S. paper and allied products industry and about 12% of total manufacturing energy use in the U.S.(1) Home to 11% of the nation's paper mills, the pulp and paper industry has long played a major role in the Wisconsin economy and produces more paper products than any other state. There are five operating pulp mills and 33 operating paper mills in Wisconsin.

Pulp and paper manufacturing is energy intensive and the second most energy-intensive industry group in the manufacturing sector. The industry has made large strides in reducing total energy use and in increasing the portion of energy provided from self-generated biomass sources. Energy cost represents 10% to 30% of total manufacturing cost and can be the third largest cost sector for a site. However, energy cost can be controlled through implementation of practices and methods contained within the Energy Guide.

Energy distribution in pulp and paper mills

The following graphs capture energy distribution within pulp and paper facilities. The relative breakdown of energy is very typical of manufacturing sites. Knowing the relative breakdown for energy consumption guides an overall strategy for energy-reduction opportunity.

Figure 1 captures an example of the total energy in MMBtu as distributed and consumed in a pulp mill.

Figure 1: Total energy consumption by end use, pulp mill

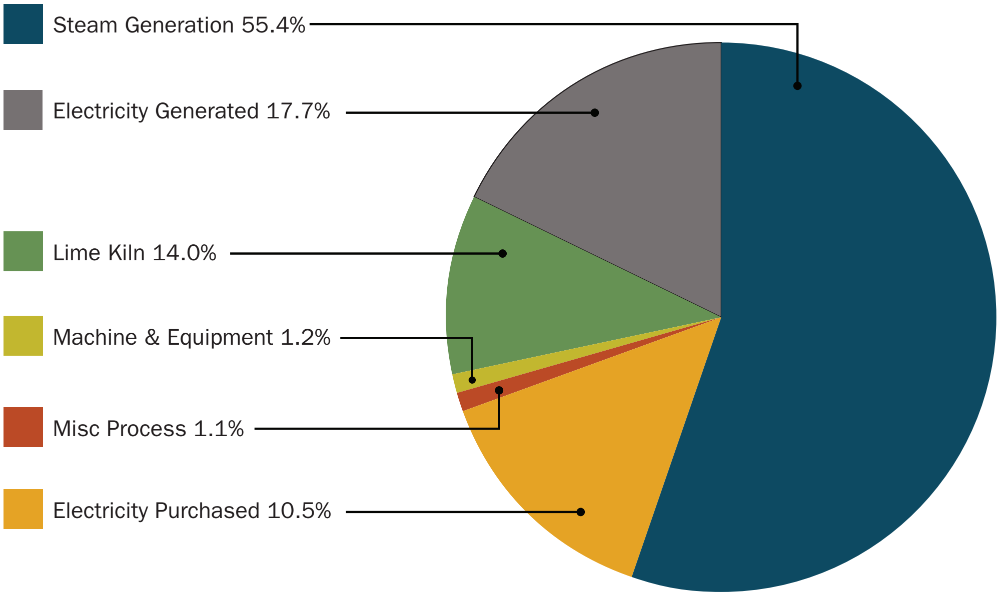
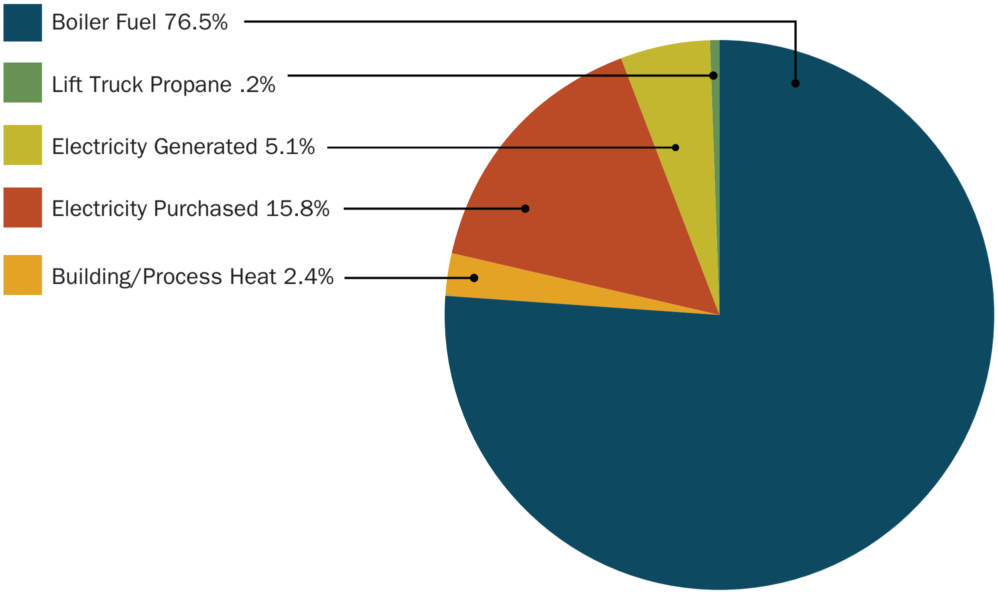


Figure 2: Total energy consumption by end use, paper mill



Energy use in pulp manufacturing

Pulping is the process by which the fibers in wood are separated and treated to produce pulp. Kraft pulping is the main chemical pulping process and accounts for about 80% of all pulp produced in the United States. The Kraft process relies on sulfur and sodium compounds as principal pulping chemicals. In high-yield mechanical pulping, wood is subjected to shear and compression forces to separate the fibers. Recycled paper is repulped through primarily mechanical treatment. Most pulp is pumped as a slurry directly to an integrated paper or paperboard plant where it may be mixed with other pulps, recycled fiber, or fillers such as clay before going to the paper machine.

Benchmark information is used to establish best practices based on the energy used in the total plant. Table 1 provides typical energy intensities of the pulping process and Table 2 shows energy intensities of the pulping process at state-of-the-art facilities.

Table 1: Typical energy intensities for pulp processes

		ENERGY INTENSITY BY PROCESS (MMBtu/TON)			
TYPE OF PULP	PRODUCTION (1,000 TONS/YEAR)	WOOD COOKING	LIQUOR EVAPORATION	LIME KILN/ PULPING CHEMICAL PREP	BLEACHING
CHEMICAL PULP					
Sulfite	326	2.99	2.64	2.20	2.39
Kraft, Unbleached	20,338	2.58	3.69	2.12	–
Kraft, Bleached, Softwood	13,153	2.51	3.66	2.07	2.32
Kraft, Bleached, Hardwood	13,317	2.41	3.29	2.05	2.33
NSSC, Semichemical	3,121	3.24	3.35	1.84	–
Subtotal Chemical Pulp	**50,255**				
Weighted Average Energy Intensity (MMBtu/ton)		**2.56**	**3.55**	**2.07**	**2.33**

https://www.energy.gov/sites/prod/files/2015/08/f26/pulp_and_paper_bandwidth_report.pdf

Table 2: State-of-the-art energy intensities for pulp processes

TYPE OF PULP	PRODUCTION (1,000 TONS/YEAR)	ENERGY INTENSITY BY PROCESS (MMBtu/TON)			
		WOOD COOKING	LIQUOR EVAPORATION	LIME KILN/ PULPING CHEMICAL PREP	BLEACHING
CHEMICAL PULP					
Sulfite	326	2.98	2.34	2.20	2.59
Kraft, Unbleached	20,338	2.09	3.27	1.67	–
Kraft, Bleached, Softwood	13,153	1.91	3.05	1.68	1.56
Kraft, Bleached, Hardwood	13,317	1.89	2.70	1.50	1.52
NSSC, Semichemical	3,121	3.10	3.05	1.44	–
Subtotal Chemical Pulp	**50,255**				
Weighted Average Energy Intensity (MMBtu/ton)		**2.06**	**3.04**	**1.62**	**1.55**

https://www.energy.gov/sites/prod/files/2015/08/f26/pulp_and_paper_bandwidth_report.pdf

Energy use in paper manufacturing

The production of paper involves preparing the stock from pulp, forming a sheet, dewatering and drying, and sometimes coating the paper. All paper machines have three basic elements: wet end, press section, and drying section. Economies of scale have resulted in larger and faster paper machines.

Figure 2 captures an example of the total energy in MMBtu as distributed and consumed in a paper mill.

Table 3 shows typical energy intensities for paper processes, and Table 4 shows state-of-the-art energy intensities.

Energy intensity estimates were based on installing technologies identified in the referenced bandwidth study. Many of the energy intensity values considered state-of-the-art have been achieved and exceeded in pulp and paper mills. The American Forest and Paper Association (AF&PA) set a goal in 2005 to achieve at least a 10% improvement in members' purchased energy efficiency by 2020. By 2016, members had achieved a 11.6% improvement, reducing the MMBtu per ton of product from 12.94 MMBtu to 11.43 MMBtu.

Table 3: Current typical energy intensities for paper processes

TYPE OF PAPER	PRODUCTION (1,000 TONS/YEAR)	ENERGY INTENSITY BY PROCESS (MMBtu/TON) PAPER DRYING	PAPER MACHINE WET END
Corrugating Medium	9,786	4.84	2.62
Linerboard	24,119	4.88	2.61
Recycled Board	3,601	4.75	2.54
Folding Boxboard	2,421	4.75	2.26
Gypsum Board	865	4.74	2.58
Bleached Folding Boxboard/ Milk	5,378	4.71	2.40
Other Board, Unbleached	1,288	4.39	2.42
Kraft Paper	1,427	4.62	2.36
Special Industrial	2,683	4.62	2.35
Uncoated Free, Bristol and Bleached Packaging	10,589	4.80	2.39
Coated Freesheet	4,146	4.42	2.35
Newsprint	3,429	4.02	1.80
Groundwood Specialties	2,130	4.02	1.80
Coated Groundwood	3,765	4.03	1.61
Tissue/Towel	7,309	6.34	0.94
Other Specialties	23	5.00	2.30
Market Pulp	8,769	3.31	0.14
Subtotal Paper	**91,728**		
Weighted Average Energy Intensity (MMBtu/ton)		**4.68**	**2.07**

https://www.energy.gov/sites/prod/files/2015/08/f26/pulp_and_paper_bandwidth_report.pdf

Table 4: State-of-the-art energy intensities for paper processes

TYPE OF PAPER	PRODUCTION (1,000 TONS/YEAR)	ENERGY INTENSITY BY PROCESS (MMBtu/TON)	
		PAPER DRYING	PAPER MACHINE WET END
Corrugating Medium	9,786	3.00	1.95
Linerboard	24,119	3.04	1.59
Recycled Board	3,601	3.86	1.34
Folding Boxboard	2,421	3.86	1.14
Gypsum Board	865	3.86	1.34
Bl. Folding Boxboard/Milk	5,378	3.04	1.39
Other Board, Unbleached	1,288	3.54	1.39
Kraft Paper	1,427	3.04	1.29
Special Industrial	2,683	3.04	1.39
Uncoated Free, Bristol and Bleached Packaging	10,589	4.05	1.47
Coated Freesheet	4,146	3.39	1.43
Newsprint	3,429	3.12	1.07
Groundwood Specialties	2,130	3.76	1.07
Coated Groundwood	3,765	3.79	1.35
Tissue/Towel	7,309	6.16	0.74
Other Specialties	23	3.94	1.39
Market Pulp	8,769	2.40	0.54
Subtotal Paper	**91,728**		
Weighted Average Energy Intensity (MMBtu/ton)		**3.47**	**1.35**

https://www.energy.gov/sites/prod/files/2015/08/f26/pulp_and_paper_bandwidth_report.pdf

Energy use in paper machines

Paper machine energy performance indices are published by TAPPI in Technical information paper (TIP) 0404-63. Paper machine energy conservation targets are shown in Table 5. The TIP is updated every five years. Additional grade specific information can be found in TAPPI TIP 0404-47 Paper machine performance guidelines.

Table 5. Paper machine performance targets

GRADE	UPTIME (%)	OVERALL MACHINE EFFICIENCY	COUCH SOLIDS	PRESS SOLIDS	STEAM lb/t	TOTAL ENERGY MMBtu/t	WATER USE gal/t	PV TEMP (F)	CONDENSATE RETURN (%)
Uncoated Woodfree	95	89	20	42-45	4,000	6.0	2,000	180	85
Bleached Board	93	84	27	42	4,000	7.0	2,000	180	85
Linerboard	95	92	27	42-50	2,800	5.0	1,500	180	85
Corrugating Medium	95	92	27	42-50	2,750	5.0	1,500	NA	85
Market Pulp	95	94	27	50	2,000	4.0	500	NA	85
Fluff Pulp	95	92	30	45	2,500	4.5	500	180	85
Recycled Paperboard	93	86.5	27	48	2,800	6.0	1,000	180	85
Newsprint	93	92	21-22	43-48	2,800	5.0	2,000	180	85
Lightweight Coated	93	79	18-22	43-49	3,000	5.5	2,000	180	85
Kraft Paper	94	91	22	42-46	5,000	6.0	1,500	180	85
Specialty Fine	93	85	20	42	5,000	7.0	2,500	180	85

GRADE	UPTIME (%)	OVERALL MACHINE EFFICIENCY	SOLIDS AFTER FORMING SECTION	SOLIDS AFTER TAD SECTION	STEAM lb/t	TOTAL ENERGY MMBtu/t	WATER USE gal/t	TAD EXHAUST (F)	CONDENSATE RETURN (%)
Through Air Dried	97	94	25	85	1400	15.0	<2,200	<250	85

GRADE	UPTIME (%)	OVERALL MACHINE EFFICIENCY	SOLIDS AFTER FORMING ROLL	SOLIDS AFTER PRESSURE ROLL	STEAM lb/t	TOTAL ENERGY MMBtu/t	WATER USE gal/t	HOOD THERMAL EFFICIENCY (BTU/LB H_2O	CONDENSATE RETURN (%)
Dry Creped Tissue	97	95	12	45-48	2,200	7.5	<2,000	1,800-2,200	85

Reference: TAPPI TIP 0404-63 Paper machine energy conservation

Performing a paper machine audit

A site audit is a valuable tool to uncover energy reduction opportunities and consider site interaction and process interrelationships. Paper machine energy scorecards are used to benchmark energy performance and identify energy reduction opportunities. Energy scorecards were first developed in 2008 with funding by the United States Department of Energy (DOE). The scorecards are an Excel spreadsheet which is updated and expanded regularly. It currently includes the following worksheets:

- Introduction.
- Paper machine basic data.
- Grade energy scorecards: Benchmarking information for bleached board, corrugating medium, fluff pulp, Kraft paper, linerboard, lightweight coated, market pulp, newsprint, paperboard, specialty fine paper, and uncoated woodfree grades.
- Paper machine energy monitoring.
- Dryer section.
- Press section.
- Paper machine auxiliary systems: Refining, vacuum application, water systems, stock preparation and pumps, steam showers, cross machine profile control, size press, machine room ventilation, and compressed air systems.
- Gas-fired boilers.
- Summary results.

Spreadsheets for entering information on equipment related to energy use for dryers, press section, refiners, vacuum pumps, pulper agitators, and pumps are included.

Energy benchmarks included in the scorecards are taken from TAPPI TIP 0404-63 Paper Machine Energy Conservation. Alternate answers to questions on each worksheet are scored based on energy efficiency. The “average” score for all machines is 50% for each scorecard, so relative performance can be compared.

Separate scorecards are available for other grades that do not have conventional cylinder dryers, including tissue, towel, and floatation-type pulp dryers. The scorecards are used worldwide and have been translated into French, Spanish, Chinese, and Korean languages.

Site audit preparation

Based on energy evaluations on more than 250 pulp and paper machines in North America:

- Annual energy-saving opportunities range from $100,000 to $10 million on a single machine. The $10 million energy-saving opportunity was on a paper machine evaluated in 2008 when energy costs were high. The machine has since been shut down.
- Annual energy-savings opportunities averaged over $250,000 per machine on 20 tissue and towel machines evaluated.
- Typically, 25%-50% of savings opportunities identified can be implemented with no capital cost.
- The most successful energy-reduction programs have an energy champion to monitor and expedite energy-reduction projects.

Focus on Energy can provide site audits to further uncover energy-reduction opportunities, which consider site interactions and process interrelationships. A typical Focus on Energy site audit follows the outline below:

1. Mill visit is scheduled with the paper mill.
2. Mill personnel complete paper machine energy scorecards and equipment spreadsheets before the mill visit.
3. Mill personnel submit other energy-related information including clothing supplier service reports, dryer studies, vacuum studies, refiner studies, DCS printouts on major grades, etc.
4. Kickoff meeting on the first day of the mill visit to discuss mill objectives, preliminary conclusions from scorecard review, establish a schedule for the visit, etc.
5. Review scorecards with operating personnel.
6. Mill walkthrough to identify energy-reduction opportunities.
7. Flow measurements are taken to identify water conservation opportunities, etc.
8. Discuss observations from walkthrough and potential energy-savings opportunities with mill personnel.
9. Develop energy performance indices.
10. Develop recommended energy-reduction actions and review report with mill energy coordinator.
11. Have mill visit exit meeting to discuss findings and recommendations.
12. Follow up and provide assistance on implementing energy efficiency projects.
13. Energy advisor provides assistance on applying for Focus on Energy incentives.

ENERGY MANAGEMENT

Energy management program development goes beyond lowering on-peak demand and improving energy efficiency. Pulp and paper companies should incorporate a broad range of energy management goals, including:

- Improving energy efficiency to reduce the facility's total energy cost.
- Learning how and when the facility uses energy.
- Minimizing fee/rate impacts by controlling peak electric demand.
- Managing systems when there is energy-cost volatility.
- Improving the efficiency and effectiveness of the operations serving the company's core mission.
- Striving for energy neutrality when opportunities exist.
- Implementing cost-effective renewable energy.

Pulp and paper facilities are tasked with maximizing productivity while protecting the environment and creating shareholder value. The goals listed above consider both the costs associated with energy consumption and system reliability. A good energy management plan needs to balance these goals according to their feasibility and the priorities of the facility.

Understanding goals

The goals of an energy management program often overlap with other best practices for pulp and paper mill management. For example, an effective preventive maintenance program can improve motor efficiency and system reliability. Computerized maintenance programs can also contribute to the achievement of energy management goals if they provide specific information about equipment, such as motor size and equipment capacity, which can be used in profiling facility energy use. Preventive maintenance can be scheduled to indicate when equipment needs to be replaced, ensuring that adequate time will be available to assess energy efficiency options.

Programming can include energy benchmarking at the facility level. The data can enable the tracking of specific end uses, as well as the overall mill energy usage. Energy benchmarks based on output–for example, gallons used, steam consumption, and kilowatt hours of electricity consumed per ton of product–can give the mill a better sense of overall usage trends and how its energy efficiency investments perform over time.

The implementation of energy management practices can also have additional beneficial effects, such as:

- Higher production rates.
- Improved pulp and paper quality.
- Lower water consumption.
- Reduced effluent treatment requirements.
- Lower maintenance.
- Increased equipment life.
- Reduction in chemical consumption.
- Lower utility surcharges.
- Improvement in staff communications and morale.
- A better understanding of mill operations.

These ancillary benefits should be considered when evaluating prospective energy management opportunities.

Understanding energy cost as it relates to usage is critical in managing energy at a mill. To do so requires a full understanding of the energy rate structure relative to quantity of usage and time of use. Pulp and paper mill manufacturing are intrinsically energy intensive. Energy monitoring and detailed analysis can have significant bearing on the ability of a facility to manage its energy usage.

Building a program

This section outlines a nine-step approach to developing an effective energy management program. This approach will ensure a systematic process to document, analyze and support energy-related decisions both the Energy Team and stakeholders can understand.

Most options for reducing energy use involve some commitment of resources, typically a capital investment, maintenance spending, or a modification to standard operating procedures. Trade-offs among various values can make investment decisions difficult, underscoring the need for a diverse Energy Team that can evaluate changes from a variety of perspectives to ensure none of the company's primary goals are compromised. High-quality energy use information allows the team to evaluate the benefits and costs and fully address the facility’s priorities in the decision-making process.

When pursuing the goal of system-wide energy efficiency, it is imperative to continually monitor and assess where additional energy efficiency can be achieved. Energy management is a continuous effort requiring long-term support.

Each of the nine steps are described in more detail on the following pages.

Basic steps in building an energy management program

Step 1

Establish organizational commitment

Step 2

Assemble and initiate an Energy Team

Step 3

Develop a baseline of the facility’s energy use

Step 4

Prioritize opportunities for implementation

Step 5

Identify and assess project opportunities

Step 6

Develop profiles of energy usage for major equipment types

Step 7

Develop and implement the plan

Step 8

Track and report progress

Step 9

Continually update plan and achieve energy management goals

Step 1—Establish organizational commitment

While this may seem simple, this step may be the most critical to the success of an energy management plan. In addition to approving and supporting the formation of an Energy Team, this step ensures projects will be able to advance to implementation. Successful energy management requires a focused, coordinated, and empowered effort across all levels and disciplines within an organization.

KEYS TO SUCCESS

- Understand the value of system-wide energy efficiency.
- Identify and secure management support.
- Establish and communicate measurable long-term energy goals.

Step 2—Assemble and initiate an energy team

This step focuses on building a solid Energy Team that is comprised of key stakeholders. Representatives must be committed to supporting long-term energy management. Because energy management intertwines many organizational boundaries, a diverse team that understands the wide array of issues around energy use needs to be in place. While the specific level of effort required from different team members may vary over time, it is essential to maintain involvement, commitment, and support from each team member.

Pulp and paper mills should assemble an Energy Team that represents as many stakeholders as possible, including management, administration, accounting, compliance, operation, and maintenance. The integration of all of the disciplines into the team allows for input from all business and operational perspectives and distributes the responsibility of achieving the goals.

The team must also seek and maintain the support of management, so it can continue to be empowered to take actions necessary to guide the facility toward energy plan implementation.

An Energy Team is responsible for:

- Profiling energy use.
- Identifying and evaluating opportunities.
- Establishing attainable energy goals.
- Prioritizing and selecting projects.
- Procuring the resources necessary to make each project successful.
- Measuring project impacts.
- Reporting impacts and results to management.

A strong Energy Team will help to resolve many of the organizational barriers to improving energy use. In some facilities, the operations staff is never involved in evaluating energy-procurement decisions and may never see energy bills. This lack of awareness of the impact of energy usage on production is counterproductive not only to the achievement of energy efficiency goals, but to fiscal responsibility as well. In an effective energy management model, a cross-functional Energy Team improves communication between the business group and the operations staff, reinforcing the connection between energy use and energy procurement.

To start this step, an Energy Team should invite representatives from all major departments in the mill.

An advanced Energy Team will:

- Consist of representatives of each critical stakeholder.
- Set a reasonable schedule for meeting that takes advantage of early momentum.
- Develop an Energy Management Plan (EMP). This plan should establish the overall mission and document the organization's commitment to achieving system-wide energy efficiency goals. Details of the plan, including scheduling and assignments, will be added as the team gains a better understanding of needs, resources, and opportunities through initial investigations.
- Establish performance goals, metrics, and incentives. This task includes establishing benchmarks and targets, and identifying ways to measure changes in performance indicators, as well as ways to encourage support of these efforts. This also includes establishing a communication plan to define how information will be shared, assigning tasks, and setting a schedule of milestones and deadlines.
- Define resource needs. Facility management should demonstrate a commitment to the team by allocating resources to achieve the stated goals. The team will be responsible for identifying resource needs such as staff time, equipment, external consulting support, and budget. Resource requests should be balanced by projected energy benefits with respect to core functions.
- Assign responsibilities and tasks to team members and support staff as needs are identified.
- Serve as an energy information clearinghouse. The Energy Team should be a facility-wide resource that provides information about energy use and coordinates communications about any projects that affect energy use. For example, recommendations from the Energy Team should be coordinated with the capital improvement planning process and annual maintenance program.

KEYS TO SUCCESS

- Achieve management support and participation.
- Attain cross-functional representation.
- Allocate adequate resources (time, staff, budget, expertise).
- Establish performance indicators demonstrating progress.
- Communicate intent to all employees.

Step 3—Develop a baseline of the facility's energy use

This step focuses on gathering readily available energy use information and organizing information into a basic model able to help facilities understand energy use patterns and communicate findings. The model can be as simple as plotting energy bills over time (e.g., total kWh by day or month) or as complex as listing all of the major energy-using processes and specific power data.

In this step, facility personnel will collect the data needed to provide an energy baseline against which future energy use will be compared. This will be especially useful to assess the energy, and non-energy, impact of projects. Data should be relatively easy to collect, such as that obtained from existing metering, and should be time-labeled. Baseline data should include production data along with steam consumption, fresh water consumption, electricity use, process heating, compressed air use, and effluent flows.

Based on the facility's goals, the Energy Team will need to identify a way to measure success in terms of energy usage. The measure of success, or Key Performance Indicator (KPI), will be expressed in production units such as kilowatt-hours per ton of product. By tracking the KPI over time, facility personnel will be able to detect changes in energy usage per unit of output from changes in activities or equipment.

Each time an intervention is made, such as the installation of new equipment, the time should be recorded on the timeline of the tracked data so the impact of the energy improvement can be seen and quantified. For the most accurate results, the energy use data on large process equipment should also be collected, especially equipment that can be impacted through established energy-reduction procedures. The data can then be assembled into systems for analysis of the process system. Tracking KPIs can also show changes in procedures, changing process requirements, or equipment wear. It can even show how energy usage changes with new equipment or facility additions.

An Energy Team should focus on improving the understanding of where, when and why energy is used within pulp and paper manufacturing processes and include it in their energy management plan. Studies have demonstrated that even the process of investigating energy use and improving awareness among staff can provide measurable annual energy savings ranging from 3% to 5% per year.

An advanced Energy Team will:

- Collect and organize data on equipment, energy use, energy costs, process vent losses and excess utility consumption. At a minimum, one year of data should be analyzed to identify any seasonal patterns, with preference for three or more years worth of data for a more thorough analysis. Data sources can include utility-billing records, supervisory control, and data-acquisition system records, Operations and Maintenance (O&M) records and equipment/motor lists with horsepower and load information.
- Develop an understanding of where, when, and why energy is used. Organizing treatment processes by functional area will facilitate energy planning and management on a process level and will also make performance measurement and baseline development easier.
- Evaluate energy bills and understand the energy-rate structure. Many energy-management strategies are directly linked to the pricing of energy, and it is critical to understand how the energy-rate structure affects energy costs. Reaching out directly to the power utility account manager for additional assistance in understanding your electric bill and available rate structures should be considered.

- Assess the relationships between production and energy use. Analyze data at several time frames to identify seasonal patterns and the effects of changing grade requirements.
- Build a basic energy use model based on a conceptual understanding of the utility operation to organize data and capture energy use patterns. In the early stages of energy management, typical models can be created using a generic spreadsheet. Larger operations should consider purchasing specific software for organizing energy data. The level of modeling sophistication can range from a basic motor list, providing horsepower and energy demand (kW), to a time-varying (dynamic) model predicting hourly demand and energy costs. The process of modeling can help to identify the most helpful types of information, the limitations on currently available information and what data needs to be gathered. In addition, an energy use model can be a valuable tool for testing theories, validating an understanding of energy use, calculating performance metrics, and visualizing and communicating energy use patterns.
- Create basic graphics and reports to communicate initial findings. Although this step occurs early in the process, it can produce some valuable insights that should be shared with a wider audience, including systems management, administration, and operations and maintenance personnel.

KEYS TO SUCCESS

- Begin with simpler tasks and gradually increase the complexity of the information gathered to match goals, needs and resources.
- Use initial findings to organize and justify more detailed information gathering in the future.
- Develop and maintain accurate utility and process flow sheets.

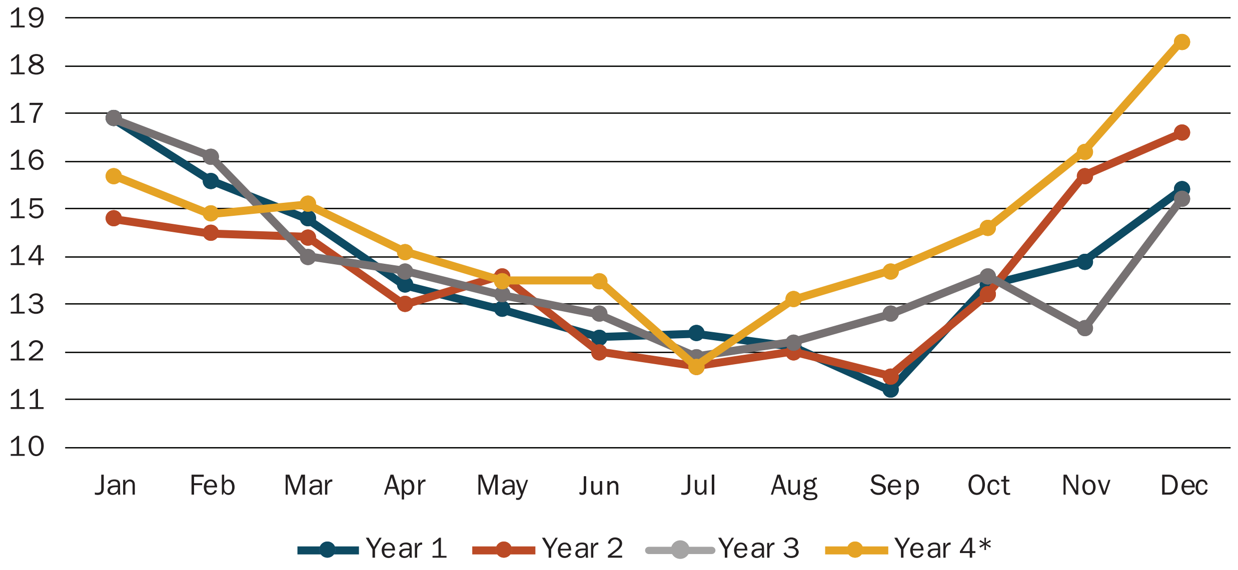
For any type of facility, baseline energy use is the actual energy use under current operating conditions for a given period of time, such as one year. One year is usually preferred so that seasonal energy use is considered. For purposes of comparison, a baseline is usually measured before new best practices are implemented. Baseline energy use can be measured both at the specific process level and at the entire system levels. Energy baselines can be measured at different levels of operation and can be derived from energy bill data. When an energy improvement measure is completed, the new usage can be compared directly with the previous baseline usage to determine energy savings.

Many pulp and paper mill managers index their facility's energy usage through a production or demand index, such as million Btus per ton of product. This index is called a Key Performance Index (KPI) or Energy Performance Index (EPI).

Establishing an energy baseline helps facility managers understand the change in efficiency relative to producing pulp and paper products.

Figure 3 illustrates an example pulp and paper mill's KPI tracking relative to their goal. The elevated levels in the cooler months illustrates the impact of process water heating and, to a lesser extent, building heating. Water reduction, and reuse projects will tend to flatten the profile. An improvement of 3% per year is very achievable as a site energy-reduction goal. If this KPI shows a decline in energy efficiency, internal action should be taken to identify and resolve root cause.

Figure 3: Monthly KPI tracking MMBtu/ton



Note: Even though Year 4 KPIs exceeded Years 1-3, an explanation of increased energy usage could be tracked and identified through the exercise of establishing KPIs.

Step 4—Develop profiles of energy usage for major equipment types

This step relies on collecting data for current operations to be used in tracking energy usage. The facility manager should know which end uses in the operation–such as pulping or refining–consume the most energy. A full profile of energy use with respect to end use should be developed. See Appendix E: Electrical Distribution for typical electrical consumption by end use for pulp and paper manufacturing.

An advanced Energy Team will:

- Perform system walk-through assessments to verify equipment lists, size and capacity of equipment, and operating status, particularly for major processes.
- Conduct staff interviews. Use these interviews to build understanding of operating practices, maintenance practices and history, regulatory and engineering limitations, and operational priorities. In addition, collect suggestions for energy-efficiency project opportunities.
- Gather energy performance data. Fill gaps in the energy model with field data. This may include direct measurements using a power meter, tracking average equipment run times of motors throughout the day or using a more sophisticated submetering system to gather actual energy use and time-of-use data.
- Track energy performance by equipment process. The data from the various end-use systems can be applied to understanding the overall facility KPI discussed in Step 3. Furthermore, if an equipment process contributes significantly to total energy use, it may be worthwhile to develop an individual baseline and process performance index (ppi) for the specific process. When KPIs and equipment performance characteristics are obtained for the system and key processes, the performance of energy projects can be measured and tracked. Performance

metrics can be compared with historical data or engineering design criteria or can be used for benchmarking comparing performance with peer facilities (see Step 7).

- Update the energy use model, detailing it with equipment-specific data. Make any improvements and/or corrections in the energy use model using newly gathered field data and observations. This may include refining assumptions such as the loadings or times of use for various pieces of equipment and processes.

KEYS TO SUCCESS

- Use energy baseline results (Step 3) to discover and prioritize field efforts on the most promising opportunities such as large motors and energy-intensive processes. It may be economical to collect field data only for the largest equipment. Approximations may be an acceptable alternative to field data for smaller systems and motors.

Step 5—Identify and assess project opportunities

Achieving system energy efficiency requires consideration of both energy efficiency and renewable energy opportunities. While efficiency reduces energy consumption, renewable energy enables the system to use available “free” energy from the system, including solar, wind, and biogas. Each opportunity must succeed on its own cost-effectiveness with respect to the system’s specific needs, and both types of projects should be considered side-by-side when making energy project investment decisions.

Begin by using the data profile to identify energy project opportunities and prioritize them in the context of the overall business and priorities of the company. If the expertise to analyze the opportunities does not exist in-house, consider hiring an external expert who can develop a list of priorities and an implementation plan.

An energy efficiency opportunity can be any system change (equipment or operations) reducing energy consumption or power demand. A renewable energy opportunity can be any usage of available energy from the wind, sun or biogas able to displace purchased energy. In this stage, the Energy Team will identify a list of energy efficiency opportunities with the intention of evaluating and prioritizing them according to feasibility and cost-effectiveness. Ideas for energy efficiency may come from a variety of sources, including reference materials, success stories from similar pulp and paper mills, interviews with staff, consultant recommendations, or discussions with energy providers or energy efficiency program advisors. Categorizing energy efficiency opportunities by process area or funding approach can help organize a large amount of information into a manageable format. Examples of categories for organization include:

- Capital program versus equipment replacement.
- Process (refining, pumping) versus ancillary technology (lighting, HVAC, etc.).
- Operational change (a change in the sequence or the way operations are done by facility personnel).
- Automation or controls.
- Maintenance improvements.
- Business case analysis results.

An advanced Energy Team will:

- List and categorize best practice opportunities, focusing on large equipment and processes where the greatest savings opportunities exist.
- Investigate similar projects implemented at peer facilities.
- Discuss energy efficiency opportunities with external experts, such as utility account representatives, energy efficiency program providers, and other external consultants.
- Rank projects based on business case analysis results (payback, life cycle cost, ROI, etc.).

ATTAIN ENERGY NEUTRALITY

Is it better to save energy or to produce it? The goal of attaining energy neutrality can be incorporated into any system's energy management plan.

BECOME ENERGY EFFICIENT

The trade-offs between energy efficiency and renewable energy development are often complex. Generally, placing emphasis on energy efficiency before renewable energy projects makes sense because, when a system's energy-usage footprint is minimized, it becomes easier to meet the remaining energy needs with internally generated renewable energy resources. Pulp and paper mills often have opportunities to recover and reuse wasted energy, and in some cases, waste streams can be used to generate electricity onsite.

ASSESS THE SITUATION

In the normal sequence of project development, once energy efficiency has been achieved at a facility, the next step is to assess the feasibility of renewable energy options. A variety of renewable sources are available: solar, wind, hydro and biogas, among others. Each source should be assessed site specifically for feasibility and lifecycle cost. A combination of renewable resources may even be appropriate for a site. If the effluent characteristics allow, biogas production and beneficial reuse can be considered. Hydro generation could also be considered, provided the system is continually maintained and optimized.

FIND THE RIGHT FIT

Each renewable resource can be assessed for what may best fit its system requirements in terms of technical feasibility and cost-effectiveness. If the effluent characteristics allow, biogas production and beneficial reuse can be considered. Hydro generation is also a possibility at many mills, and if implemented, should be optimized and well-maintained.

KEYS TO SUCCESS

- Complete a list of energy-project opportunities.
- Consider the relationship of each listed opportunity to the Energy Team's stated goals.
- Initially focus on the larger system opportunities while including a wide array of energy-efficiency opportunities.
- Consider renewable energy opportunities, as well as energy efficiency, that will be cost-effective and make sense for the system.

Step 6—Prioritize opportunities for implementation

The final product of this step is a short, prioritized list of energy projects that have been carefully evaluated for energy-saving benefits from the list of opportunities generated in Step 5. This short list of prioritized energy projects should be based on the mill's business priorities and the ability of the projects to meet the facility's stated energy goals. As identified and evaluated by the cross-functional Energy Team, the listed projects must be economically viable and able to be implemented with minimum risk or conflict.

Prioritizing energy projects may be difficult when comparing the goals and risks of different, competing projects. In this step, the Energy Team will compare the various benefit and cost trade-offs. Whenever possible, a benefit-cost test should be applied to prioritizing projects. The energy team should initially focus on projects that are easy to implement with no capital cost. The company will also apply its own economic evaluation methods such as payback, return on investment, or lifecycle cost to prioritize energy projects.

Any complete evaluation of options must also consider intangible effects such as risk to compliance or the potential impact on the health and safety of workers. Assigning a dollar value to benefits—such as reducing the risk of process failure or improving operator safety—can be challenging. In such cases, it may be necessary to develop more specialized evaluation criteria.

An advanced Energy Team will:

- Evaluate the monetary characteristics of the proposed energy projects. Choose appropriate evaluation methods, quantify the benefits and costs, convert all costs into equivalent terms, and tally the results.
- Identify suitable evaluation criteria to compare the benefits and costs of nonmonetary features of the proposed energy projects.
- Combine the nonmonetary and monetary values. Score and rank the benefits and costs of each proposed project and organize the summary evaluation into a presentable format for communication.
- Ensure the results make sense with respect to the facility's overall capabilities and mission. Implementing energy projects should not undermine a facility's capacity to implement necessary changes with respect to production or compliance.

KEYS TO SUCCESS

- Convert all benefit-cost criteria into monetary terms whenever possible (monetary terms are easy to compare and communicate).
- Evaluate all energy goals, including ancillary benefits, whenever possible.

Step 7—Develop and implement the plan

This step ensures the energy management plan reflects the priorities of the stakeholders and is effectively executed to realize energy benefits. The plan will include specifications for projects, a schedule for completion, a budget, task assignments ,and expected results based on previous analysis. The plan will show relationships of energy projects to each other and existing processes, potential shutdowns or other changes in routine schedules, and any risks to performance of core activities. Tracking and reporting mechanisms will be put in place to report results once the projects are installed and operational.

Ultimately, any implemented project must demonstrate an impact on the facility's overall energy performance, with respect to its designated KPI. The energy management plan can help forecast the change in KPI based on evaluations conducted prior to installation.

Steps 4, 5 and 6 helped identify and prioritize energy-project opportunities. This step focuses on implementation.

An advanced Energy Team will:

- List the energy-project opportunities selected for implementation and clearly describe the objectives of each.
- Indicate the resources needed, including time, staffing, budget, and financing plan.
- Discuss any associated production factors, including technical risks.
- Develop and procure any specifications needed, including design criteria and procurement-related documents.
- Identify any expected changes in standard operating procedures and/or process control strategies.
- Develop a schedule for implementation, including milestones and the procurement of the necessary regulatory approvals (if applicable).
- Set realistic expectations for the project(s) in terms of resource procurement, scheduling, anticipated production impacts, energy impacts, and forecast benefit cost.
- Tie the forecasted impacts to the KPI.

KEYS TO SUCCESS

- Describe clear, measurable project objectives, including benefits, costs, and risk abatement.
- Receive authorization for the requested resources, including budget and contractor approvals.
- Establish a reasonable schedule for implementation.

Step 8—Track and report progress

The success of a selected project should begin to be measured upon installation. Measurements should focus on performance metrics, including the status of the installation schedule as well as the resulting impacts on energy usage, operations, maintenance, process performance, staff attitudes and productivity. Tracking provides historical documentation of patterns, trends and the impacts of project interventions. Depicted graphically, they can show dramatic results arising from Energy Team efforts. Results of performance monitoring should be communicated to stakeholders, including anyone involved in the planning process, the operations and maintenance (O&M) staff responsible for implementation, and facility management.

Often overlooked, this step is critical to sustaining an energy management program. It provides insight into making necessary adjustments to improve performance, guidance for future decision-making, and motivation for staff to continue on course and achieve goals.

An advanced Energy Team will:

- Establish the appropriate performance metrics.
- Find or create a reasonable benchmark able to serve as a performance target with respect to KPI.
- Assign responsibility and allocate resources for tracking and reporting the progress of a project.
- Create a communication plan specifying what should be reported, to whom progress reports are delivered, when the reports should be delivered, and any follow-up actions required.

KEYS TO SUCCESS

- Use reliable, measurable performance metrics.
- Follow up on data analysis, e.g., investigating when data appear irregular or celebrating when success is indicated.

Step 9—Continually update plan to achieve energy management goals

As lessons are learned and progress is made toward achieving the energy management plan's goals, the Energy Team will want to adjust the plan to reorder priorities, procedures and assignments to ensure the long-term plan is a success. The Team should employ a continual improvement process by identifying and refining new project opportunities and adjusting the implementation plan according to changing needs.

This step is a reminder that energy management is not a one-time action and needs to be embraced as a continuous and ever-changing process so it becomes a seamless part of the business practice of the facility. The pulp and paper industry in general should continue to move forward in its quest to implement energy efficiency and renewable energy, both in retrofits and new designs.

Over time, needs and priorities for a mill process will change. This may be, in large part, due to the impact energy projects have had on the system, as well as a variety of external factors such as grade mix and market conditions. In addition, the system operators will learn valuable lessons over time regarding team dynamics, project development, and communications.

An advanced Energy Team will:

- Monitor the impacts of projects on the system and determine results.
- Learn where there have been successes or failures so future adjustments can be made.
- Monitor the KPI and process performance indices to look for additional improvements.
- Reset goals and tasks as circumstances require.

KEYS TO SUCCESS

- Use the KPI to identify irregularities and successes.
- Recognize shortcomings and adjust accordingly.
- Maintain motivation through acknowledgment and celebration.

Constraints

Most engineering decisions must be made within the context of a larger business plan, which requires determining all the impacts of proposed projects, showing a benefit-cost analysis and identifying those projects with the most promising benefits, with respect to all departments within a facility. Comprehensive awareness and understanding of all concerns and issues are requirements for good energy planning, management, and decision-making.

Typical constraints on an energy management plan include the following:

- Organizational.
- Capital costs.
- Process reliability.
- Acceptance of modifications by facility personnel.
- Regulatory requirements, approvals, and limits.
- O&M capabilities and non-energy O&M costs.
- Engineering feasibility.
- Space availability.

While effective energy management remains a very important goal, projects should not undermine design limitations or compliance with regulatory requirements. Site characteristics and all the variables influencing project selection (labor, chemical costs, disposal costs, capital costs, etc.) may render even the most energy-efficient solution or renewable energy project unfeasible.

PAPER MILL BEST PRACTICES

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Refining

Vacuum Systems

Press Section

Ventilation

Doctor Blades

Operations

DSC1—Dryer condensers and condensate return

Paper drying is the largest steam consumer in the paper manufacturing process. Measuring and optimizing dryer drainage operational efficiency is a focal point for steam efficiency and water heat recovery efficiency. It represents the starting point for a paper machine water balance.

- Condensate can contain as much as 16% of the energy used to produce steam.
- Condensate return should target 90% returned back to the boiler.
- Return all condensate from indirect steam users to the powerhouse at as high pressure and temperature as possible.
- High-pressure condensate can be returned to the boiler deaerator.
- Ensure no condensate pump, piping, or drain line leaks.
- Ensure proper level control of all flash tanks and condensate collection tanks. Use high quality visual level indicators.
- Higher pressure condensate should be pumped to lower pressure collection tanks and not to the vacuum condenser.
- If condensate must be flashed at low pressure, reuse flash steam where it will replace fresh steam:
    - Wet end dryers.
    - Preheat pocket ventilation air.
    - Steam showers (with proper trapping and piping design).
    - Flash steam should generally not be used to heat water.
- Measure and display dryer vent rates to the condenser.
- Do not control dryer drainage vacuum levels beyond what is necessary to evacuate the dryers.
- Cooling water outlet temperature is preferred condenser control. Vacuum level control is a second choice.
- Minimize blow through to the condenser through proper differential pressure setpoints, and proper use of cascade systems.
- Periodically check for vacuum leaks in the condensate system. Reference: Appendix C.

Productivity impact	No significant impact when the condensate is properly handled.
Economic benefit	Reduces amount of steam generation and steam cost per ton of paper.
Energy savings	Reduces steam consumption and boiler feedwater makeup.
Water savings	Reduces water make-up in power house. Minimizes vented steam loss, reducing the amount of vented heat being recovered from the dryer system, allowing other water sources to be reclaimed.
Stage of acceptance	Medium.
Applications and limitations	Separator tank pumps can be shut down on paper machines operating with sufficient differential pressure between steam sections.
Practical notes	Value of condensate ranges from $2,500 to $3,500 per gallon per minute per year depending on steam cost and other factors.
Resources	Inveno Engineering steam system best practices 1, 2, 3, 25, 26, 43, 51, 52, 53, 54, and 58.

DSC2—Dryer steam system maintenance

- Maintain accurate flow sheets for the steam and condensate system and measure and display real time dryer condenser vent rate.
- Add or repair steam and condensate piping insulation and inspect steam traps on a routine basis.
- Use ANSI Class IV shut-off valves (tight) for dryer section vent and safety relief valves.
- Use pilot-operated safety-relief valves on each steam section. Dryers can operate at their pressure rating.
- Use Smart transmitters on all pressure, differential pressure, blow through, and level control loops.
- Check calibration (annually) and zeroing (every outage) of dryer section pressure and steam flow meters. Maintain an accurate instrument loop record which captures the transmitter calibration, transmitter type, water leg compensation, and algorithms.
- Most issues with dryer drainage control result from improper tubing practices or transmitter calibration. Ensure accurate pressure and differential pressure (dp) indication.
- Pressure and dp transmitters positioned below the process line with properly designed impulse tubing. IMPORTANT: Any drip of an impulse line or uphill routing is a major concern and will create issues. Reference: Appendix B. Follow Kadant recommended practices.
- Install visible level indicators on all flash tanks.
- Operate thermocompressor systems without venting through the full range of operating pressure.
- Thermocompressors are specifically tuned to a specific process application. Internal components are NOT interchangeable.
- Thermocompressor motive steam must be of 1.4 times greater than the operating pressure. Follow manufacturer’s specification.
- Condensate should not be sewered. Goal is 90% condensate return.
- Replace steam powered condensate pumps. They are high maintenance items and consume motive steam.
- Repeated leaks on condensate piping can indicate excessive two-phase blow through flow or low pH.

Productivity impact	Supports high production rates. A poorly maintained system will negatively impact productivity and uses excessive energy.
Economic benefit	Steam savings.
Energy savings	Steam savings can be significant.
Water savings	Excess dryer blow through creates significant amounts of heat into dryer condenser cooling water. This heated fresh water must be recovered to avoid wasting large amounts of energy.
Stage of acceptance	Medium.

Applications and limitations	• Requires good maintenance to maximize results. • Many thermocompressors are undersized for current grade mixes. High efficiency thermocompressors have a wider operating range. • High efficiency thermocompressors represent a transitioned emerging technology.
Resources	• Inveno Engineering steam system best practices 1, 25, 26, 42, 44, 45, 52, 53, 54, and 58. • TAPPI TIP 0404-66 Thermocompressor applications for paper drying.
Synergies	Dryer steam management, resulting in reduced cooling water, impacts availability of process water reuse. The dryer system must be understood and efficiently managed as part of the overall paper machine water management.

DSC3—Components of an ideal dryer system

- Thermocompressor or modern cascade system includes:
  - High efficiency thermocompressors.
  - High pressure motive steam (100 psi over operating pressure).
  - Lower pressure make-up steam. Use of low pressure header for makeup.
  - Pressure, temperature, and flow indication on steam supply headers.
  - Temperature indication on all thermocompressor branches including after desuperheating.
- Steam splits that match the dryer splits.
- Pilot operated safety relief valves on each section header.
- Steam disconnected to bottom Unorun dryers or felt dryers.
- Desuperheaters included on each supply header; display the temperature after the desuperheater.
- Full-width dryer bars and sightglasses used in all dryers where condensate is rimming.
- Steam and condensate system should use straight piping as much as possible with minimal elbows. Bleed lines in the condensate drops. Utilize condensate flow meters for all separators and condenser tanks. Controllers tied into a distributed control computer system or dryer management system.
- Blow through flow control, or means to reduce sheet break blow through.
- Utilize visual level indicators on all flash tanks and recover flash steam.
- Few dryers shut off.
- Minimal overdrying into the size press

Productivity impact	The ideal dryer system results in maximum productivity for the asset and overall energy efficiency. Paper machine drying sections without ideal components have opportunity to improve productivity on dryer limited grades.
Economic benefit	Use of low-pressure flash steam can Include: • Cascade to lower pressure sections. • Pocket vent preheat. • Steam box supply. • Roof supply or air make-up preheat.
Energy savings	High opportunity for energy savings through efficient design of paper machine steam systems.
Water savings	Condenser cooling water and subsequent recovery can be reduced with the listed ideal system components.
Stage of acceptance	These are industry accepted components.
Applications and limitations	Application is according to the specific machine, but the principles are widespread.
Resources	TAPPI TIP 0404-063 Paper machine energy conservation. Paper machine steam system vendors.

DSC4—Paper machine steam dryer process steam and condensate

- Paper machine drying accounts for up to 80% of the steam consumption on a paper machine.
- Install stationary siphons in lead-in predryer and afterdryer section. Operate these sections with recommended minimum differential pressures.
- Stationary siphons require lower differential pressure to evacuate the dryer, hence less blow through steam venting, and fewer issues with dryer flooding.
- Scoop siphons should be considered for machines running slowly:
  - 1,000 fpm or less for 4-ft dryers.
  - 1,300 fpm or less for 5-ft dryers.
  - 1,500 fpm or less for 6-ft dryers.
- Use blow through control or managed differential pressure control to minimize steam venting on sheet breaks.
- Install dryer bars. Longitudinal bars placed inside a dryer eliminate the condensate layer and improve heat transfer.
  - Dryer bars can increase dryer surface temperatures by 20-35°F and increase drying capacity by up to 30%, depending on machine speed.
  - Full-width dryer bars ensure uniform heat transfer across the width of the sheet.
  - If retrofitting, start with the lowest pressure dryer sections, usually the predryers and afterdryers.
- Minimize the number of dryers directly draining to condensers.
- Utilize cascade or thermocompressors to reduce steam venting under operating conditions.
- Over-drying sheet by 1% moisture can require almost 3% more steam.

Productivity impact	Relative effect of dryer variables on drying efficiency: • Condensate removal: 30%. • Furnish, grade, sheet properties: 25%. • Dryer fabric design, permeability and tension: 20%. • Pocket ventilation: 15%. • Hood and dryer air systems: 5%. • Other: 5%.
Economic benefit	Reduces steam consumption per ton of paper.
Energy savings	Varies based on scope of changes.
Water savings	Dryer drainage system efficiency reduces condenser cooling water flow and quality for reuse.
Stage of acceptance	Medium.
Practical notes	Many papermakers do not have a good understanding of steam and condensate systems. Regular steam and condensate system evaluations are recommended with regular system training. Focus on Energy incentives may be available for steam and condensate system audits.
Resources	• TAPPI TIP 0404-63 Paper machine energy conservation. • Inveno Engineering steam system best practices 1, 2, 3, 25, 26, 43, 51, 52, 53, 54, and 58.

DSC5—Paper machine steam boxes

- Steam boxes improve wet end dewatering by increasing sheet temperature. In addition, steam boxes can provide cross direction (CD) profiling. Hardware on profiling steam boxes should be regularly checked.
- Steam boxes installed ahead of the last press are the most energy efficient. Since there is less water to heat than on the forming section and less sheet cooling occurs when vacuum is applied to draw steam into the web, water condenses in the sheet.
- Each 18°F increase of sheet temperature at the last press nip increases press exit consistency by one percentage point.
- Some steam boxes are installed over uhle boxes on press fabrics to improve fabric conditioning. Speed increase can be experienced, but steam application efficiency is lower than for steam box applications applying steam directly to the sheet.
- Control superheat to 5°F with desuperheating control. Excessive superheat will reduce steam box effectiveness. Insufficient superheat results in dripping or spitting.
- Supply steam boxes from low pressure steam supply. More steam pressure is not always better, as the sheet has a limit to what it will condense. A steam cloud coming out of the press section is not adding value.
- Pay attention to proper steam trap and trap piping practices for the low pressure steam supply and steam box drains. Traps selected must be vented traps.
- Check the preheat supply by dripping a small amount of water on the surface of a preheat zone: if the droplet does not vaporize, the zone is too cold.

Productivity impact	Steam box applications usually permit higher production rates. CD profiling addresses moisture streaks.
Economic benefit	Higher production rates can improve profitability. Better moisture profiles can permit higher production rates.
Energy savings	Few wet end steam box installations result in lower overall total steam consumption.
Stage of acceptance	Medium.
Applications and limitations	• Waste low pressure steam can be used on steam boxes. Steam boxes with cross machine compartments can be used to improve moisture profiles. • Energy and economic justification for steam boxes typically comes from improved moisture profile, enabling more efficient drying.
Practical notes	• TAPPI guidelines for steam boxes are 0.15–0.25 lb steam per lb of paper on forming section installations and 0.05–0.15 lb steam per pound of paper for press section steam boxes. • Steam boxes should be positioned at supplier-recommended clearances from the web. Steam boxes should be turned off when the paper machine is not dryer limited because water removal on cylinder dryers is more energy-efficient. Flow indication (not pressure) is necessary for good control. If dryer steam pressure does not go down when pressure on the steam box is increased, the added steam is not being condensed in the web. CD actuators should be checked regularly on machine shutdowns.
Resources	• TAPPI TIP 0404-58 Steam shower applications.

DSC6 Yankee dryer operation

Yankee Dryers are used predominately in tissue production but are also used in specialty paper applications. The efficiencies gained by extended contact between the paper and the surface of the Yankee dryer leads to efficient heat transfer from the high pressure steam inside the Yankee and the potential to blow hot air on the opposite surface of the paper using blowers inside the hoods surrounding the Yankee cylinder.

- Steel Yankee Cylinders:
  - Steel Yankees offer a 2% increase in thermal conductivity and due to the increased strength of stainless steel, the shell can be considerably thinner giving an approximately 6–8% increase in drying capacity at the same steam pressure.
  - Superior strength characteristics of steel (vs. cast iron) allows for significant increases in steam pressure to the Yankee.
  - A cast iron Yankee generally has an evaporation rate of 1350 to 1450 Btu/lb of water where steel Yankees typically range from 1200 to 1300 Btu/lb.
  - Steel Yankee heads can be much more easily insulated because they do not require the same frequency of inspections. Inspecting the bolts generally requires the removal of insulation which reduces the practical life of the insulation on cast dryers. Insulating steel Yankee heads yield a 2–3% increase in the drying efficiency of the Yankee.
- Linkageless Burner Controls:
  - Use of modern linkageless hood burner controls and specialized valves save from 3–7% of the burner fuel requirements (natural gas).
  - Modern burners can reduce fuel use by an additional 2%.
- Hood Design and Hood Management Programs:
  - Proper hood design and maintenance fits the hood to a clearance of between ¾ inch and 1¼ inch from the cylinder. Too little clearance risks damage to the cylinder and too much clearance wastes energy by spilling heat. Hood clearance should be checked regularly and centerlined every 1-2 years.
  - Hood air balance is critical to energy efficiency with the Wet End Hood targeted at 100% and the Dry End Hood targeted at 95%. Below these targets causes excess gas usage, dust build up and profiling issues. Running above these targets causes blow outs, reduced heat recovery and even fires.
  - Modern design can control for humidity within a desired range while keeping the hoods in balance. Control of the hood balance coupled with humidity control can reduce gas usage by up to 25% versus a hood where neither are automatically controlled.
  - Gas input to each hood section (Wet End and Dry End) should be measured on an on-going basis and tracked to find emerging issues.
  - The velocity of the hot air impinging on the paper surface is critical and should be verified according to the OEM specifications every time the hood is audited.
- Hood Exhaust:
  - Hood Exhaust should be cascaded towards the wet end of the machine.
  - Hood Exhaust from a Yankee can exceed 400°F and needs to be captured for heat recovery. Typically, that is two or preferably three stages of heat recovery: 1) air to air) air to glycol 3) air to water (spray economizer).

  - Limiting the exhaust concentrates the heat making it easier to recover and more valuable to the recovered heat users.
  - Waste exhaust heat from Yankees is hot enough to operate a steam generator.
- General Operation:
  - Cylinder drying (with steam) is more efficient than gas fired air impinging on the surface of the paper, with an evaporation rate of 1200 to 1450 Btu/lb of water for cylinder drying and 1650 to 2200 Btu/lb of water for modern hood air systems. Run with a maximum of cylinder drying whenever possible.
  - Fans and blowers should operate with VFD's to allow for computer control.
  - Hood and dryer audits should be conducted every 5–7 years.

Productivity impact	• Most vendors of steel Yankees estimate a 10–15% increase in productivity. Hood controls can add significant capacity (>10%) on dryer limited machines. • Productivity gains are also associated with reduced downtime for safety inspections on steel Yankees.
Economic benefit	• Energy savings. • Long term maintenance savings on steel Yankees.
Energy savings	• Steam savings, although steam use will be maximized to increase production and reduce natural gas use in the burners which ultimately saves on total energy used. • Head insulation is common on steel Yankees. • Significant heat recovery opportunities.
Other benefits	Safety is enhanced by steel Yankees being less brittle and having increased elasticity versus cast iron.
Stage of acceptance	• Low. It is estimated that >90% of all Yankees in Wisconsin are cast iron. • Humidity control is considered an emerging technology in Wisconsin. • Modern linkageless burner controls and valves are well accepted but still only found in <20% of installations in Wisconsin.
Applications and limitations	Each of the best practices described are applicable to most Yankee dryer installations. The cost of moving from a cast iron Yankee that is not at the end of life to a new steel Yankee is considerable with the payback versus grinding and remetallizing an existing cast iron Yankee giving a 6-10 year payback before considering productivity gains, maintenance savings and increased asset life. Similar paybacks are seen with full hood replacements and controls with the same exclusions for increased productivity, reduced maintenance, and increased asset life.
Practical notes	It is not economical to replace a cast iron Yankee with a new cast iron Yankee given all of the energy savings and other benefits of steel Yankees.
Resources	TAPPI TIP 0404-25 Through drying. TAPPI TIP 0404-49 Yankee dryer steam condensing rates.
Synergies	Because a majority of the energy use on a paper machine is in the dryer section, proper operation of the Yankee dryer and hoods is essential to efficient operation of the paper machine.

WT1—Water conservation

- Investigate all sources of water used in the papermaking process to identify potential areas of conservation. Use a down-day to perform a “sewer walk” to identify all entry and sources of fresh water.
- Identify all processes where heating of process water occurs. Measure the heating required.
- Establish a cost of water. Costs include:
  - Water heating from average fresh water supply to process temperature.
  - Water supply and its treatment.
  - Wastewater treatment.
  - Fiber and chemicals carried through water.
  - Each source of water should have known cost, such as potable water vs. process water.
- Water infiltration into an evaporative process carries very high heating costs.
- Measure fresh water flows. Use a clamp-on flow meter to identify flows. Measured flows should include:
  - Gallons per minute (gpm) and temperature of flows into the machine hot water collection tanks.
  - Dryer condenser cooling water flow and any flow that contains tempered water.
  - Fresh water make-up.
  - Estimate tank overflow to determine how much water is being wasted.
- Rotating seals are a significant entry for fresh water.
- Cascade use of fresh water. Use the coldest water for cooling application. Reclaim and reuse, retaining the heat value. Keep cold water cold, and hot water hot.
- Find beneficial use for all tempered water according to the temperature. Do not displace warmer water with colder sources.
- Pulp mills tend to have excess heated water. Find uses for the water to displace heating. Heat can also be recovered from paper mill effluent or hood exhaust.
- Increase use of clarified whitewater to displace fresh water. Use filtered whitewater for all showers where possible. Good filtration and proper piping practices are essential to avoid shower plugging.
- Reduce use of seal water on pumps, agitators, refiners, etc. Install seal systems, which require no added fresh water. Use tank systems, and, at minimum, control seal flows.
- Shut off seal water when equipment is down, reuse vacuum pump seal water, or install blowers.
- Minimize mill water make-up to stock and whitewater systems. If you are running out during a batch, design an alternative supply.
- Maximize entering stock temperatures.
- Use single nozzle traversing showers and smaller diameter nozzles.
- Keep cool water out of warm and hot water systems.
- Modern saveall in good operating condition.
- Eliminate once-through vacuum seal water with cascade or recirculation system.

Water Conservation

Economic benefit	Reduced steam use. Lower water treatment cost.
Energy savings	Steam savings will result from excellent water conservation practices. Savings are significant but vary by application.
Water savings	Warm water from pulp mill and greater use of clarified whitewater reduces mill water use.
Stage of acceptance	Medium.
Practical notes	Wet end chemistry and food grade requirements may restrict tightening water systems on some grades. Usually that tight of a system is seen by very few. Most mills are very open on the water consumption side.
Resources	TAPPI TIP 0404-63 Paper machine energy conservation.

WT2—Shower water

- Use filtered/polished whitewater for low- and medium-risk showers:
  - Breast roll showers.
  - Knockoff showers.
  - Lubrication showers.
  - Wetting showers
- Use warm water within 5 °F of silo temperature for high-risk showers:
  - High pressure wire cleaning.
  - High pressure felt cleaning.
  - Investigate use of single nozzle traversing showers.
- Minimize shower water demand with smallest practical nozzle sizes. Change high pressure nozzles on a regular bi-annual basis to minimize excess flow due to wear.
- Modern saveall in good operating condition.
- Clarified process water can substitute fresh flush water in rotating equipment.

Productivity impact	Higher production due to better fabric cleanliness.
Economic benefit	Use of clarified whitewater reduces fresh water use and water heating requirements. Each gallon per minute of mill water reduction can reduce annual heating cost by $750–$1,250 depending on steam cost.
Energy savings	Can be significant.
Water savings	Can be significant.
Other resource savings	Reuse of process water also captures process water chemistry and may recover associated fiber.
Stage of acceptance	Medium. Robust systems that do not plug nozzles are critical in operations acceptance.
Applications and limitations	Clarified whitewater solids content must be low to avoid plugging shower nozzles.
Practical notes	• Whitewater solids content and filtration equipment operation must be monitored to avoid plugging showers. • Some mills use super clear whitewater for high pressure felt cleaning. • Typical high pressure nozzle diameters are 0.040 inches. Some mill with excellent whitewater clarification and filtering use smaller diameter nozzles (0.032 inches) to reduce water use.
Resources	• TAPPI TIP 0404-61 Paper machine shower recommendations. • TAPPI TIP 0404-65 Chemical cleaning guide for press fabrics. • TAPPI TIP 0404-27 Press fabric dewatering and conditioning - suction box (Uhle box) design and vacuum requirements.

WT3—Water heating

- Eliminate continuous usage of steam for heating whitewater to be most energy efficient.
- Establish a baseline water use per ton and compare water usage to TAPPI Benchmarks found in Table 5 of the introduction. Machines with high water usage have the greatest opportunities with minimal capital.
- Determine optimum silo temperature for each machine and machine grade:
  - Minimize total specific steam consumption.
  - Warm water from the pulp mill/evaporators at least 5 °F above silo temperature.
  - Stock temperature to the high-density tank at least 5 °F hotter than silo temperature.
- No fresh water make-up into warm water and whitewater systems during normal operation.
- Ensure no leakage of fresh water through valves or emergency back-up systems.
- Reduce fresh water entry into the wet end process.
- Operate cleaning and lube showers at design pressure and flow.
- Monitor/minimize fresh water seal water flows to rotating equipment (pumps, agitators, etc.).
- Do not return tepid cooling water return into warm water tanks. Return to mill water supply or other beneficial reuse, fresh water header or makeup vacuum seal water.
- Emergency fresh water make-up set on deadband control as to minimize make-up. Measure fresh water make-up to provide visibility.
- Model the wet end water heating process.
- Measure all heated fresh water flow and temperature going into the hot/warm water recovery tank.
- Measure outflow of the hot/warm water recovery tanks.
- Identify location, quantity, and temperature of any overflow.
- Identify uses of fresh water, flow and temperatures, where process water or alternative water source could be considered.
- Recover heat from paper machine process as a source for process water heating. Non-contact heat exchangers are a better choice than direct-contact heating.

Productivity impact	Process water use displacing fresh water should not impact productivity when properly filtered, and supplied.
Economic benefit	Less steam use, less pumping, less waste treatment is required.
Energy savings	Less steam use and less pumping required. Each 1 gpm of fresh water heated from average river temperatures to paper machine process temperature has a heating cost of about $1000/year.
Water savings	Water savings can be significant.
Stage of acceptance	Medium.
Applications and limitations	Approximate cost of heating fresh water to whitewater temperature is around $1,000 per gpm per year depending on steam cost.
Practical notes	Increasing whitewater temperature can improve drainage on drainage-limited grades. Whitewater temperature above 140 °F does not increase wet end drainage capacity.
Resources	TAPPI TIP 0404-63 Paper machine energy conservation.

WT4—Wet end water balance

Gather data:

- Measure flow and temperature of all water sources, consumers and overflows at hot/warm/cold fresh water reclaim tanks.
- Measure cooling water flow along with inlet and outlet temperatures of dryer drainage condenser(s).
- Measure temperature of all condensate flash tanks.
- Consult DCS graphic to determine whether any dryer drainage vent valves (either to atmosphere or condenser) are open.
- Determine where process water is being heated and quantity of heat used.
- Measure flow to any make-up water valves that appear to be shut, to determine if they leak through.
- Determine whether any thermocompressor loops are venting.
- Determine whether any condensate tanks at paper machine or boiler house are venting any steam vapor.

Develop heat and flow balance:

- Calculate total amount of heat provided to tank(s) by recovered sources.
- Calculate total amount of heat leaving tank and determine quantity of steam being added.
- Calculate amount of heat provided by dryer drainage condenser(s).

Determine action plan based on balances:

- Are there cool water sources that cause tank overflow, while reducing average temperature?
- Does quantity of heat from dryer drainage condenser appear reasonable, based on number of dryers venting directly to condenser and vent valve positions?
- If tanks have excess input flow that causes overflow, determine if any heat exchangers can be operated in series to reduce flow.
- Are there any fresh water showers that can be reconfigured to reduce flow, converted to process water, or eliminated?
- Are thermocompressor loops venting because of incorrect design, inappropriate use, or condition issues?

Options to eliminate condensate tank venting:

- Pump higher pressure flash tanks to lower pressure flash tanks instead of an atmospheric flash tank.
- Use hot condensate to pre-heat pocket ventilation air.
- Institute a low-pressure steam header to make use of flash steam.
- Pump condensate at high temperature directly to deaerator or high pressure condensate tank.

Economic benefit	Payback is very good when the thermal heating value of reclaimed water is considered. A water/heating mass balance will assist more energy efficient modifications.
Energy savings	Thermal savings for water reuse or displacement in the wet end is about $1,000 per year per gpm.
Water savings	The wet end water balance helps identify the best places for water system changes and saving dryer energy.
Stage of acceptance	High. Modern machines integrate water conservation best practices.
Practical notes	Excellent flow sheets complete with shower design information are very helpful in the modeling of the water balance.
Resources	TAPPI presentations cover many water conservation practices.

SW1—Forming fabric-cleaning showers

Operate forming fabric high- and low-pressure showers at design pressure and flow to minimize energy and water used. Shower water temperature should be process water temperature, +/- 10ºF of wet end temperature.

Recommended showers for forming fabric:

1. Face side high-pressure shower (HPS), 6–10 inches from face of fabric, nozzles on 3- or 6-inch centers, 0.04-inch nozzles, 450 psi max, oscillated 1 nozzle diameter per fabric revolution.
2. Recommended inside high-pressure shower.
3. Flooded nip shower, fan nozzles forming puddle in ingoing roll/fabric nip: volume equal to fabric running void volume for sheet knockoff (see TAPPI TIP 0404-61), lower volume adequate for flushing cleaning.
4. Conventional knock-off shower inside flushing shower for sheet knockoff and cleaning: Volume over 1 gpm/inch.
5. Chemical passivation shower: low volume shower with double nozzle coverage applied as close before headbox as possible.

Productivity impact	Sub-optimal showering results in compromised overall fabric drainage efficiency and CD profile with consequent loss of sheet formation, drainage efficiency, and reduced fabric life.
Economic benefit	Optimal showering contributes to maximum fabric efficiency. Clothing cost depends on good showering, but the most important benefit of good operation is optimal sheet drainage and formation with consequent downstream efficiency impacts.
Energy savings	Reclaimed tempered water or recycled water used in showers results in steam savings from reduced water heating. Improved profile and dryness improve press efficiency and, thus, saves drying energy.
Water savings	Reused whitewater for showers, especially high volume knock-off showers, saves water, and decreases water heating demand.
Other benefits	Improved forming section hygiene from controlled contaminants.
Stage of acceptance	All paper machines have some fabric showering, but because sub-optimal shower operation tends to develop long-term, showers are often neglected. Most commonly, nozzles wear or plug, and showering becomes sporadic. Often too much water is used.
Applications and limitations	Simple measurement (good pressure gages) and observation can ensure good shower operation, but good habits must be formed. Nozzles must be periodically maintained.
Practical notes	The most common misconception is that HPS operation is better when the shower is close to the fabric. Such operation compromises effectiveness and wastes water and energy.
Resources	TAPPI TIP 0404-61 Paper machine shower recommendations.

SW2—Forming section-cleaning showers

Operate forming section high- and low-pressure showers at design pressure and flow to minimize energy and water use. Shower water temperature should be process water temperature, +/- 10°F of wet end temperature.

Recommended showers for forming section:

1. Couch roll HPS: Mount shower 6–10 inches from face of the roll with nozzle spacing on 3 or 6 inch centers, 0.040-inch nozzles, 500 psi max, oscillated multiple of 1 nozzle diameter per roll revolution, stream radial to roll.
2. Flooded nip knock-off shower: flow volume must be greater than running void volume of fabric to achieve positive sheet knock-off (see TAPPI TIP 0404-61).
3. Breast roll (apron) shower: target bottom of headbox apron to prevent build-up, even flow about 0.12 gpm/inch.
4. Wire return roll doctor lube showers: even flow across roll, contact roll just before doctor blade, typical flow 0.15 gpm/inch.
5. Lumpbreaker shower: minimal flow and even distribution to prevent picking to lumpbreaker, typical flow 0.03 gpm/inch.

Productivity impact	Sub-optimal showering results in compromised dewatering performance, poor fabric life, and poor sheet profile resulting in loss of press and, thus, drying efficiency.
Economic benefit	Optimal showering contributes to maximum machine efficiency. Clothing cost depends on good showering, but the most important benefit is optimum sheet dryness, formation, and profile.
Energy savings	Adequate shower temperature reduces or eliminates steam whitewater heating. Improved profile and dryness improves press efficiency and, thus, saves drying energy.
Water savings	Filtered whitewater should be used for the very high volume flooded nip shower and wire return doctor lube, saving hundreds of gallons of fresh water with minimal risk. Process water cleanliness is more critical for breast roll showering and most critical for consideration of any high pressure application.
Other benefits	Improved forming section hygiene from controlled contaminants.
Stage of acceptance	All paper machines have some showering, but because sub-optimal shower operation tends to be long-term, showers are often neglected. Most commonly, nozzles wear or plug and showering becomes sporadic. Often, too much water is used.
Applications and limitations	Simple measurement (good pressure gauge) and observation can ensure good shower operation, but good habits must be formed. Nozzles must be periodically maintained.
Practical notes	The most common misconception is that high-pressure shower operation is better when the shower is close to the roll or fabric. Such operation compromises effectiveness and wastes water and energy.
Resources	TAPPI TIP 0404-61 Paper machine shower recommendations.

SW3—Press section showers

Operate press section high- and low-pressure showers at design pressure and flow to minimize energy and water used. Very good operation governs HPS pressure and chemical cleaning with felt permeability or uhle vacuum and uhle water turbidity. Shower water temperature should be process temperature; hotter is better. Each 20°F increase in press exit sheet temperature increases press exit dryness by one percentage point.

Recommended showers for each felt:

1. Face side HPS: 6-10 inches from face of fabric, nozzles on 6-inch centers, 0.040-inch nozzles, 250 psi max, oscillated 1 nozzle diameter per fabric revolution.
2. Uhle pipe lube shower: fan nozzles with double coverage directed at felt just before uhle box, applied volume of 0.07 gpm/inch width.
3. Chemical cleaning shower: fan nozzles with double coverage, inside fabric as far as possible before uhle box. Benchmark volume 0.07 gpm/inch width, as determined by chemical supplier.
4. Other showers as required (roll cleaning, doctor lube) using guidelines above.

Productivity impact	Sub-optimal showering results in compromised overall press efficiency and CD profile with consequent increased drying energy and lost production, and reduced fabric life.
Economic benefit	Optimal showering contributes to maximum press efficiency. Clothing cost depends on good showering, but the most important benefit of good press operation is minimization of drying energy. Steam savings can be realized or, if sufficient fiber is available, production can be increased.
Energy savings	Rule of thumb: 1% improvement in press solids results in 4% decrease in required dryer steam.
Water savings	Excess showering can result in poor press mass balance and wasted water.
Other benefits	Improved press section hygiene from controlled contaminants. Most commonly, nozzles wear or plug and showering becomes sporadic. Excess shower supply pressure or wear results in wasted water.
Stage of acceptance	All paper machines have some press fabric showering, but because sub-optimal shower operation tends to be long-term, showers are often neglected.
Applications and limitations	Simple measurement (good pressure gauges) and observation can ensure good shower operation, but good habits must be formed. Nozzles must be periodically maintained.
Practical notes	The most common misconception is that HPS operation is better when the shower is close to the fabric. Such operation compromises effectiveness and wastes water and energy.
Resources	TAPPI TIP 0404-61 Paper machine shower recommendations. TAPPI TIP 0404-65 Chemical cleaning guide for press fabrics.

PB1—Pulper operation

Batch and under machine pulpers are among the larger motors in a paper manufacturing facility. Operation of pulpers/agitators represent an area for significant energy savings.

- Manage/sequence stock preparation pulpers to minimize peak electricity loads.
- Operate pulpers at optimum level and consistency. Shut down batch pulpers when defibering is complete.
- For dry end under machine pulping or trim pulping:
  - Install VFD on pulper rotor. Reduce rotor speed when full sheet is not present. 40Hz has proven sufficient for trim handling.
  - Install VFD on pump out pump, especially if the pump is used for trim knockdown. Alternative: Use a jockey pump for lower flow conditions.
- Control bale addition to avoid damaging gear boxes. Install bale breaker bar and assure a sufficient minimum water fill before adding bales. Presoak bales to ease pulping or for frozen bales.
- Install solenoid valves to shut off seal water when pulpers are down. Make sure water make-up valves are not leaking.
- Preferentially use process water for batch-charge water. Add charge water tank or chest to provide an adequate supply for a quick pulper fill with a more gradual charge water tank refill. Minimize freshwater entry.
- Introduction of final charge water into the pulper dump-pump suction can assist with the pulper pump out. This, with a combination of slowing down the rotor during the pump out process, greatly reduces additional water requirement.
- Install a rotor most suitable for the fiber type. Newer rotors tend to have more energy efficient designs that retain better agitation with excellent defibering. They tend to have a higher profile. It may be possible to shut down one rotor where multiple rotors are installed.
- Replace the extraction plates when worn. Extraction plate design and condition must compliment the rotor design.
- Use process water for under rotor flush, and meter the agitator shaft seal water.

Productivity impact	Can support higher production rates.
Economic benefit	Electricity savings. Can support higher production rates.
Energy savings	Electricity savings varies by application. High-efficiency rotors and extraction plates can reduce energy requirements by 25%.
Water savings	Water savings can be realized with process water prioritization and reduced freshwater entry.
Other resource savings	Longer equipment life. Less maintenance required.
Stage of acceptance	Medium.
Applications and limitations	Interlocks with reliable sheet break detectors are necessary to avoid pulper plugging in under machine pulpers that are shut off when machine is running.
Practical notes	Many pulping agitators are over-designed for the tonnages. Reducing the speed for trim handling has shown no adverse impacts.

PB2—Wet strength broke processing

Wet strength broke is typically processed by heating a batch pulper to 150°F, adding hypochlorite, and circulating through a deflaker or refiner for several hours. More energy efficient designs use dispersion technology.

- Use of deflakers should be avoided, as they operate at high rpm and have high no-load (turning) hp use.
- Reduced batch size followed by thickening and dispersion technology has proven to be a more energy-efficient means.
- Manage wet strength inventories to process wet strength broke when it is fresh.

Productivity impact	Faster processing of wet strength broke, allows increased usage of this fiber stream.
Economic benefit	Less energy required for processing.
Energy savings	Varies depending on application but can be significant.
Other benefits	Eliminates need to use hypochlorite.
Stage of acceptance	Only a handful of paper sites have incorporated this technology.
Applications and limitations	Application for sites using wet strength.
Resources	Machine vendors can provide advisement regarding the technology.

RF1—Disk refiner operation

Disk refiners offer pulp and grade specific refining flexibility with lower energy use than most conical refiners, but they need to be operated within their design criteria and under good mechanical condition to properly refine the fiber while saving energy.

- Operate at recommended rpm, stock consistency, and design hydraulic flow range.
- Control to hpd/t or freeness.
- Check mechanical condition regularly.
- Separately refine each type of pulp.
- Shut down or bypass unnecessary and underused refiners.
- Use smaller diameter plates when possible.

Productivity impact	Optimizing refining allows the operator to meet fiber and sheet specifications at higher machine speeds.
Economic benefit	Optimizing refining reduces refining electricity consumption per ton of throughput while reducing sheet breaks and improving machine runability. Proper refining can be used to control freeness and, thus, drainage on the wet end.
Energy savings	No-load (turning HP) can increase up to 20% with poor operating conditions. Also, no-load is proportional to rpm^3 and $\text{diameter}^{4.25}$. As a result, running at an rpm higher than specified by the OEM increases (wasted) no-load hp to the third power. By reducing the plate diameter, no-load hp is reduced to the 4.25 power.
Stage of acceptance	High. Generally accepted practices call for running to hpd/t, which is well accepted in the industry. Running at proper rpm is often lost as changes are made to older equipment and the use of smaller diameter plates where appropriate is not well established.
Practical notes	Refiner plate intensity affects test development. Refiner components wear over time. Checks include alignment of rotating head, hub face for runout, high inlet pressure, etc. No load HP should be compared to recommended values. High no-load indicates mechanical issues.
Resources	See RF2 and RF3 Best Practices. Commercial resources. TAPPI TIP 0508-06 Refiner systems, their inspection and maintenance.

RF2—Splined rotor

For paper machine stock preparation refiners, splined rotor and hub upgrade enables the rotor to hydraulically center the plate gap, resulting in power savings and longer refiner plate life.

Productivity impact	Can increase throughput on refiner limited grades while it extends the life of the plates and reduces downtime due to changing out plates.
Economic benefit	• Extended plate life. • Higher production and electricity savings. • More consistent refining as plates wear over the life of the plates because plates show less uneven wear.
Energy savings	Splined rotors typically reduce refining hp by 12%. For a 200 hp motor running at 70% load for 8,400 hours per year a splined rotor should save 12.5 kW and 105,276 kWh annually.
Water savings	None. Indirect impact. Splined rotors use a fixed shaft. Mechanical seals or seal water limiting devices can be used.
Other resource savings	O&M is reduced by lower plate wear and even plate wear.
Stage of acceptance	High. More than half of legacy disk refiners have been converted to splined rotors. Splined rotor upgrades are not practical for some older refiners.
Applications and limitations	Refiners with splined rotors should not be operated below minimum hydraulic flow. Plates/splines will be damaged. Anti-clash systems monitor vibration and automatically open the gap in the event of plate-to-plate contact.
Practical notes	Splined rotor conversions are available. Conversion of a mechanically sound refiner is fairly straight forward. Splined rotors allow fixed refiner shaft, which allows use of standard motor couplings, and improved shaft seals.
Resources	Major refiner vendors.

RF3—Low intensity refiner plates

By installing low intensity refiner plates, development of hardwood pulps and brown and white secondary fiber are accomplished at lower energy levels and increased throughput.

Productivity impact	Can increase throughput on refiners previously limited by refining-related fiber tests.
Economic benefit	• Increased throughput. • Drive hp reductions. • Often able to reduce the plate diameter, which reduces electricity per ton and plate purchase cost.
Energy savings	Some machines refiner limited on certain grades were no longer refiner limited after low intensity refiner plates were installed. This may allow them to reduce the diameter of the plates to reduce no-load horsepower. Refiner no-load is related to the plate diameter to the 4.25 power so a small reduction in diameter provides a significant energy reduction.
Other resource savings	Operations and maintenance may be reduced by the ability to shut down unneeded refiners.
Stage of acceptance	High. Often limited by purchasing contracts that limit the choice of plates.
Applications and limitations	Low intensity plates are more easily damaged by tramp metal. Junk traps can remove metal and other contaminants. Low intensity plate selection may reduce energy to levels that merit incentives from Focus on Energy.
Practical notes	Low intensity plates may be more expensive than other plates but typically have longer life so plate cost per ton is lower.

VAC1—Vacuum measurement

Optimal vacuum system operation maximizes sheet dewatering and fabric condition with minimum energy and water use.

- Relative cost of dewatering:
    - For every $0.01 it costs to remove water on the fourdrinier, it will cost $0.10 at the press and $1.00 in the dryers to remove the same amount of water.
- Vacuum levels:
    - Former vacuum levels are graduated and couch vacuum is adequate for optimum sheet dewatering.
    - Uhle box vacuum level should be 14-16 inHg for broken-in felts.
    - Press roll vacuum is only high enough to keep throw-off from felt (12-15 inHg).
    - Pickup vacuum is not excessive.
- Liquid ring pumps:
    - Pumps inspected regularly and operating at least 80% of specified volumetric efficiency. Motor loads are nearly the same for vacuum pumps operating at design and worn pumps.
    - Conduct regular performance tests. Rebuild/replace inefficient pumps. Rebuild pumps less than 80% of rated capacity.
    - Replace obsolete vacuum pump designs manufactured before 1960 (Nash letter pumps, etc.).
    - Test rebuilt pumps with orifice plates. Rebuilt pumps should achieve 95% of design capacity.
    - Seal water flow is 50%–100% of manufacturers specification. Colder is better. Temperature rise between seal water and outlet temperature is 30°F +/- 15°F.
    - High backpressure reduces vacuum pump capacity.
    - Verify separator performance and evacuation pump operation.
- Centrifugal blowers:
    - Separators are working and adequately evacuated.
    - Maximum practical vacuum level is 16-18 inHg.
    - Blower efficiency is optimal between 7-19 inHg.
    - Rotor vibration is monitored and kept within specifications.
    - Exhaust heat can be recovered.
    - Multistage or VFD blowers provide excellent vacuum supply energy efficiency.
    - No seal water is required.

Productivity impact	Sub-optimal vacuum results in runability issues on paper machines, particularly with former sheet dewatering, press efficiency, and felt life. Large quantities of energy can be wasted from inefficient pump operation.
Economic benefit	Efficient vacuum system operation contributes to optimal paper machine efficiency, energy consumption, and water consumption.
Energy savings	Vacuum pumps are the first or second largest power users on most paper machines. Efficient operation contributes to overall power efficiency as well as optimal paper machine energy efficiency.

Water savings	Liquid ring pump seal water is often wasted. Pump seal water volume should be monitored and controlled. It can be cascaded in pumps and, in some cases, reused in the process.
Other benefits	Paper machine overall efficiency will improve with careful vacuum system operation.
Stage of acceptance	All paper machines have some vacuum system. In the U.S., these are usually based on liquid ring pumps. These machines are very robust and often neglected, and it is easy to allow them to run at sub-optimal levels, especially with too much seal water.
Applications and limitations	Regular boroscope inspection is a relatively inexpensive monitoring technique. Orifice testing of pumps is much more accurate but more involved. Seal water volume measurement techniques are specialized, but proper volumes can be ensured with regularly maintained orifice plates and pressure gauges.
Practical notes	Higher vacuum does not necessarily translate to higher water removal. Water removal measurement should be the KPI for vacuum performance. Reliable vacuum gauges are necessary.
Resources	TAPPI TIP 0502-01 Paper machine vacuum selection factors. TAPPI TIP 0404-60 High vacuum sheet dewatering. TAPPI TIP 0420-12 Guidelines for evaluating liquid ring vacuum pumps performance.
Synergies	Paper machine dewatering efficiency and press fabric life.

VAC2—Vacuum pump seal water management

Integrate vacuum systems operations with energy efficiency practices, and reduce seal water consumption by measurement and control.

Vacuum system seal water guidelines:

- Excess seal water flow creates additional motor load. Insufficient seal water flow can reduce vacuum.
- Significant whitewater carryover will increase motor loading and the temperature can reduce vacuum pump efficiency.
- Seal water hotter than stock temperature is not recommended.
- Maintain seal water orifices and spray nozzles, run seal water at specified pressure (usually 10 psi).
- Seal water temperatures should rise 15 ° F to 30 ° F across vacuum pumps.
- Manage seal water temperature to maintain acceptable vacuum system performance. Inject cool water at pump inlet to maximize vacuum.
- Optimize seal water flows. Flow meters on seal water lines are helpful.
- Use the coolest seal water at the highest vacuum application.
- Monitor pump motor loads. Pump loads increase with excess seal water.
- Treat seal water or boil out pumps regularly if water is hard.
- Seal water systems should be closed loop with cooling tower or heat exchanger to capture waste heat, or cascade seal water from higher to lower vacuum pumps.
- Keep all separators clean and functioning, including separator evacuation pumps.

Seal water management strategy overview:

- Measure and control seal water flow.
- Cascade seal water where highest vacuum receives coolest water. Consider stainless or stainless clad pumps to reduce internal chemical erosion.
- Process water is typically too warm. Vacuum pump efficiency drops with increased seal water temperatures. High seal water temperatures can result in cavitation, which increases internal pump wear.
- Reclaim vacuum pump seal water to capture the thermal value, if economics allow.

Productivity impact	Good vacuum systems operation requires adequate seal water. However, excess seal water increases energy consumption and adds to sewer losses.
Economic benefit	Vacuum system seal water typically represents large fresh water consumption with resulting treatment flows. This tends to be low grade heat and difficult to reclaim.
Energy savings	Excess seal water can increase vacuum pump load by 10%. Vacuum pumps have an ability to operate between ½ of design to as much as 3X design. This represents a very wide range of water consumption.
Water savings	Monitoring and control of vacuum seal water has a significant impact on water consumption.

Other benefits	Sheet runnability.
Stage of acceptance	While adequate seal water supply is monitored, excess seal water supply is not typically monitored. Seal water contributes to one of the highest sources of fresh water entry and subsequent sewer discharge sources.
Applications and limitations	Excess seal water temperature reduces vacuum pump capacity. Lack of any fresh water entry can provide a source of internal vacuum pump corrosion and/or buildup.
Practical notes	The lowest cost method is to install some visual flow indicator for seal water flows. These should be routinely checked.
Resources	TAPPI TIP 0502-1 Vacuum selection factors. TAPPI TIP 0404-55 Performance evaluation techniques for vacuum system evaluations.

VAC3—Vacuum pump seal water reuse

- Liquid ring vacuum pumps consume large amounts of seal water. Heat of compression and process heat are transferred to the seal water. Seal water is typically heated from 15 ° F to 30 ° F as it passes through vacuum pump. Standard practice is "once through", fresh water is used, then sent to process sewer.
- Maintain 10 psi seal water pressure, as per manufacturer's recommendations.
- Maintain the integrity of seal flow limiting orifice unions.
- Maintain the integrity of inlet spray nozzles.
- Circulate vacuum pump seal water using strainers and a cooling tower.
- Install seal water flow meters and adjust flow to minimum required.
- Cascade seal water from high vacuum pumps (like couch vacuum) to less critical pumps (like uhle boxes or flat boxes).
- Use vacuum seal water as process water where possible: whitewater makeup or noncritical shower water.
- Use a heat exchanger to pre-heat fresh water with vacuum seal water, instead of circulating seal water through cooling tower.
- Some mills use filtered whitewater as source for vacuum pump seal water and then return it to whitewater system with a higher degree of heat.
- Use the vacuum pump's heat of compression by heating fresh water for process use (only practical for plants that have excellent separators in vapor lines to vacuum pumps). Also desired would be a fail-safe system with turbidity sensors and/or separator level alarms to prevent carryover of particulates).
- Vacuum blowers eliminate the need for seal water and provide the opportunity for heat recovery.

Economic benefit	Payback depends on cost of water and wastewater treatment and whether the associated heat can be productively used. It is possible to recover more than 70% of motor electric input on a Btu basis.
Energy savings	A typical paper machine has at least four vacuum pumps. Each vacuum pump uses from 25 to well over 100 gpm of seal water. Total motor horsepower varies from 300 to several thousand. Savings depends on process change implemented and value of water.
Water savings	Water savings vary by paper machine configuration and process change implemented but could be over 1,000 gpm.
Other benefits	Using the correct amount of seal water at appropriate temperature helps support vacuum levels and efficient paper machine operation.
Stage of acceptance	• Vacuum pumps may run for years without attention and are seldom a priority except when underperforming. • Major changes to vacuum pump systems are seldom undertaken unless process needs change.
Applications and limitations	Application may be limited by basement configuration, water quality, water temperature, process water needs and whitewater temperature.
Practical notes	Spending on vacuum systems generally has low priority and low payback compared to other energy-reduction projects.

VAC4—Vacuum pump operation

Operate vacuum systems integrating energy efficiency practices:

- Review existing vacuum pump sizing to current application.
- Graduate flatbox vacuum levels to reduce drag load and properly consolidate sheet.
- Examine early low-vac elements for flooding, and utilize drainage studies to study aggressive early dewatering.
- Utilize entire table length to better distribute dewatering.
- Number of vacuum zones, slot width, and number of slots should be optimized to achieve proper vacuum densities in the high vacuum area.
- Utilize multi-compartment high-vacuum boxes.
- Evaluate drainage element materials for impact on drag load.
- Install forming fabrics that require low drive load.
- Use fans or exhausters for low vacuum applications such as vacuum foils.
- Consider variable frequency drives (VFDs) for vacuum pumps where bleed valves are open on some orders, but not all the time. Consult vacuum pump performance curve to determine if speed can be reduced, such as flat-box applications.
- Avoid couch re-wet (suction box orientation, double doctors, air doctors).
- Optimize wet end temperatures for impact on drainage and solids.
- Monitor former exit solids frequently.
- Use measured uhle and nip flow trending to optimize fabric design.
- Analyze chemical cleaning performance, frequency, and duration.
- Ensure proper uhle box slot size to provide required flow capacity and dwell time.
- Evaluate the number of uhle boxes per felt. One uhle box often provides adequate dewatering with many fabrics and grades.
- Eliminate unnecessary vacuum boxes (remove or drop out of sheet). Proper flat box set up can remove more water while reducing table drive load by as much as 10%. If reducing vacuum boxes, reduce the vacuum supply at the same time by slowing down or eliminating the pump.
  - Follow guidelines for vacuum pipe sizing and velocities.
  - Maintain vacuum system gauges.
  - Monitor pump motor loads. High loads can indicate excessive seal water, or excess vacuum.
  - High backpressure reduces vacuum pump capacity.
- Provide a separate vacuum source for each press fabric.
- Consider blowers if electricity cost is high or water use is a problem. Blower exhaust can be a source for heat recovery.
- Label vacuum system piping, and keep all separators clean and functioning, including drop legs and transfer pumps.

Productivity impact	Good vacuum systems operation is important to achieving efficient machine performance.
Economic benefit	Vacuum systems typically represent a large connected hp. Efficient operation typically allows hp reduction without negative impact to productivity.

Energy savings	• Each HP of vacuum system reduction is roughly $1/day/HP. Compare newer design vacuum pump efficiencies in hp/cfm:
	  • H4408: 0.051 hp/cfm
	  • CL4002: 0.045 hp/cfm
	  • 904 L2: 0.040 hp/cfm
	  • Turbo Blower: 0.020 hp/cfm
	• Optimizing existing vacuum systems can reduce vacuum hp by 10-15%.
	• Blower systems range about the same for connected hp with operating hp about 30% less. Blower systems have the added advantage of exhaust heat recovery.

Water savings	Monitoring and control of vacuum seal water has a significant impact on water consumption.
Other benefits	Sheet Runnability
Stage of acceptance	Changes to the vacuum system are met with initial production resistance. Vacuum performance and its impact to production is not readily known. Most systems are not measured for performance. Only for resultant effects.
Practical notes	• Not all vacuum pump rebuild shops provide good results. Rebuilt pumps should be tested in shop with orifice plates and be at 95% of design capacity. • Pumps should be rebuilt when capacity falls to 80% of design. Electricity use is the same for new pumps and pumps operating at 70% of design or lower. • Regular evaluation of vacuum systems is recommended.
Resources	TAPPI TIP 0502-1 Vacuum selection factors. TAPPI TIP 0404-55 Performance evaluation techniques for vacuum system evaluations.

PS1—Press section optimization

Good press section performance is essential to efficient paper machine operation, if only because it has such significant impact on dryer steam use. A 1% decrease in existing press moisture can result in a net dryer steam savings of 4% or equivalent productivity. Key press efficiency factors include:

- Documenting current performance.
- Implementing use of a detailed operating log book.
- Periodic press section operations review.
- Regular and routine press section monitoring.

Opportunities to optimize pressing are manifold and include:

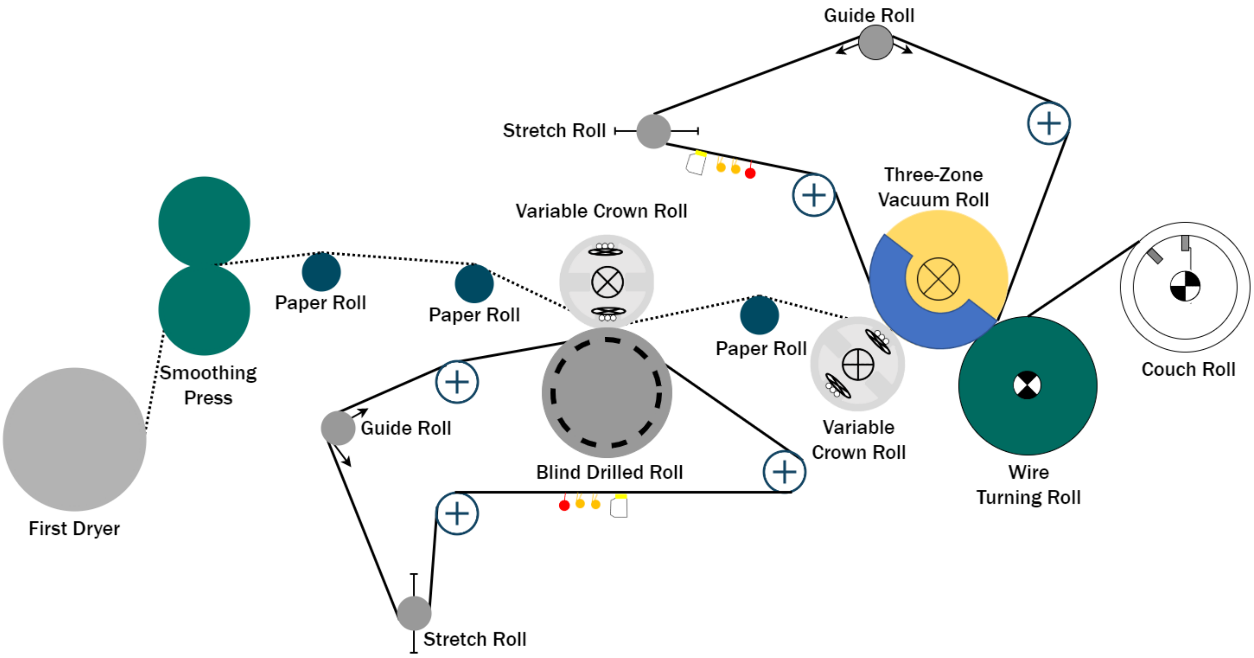
- Shoe pressing:
  - Increases dryness potential for virtually all grades.
  - Adds bulk vs. dryness for bulk-sensitive grades.
- Graduation of press loads.
- Maximize press loads.
- Determine sheet consistency after press exit:
  - Ideally with an in-place measurement system.
  - Where samples can be safely obtained.
  - If a measured value is not achievable, calculated press exit solids based on dryer steam consumption and/or hood air system balance can be considered as an alternative.
  - For machines with open draw between the last press and dryers, draw level can be an excellent indicator of sheet solids.
  - Check couch and press solids at least once every outage cycle. Maintain a database of results.
- Steam boxes increase sheet temperature and increase exiting dryness; they can also be used for profile improvement.
- Felt heating:
  - Will help clean the fabric and help maintain or increase sheet temperature.
  - May not be energy efficient.
- Optimizing rolls:
  - Cover hardness optimized for nip and press efficiency.
  - Use of blind drilled, grooved, or other cover designs to improve press dewatering.
  - Imbedded nip-pressure measurement to confirm roll performance during installation.
  - Check nip profiles and optimize crowns and dubs to improve moisture profiles.

Press Section

- Reduce first press nip intensity on high-bulk grades.
  - The first press is the most important factor affecting high bulk. The sheet is very wet and does not spring back when compressed. Reduced press loads and soft roll covers increase sheet bulk without reducing sheet dryness after the last press nip.
- Maintain shower temperature at or above sheet temperature.
- Felt and belt design optimization—press fabric design greatly impacts press efficiency.
  - Balance between nip and uhle box dewatering over fabric life.
  - Monitor pressing performance throughout fabric life.
    - Online monitoring of press water flows.
    - Frequent CD and MD monitoring of fabric permeability, moisture, and temperature.
- Minimize rewetting.
  - Optimize fabric runs/sheet runs.
  - Sleeve doctors, double doctors, air doctors.
  - Use of catch pans on high dewatering nips that generate water spray.
- Minimize draw to maximize CD strength on grades requiring high CD strength properties.
- Monitor vacuum sources to document current performance.
  - Ensure all vacuum gauges are accurate.

Productivity impact	Permits higher production rates by reducing the amount of water to be removed in the dryer section, better sheet test development and improved sheet runnability.
Economic benefit	Reduced energy consumption per ton.
Energy savings	Varies depending on changes implemented. Each one percentage point increase in press sheet dewatering reduces drying requirements by three to five percentage points.
Water savings	Can be reduced by optimizing shower applications.
Other resource savings	Press fabric life can be increased on some applications.
Stage of acceptance	Medium.
Applications and limitations	Different concepts can be applied on most paper grades depending on paper quality requirements and equipment configuration.
Practical notes	There are many variables that can be changed to optimize press section performance.
Resources	TAPPI TIP 0404-52 Press section optimization. TAPPI TIP 0404-63 Paper machine energy conservation.
Synergies	Improved press section performance can increase uptime and production rates.

Figure 4: A Schematic of a press section producing high bulk paper grade



The machine was producing 142 pounds per 3,300 square feet greeting card and had to run the basis weight four pounds high to meet bulk specifications. The first press variable crown roll permitted reducing first press load from 300 pli to 150 pli while maintaining a uniform cross machine direction nip. Basis weight was reduced from 146 lb to 142 lb while maintaining the thickness specification. Sheet dryness after the second press did not change. Machine speed was not changed although machine speed could have been increased since the basis weight was lower. Annual savings were significant due to 2.8 percent fiber savings. Roll cover hardness was 20 P&J on the 3-zone vacuum roll and 10 P&J on the variable crown roll. Installing softer roll covers (higher P&J) would provide higher bulk but would require replacement of roll covers.

MRV1—Machine room process

Operate air systems in automatic temperature control with recommended set points, and use waste-heat recovery for heat source. Up to 65% of the available heat of paper machine hood exhaust can be recovered using multiple stages of heat recovery, where the final stage is direct spray.

Industry best practice includes:

- High-performance dryer hoods. High performance dryer hoods operate with less fresh air entry, higher exhaust humidities and higher exhaust temperatures. An enclosed hood achieves 5-10% steam saving by using less air to vent the evaporated moisture.
- Heat recovery from hood exhaust used to preheat:
  - Pocket vent.
  - Glycol systems for machine room ventilation.
  - Process water heating.
- Keep dryer section hood doors closed.
- Manage hood air system to prevent hood from spilling.
- Adjust supply and exhaust air flows based on current drying load.
- Shut off steam to coils when fans are not running.
- Heat recovery from condensate flash. This is especially valuable if condensate is flashing in a subsequent condensate collection tank.
- Use air-to-air and air-to-liquid heat recovery where appropriate.
- Install and display individual heat recovery performance to assure continued performance.

Recommended set points for the following process ventilation systems are:

- Pocket ventilation: 180 °F or lower. High enough to prevent hood sweating.
- Dryer section blowboxes: 160 °F.
- Building ventilation units: 75 °F.
- Roof supply units: 120 °F.

Productivity impact	Pocket ventilation and blowbox operation is critical for paper machine drying performance without hood sweating.
Economic benefit	Payback depends on the level of action taken and baseline operating condition. Reduction of operating setpoint requires only an operator action. As much as 60% to 70% of the hood exhaust energy can be recovered. Heat recovery systems can be capital intensive, but the investment life expectancy should be decades.
Energy savings	A 1 °F decrease in supplied air temperature reduces heating requirements by 0.24 Btu per pound of dry air and more for moist air. 10,000 cfm X 0.072 lb/ft3 X 0.24 Btu/lb degree X 10 degrees X 60 minutes X 8,400 hrs/80% boiler efficiency/100,000 Btu/therm = 10,886 annual therms.
Other benefits	Sheet runnability, building preservation, and ambient conditions.

Ventilation

Stage of acceptance	Pocket vent temperatures tend to operate higher than necessary. Heat recovery systems are less efficient on older machine installations. Significant changes require extensive capital with low payback as compared to other projects. However, an asset equipped with heat recovery has a lower cost of operation.
Applications and limitations	Equipment design, such as poor hood design, will limit reduction of temperature. Heat recovery systems tend to receive less attention, so operating performance is not visible.
Practical notes	Spending on ventilation generally has low priority and low payback compared to other energy-reduction projects.
Resources	TAPPI TIP 0404-50 Paper machine room ventilation guidelines.

MRV2—Machine room building ventilation

Use automatic temperature control to operate air make-up systems at recommended setpoints:

- Building ventilation units: 75 ° F.
- Roof supply units: 120 ° F.

Recover waste heat from hood exhaust to preheat glycol systems for machine room air ventilation and process water heating.

- Shut off steam to coils when fans are not running.
- Ensure tight shut off of air make-up steam supply in warm months.
- Establish winter and summer operating guidelines for machine room ventilation supply and exhaust fans.
- Measure, display and monitor heat recovery stage performance. Take action on deviation from achievable level.
- Verify heat recovery performance for air systems supplied with recovered heat.
- Service heat recovery elements before each heating season to assure heat recovery performance.

Productivity impact	Insufficient air makeup causes negative building pressure in the winter month, affecting site access, structural degradation, and reducing exhaust fan performance.
Economic benefit	• Payback depends on the level of action taken and baseline operating condition. Reduction of operating setpoint requires only an operator action or in some cases improved heat controls. These are no-cost or low-cost actions. • Heat recovery systems can be capital intensive, but the investment life expectancy should be decades.
Energy savings	Rule of Thumb: In central Wisconsin, each 1 cfm of process exhaust requires about 2 therms of NG heated air make-up.
Water savings	There are no direct water savings.
Other benefits	Building preservation and ambient conditions.
Stage of acceptance	• Heat recovery systems are less efficient on older machine installations. • Significant changes require extensive capital, with low payback as compared to other projects. However, an asset equipped with heat recovery has a lower cost of operation.
Applications and limitations	• Setpoint verification and operating the current system to its design capability should be standard practice. • Equipment design will limit sources of heat recovery. Heat recovery systems tend to receive less attention, so operating performance is not visible.
Practical notes	Spending on ventilation generally has low priority and low payback compared to other energy-reduction projects. It should be noted that the cost of following these principles may appear high. However, the risk of not following these principles is far higher. Infrastructure repairs, higher operating costs, reduced machine room comfort, and lower production efficiency often result from deficiencies in the air and ventilation system design.
Resources	TAPPI TIP 0404-50 Paper machine room ventilation guidelines.

DB1—Doctor blades

Optimized doctoring processes can improve section performance and reduce energy consumption.

- Use appropriate blades for roll cover type.
- Set correct blade angle.
- Keep blade holders clean.
- Change pressure tubes to avoid cracks and leaks.
- Keep correct air pressure in tubes.
- Check air lines for leaks.
- Change blades in critical positions before machine performance decreases.
- Have rigid blade holders profiled by a specialist.
- Use low-drag blades on dryers to reduce drive load.
- Keep dryer doctor load less than one pound per linear inch (pli).
- Keep proper loading and unload as necessary.
- Change worn blades.

Productivity impact	Improved drying capacity, better runnability, lower doctoring costs and less waste.
Economic benefit	Higher productivity and less waste.
Energy savings	Can reduce equipment drive loads, dependent upon application. Regular blade maintenance reduces overall energy by reducing web breaks.
Other resource savings	Less damage to rolls and dryers.
Stage of acceptance	Medium.
Applications and limitations	Some corporate purchasing programs can reduce blade application options.
Practical notes	Training for safe handling of doctor blades is necessary.
Resources	Doctor blade suppliers can provide specific recommendations.

01—Operator rounds

Operator rounds can manage systems not visible in the digital control system (DCS) or data historians. Examples of areas where operator feedback from rounds can help include:

Building envelope:

- Roof or mezzanine rounds to check for leaking vents and safety relief valves.
- Roof supply and machine room ventilation temperatures.
- Building air infiltration.

Steam and condensate:

- Condenser systems.
- Steam leaks in piping, through vent valves, or safety relief valves.
- Any dumping of condensate.
- Uninsulated steam pipes or where insulation needs repair.

Equipment:

- Equipment vibrating or making excessive noise.
- Loss of ventilation.
- Vacuum system leaks or component vibration.
- Pumping system cavitation or vibration.

Process:

- Compressed air lines open or leaking.
- Water lines open or leaking to the drain.
- Tanks overflowing to the sewer.
- Note: an infrared temperature gun can be used to check stock and water systems and to detect cold water infiltration. Flat black spray paint should be used to mark areas on piping where infrared measurements are taken to ensure uniform emissivity for accurate temperature measurements.

Productivity impact	Improved uptime and efficiency.
Economic benefit	Provides awareness of energy loss potential. Addressing these observations will reduce energy consumption.
Energy savings	Varies, but can be significant.
Water savings	Water savings opportunities may be identified.
Other resource savings	Can reduce maintenance requirements.
Stage of acceptance	Low.
Practical notes	Makes operators and maintenance personnel more aware of operating and maintenance issues.
Resources	TAPPI TIP 0404-63 Paper machine energy conservation.

02—Paper machine forming section optimization

Formers consume energy directly through drive load and vacuum systems. Formation and drainage affect performance of downstream processes.

Consider the following energy-saving recommendations for former operation:

- Use former type and headbox that provides optimum formation results at higher consistency.
- Match hardware to drainage needs.
- Avoid sealing the sheet early in the forming process.
- Control low-vacuum drainage to prevent box flooding or sheet sealing.
- Graduate flat box vacuums to reduce drive load and increase sheet dryness to couch roll.
- Use multi-compartment high-vacuum boxes.
- Evaluate drainage element materials for impact on drag load. Minimize number of high vacuum elements.
- Forming fabric design can affect drive load and there may be opportunities to change to a low-drag design without adversely affecting paper characteristics or machine performance.
- Avoid couch re-wet (suction box orientation, double doctors, air doctors).
- Optimize forming temperatures for impact on drainage and solids.
- Apply applicable best forming fabric design.
- Monitor former solids frequently; maintain high level of solids.
- Use microwave instrument to regularly measure and monitor drainage on forming section.
- Change sheet transfer geometry on machines with an open draw between the couch roll and press section.

Productivity impact	Can permit higher production rates by better test development and improved sheet runnability.
Economic benefit	Reduce energy consumption per ton.
Energy savings	Varies, depending on changes implemented.
Water savings	Forming section optimization can reduce water consumption.
Other resource savings	Can reduce drive horsepower.
Stage of acceptance	Medium.
Applications and limitations	Concepts can be applied on most paper grades.
Resources	TAPPI TIP 0404-47 Paper machine performance guidelines.

03—Paper machine surveys

Paper machine surveys should be conducted at the intervals noted below to track performance and identify energy-improvement opportunities.

Ongoing:

- Optimize refining.
- Optimize press section.
- Check accuracy and condition of pressure and vacuum gauges.
- Machine down day survey should include observation and quantification of fresh water discharging to the sewer from area chests. This provides an indication of the amount of fresh water entering the process during operation.

Annual:

- Audit saveall to check capacity and filtrate quality.
- Inspect and test vacuum pumps and orifice plates.
- Check for leaks and hot spots using thermography.
- Perform maintenance and capacity review of pulp dryer.
- Balance and inspect tissue machine hood.
- Conduct surveys of:
  - Steam traps.
  - Compressed air system.
  - Mechanical system.
  - Press section nips.
  - Steam boxes.
  - Dryer steam and condensate.
  - Hood air system.

Every two to three years:

- Conduct showering surveys, including verification of pressure and flow, and replacement of worn nozzles.
- Survey and optimize vacuum system.

Every five years:

- Conduct machine room ventilation studies.
- Conduct pumping surveys to identify oversized systems or whose design does not align with current operations.

Productivity impact	Permits maximizing performance of paper machine components.
Energy savings	Varies, but can be significant.
Water savings	Water savings can result from observations.
Stage of acceptance	Low.
Applications and limitations	Surveys can be expensive unless incentives are available.
Practical notes	Machine conditions change over time and regular surveys identify areas needing attention.
Resources	TAPPI TIP 0404-63 Paper machine energy conservation.

O4—Centerlining process setpoints

Centerlining identifies and optimizes critical operating points in production. The process begins by identifying important process factors, then determining best settings or ranges for each of those factors. The impact of any changes must be weighed against effects on production and product quality. Centerlining process setpoints is an ongoing practice and any operating ranges should be adhered to during production.

Process factors to identify include:

- Wire pit and other water heating temperatures.
- Pocket ventilation, blowbox, and other air heating temperatures.
- Dryer section differential pressures (or blow through flows).
- Press loads.
- Sheet moisture at the reel.
- Refining kW, freeness, and/or hpd/t.
- Overall consumption indices such as lb steam/ton paper, kWh/ton and energy cost/ton.
- Dryer section lb steam/ton.
- Warm water flow and temperature from the pulp mill.
- Silo and process heat exchanger valve positions.
- Warm water make-up valve positions.
- Fresh water make-up valve positions into the whitewater or warm water systems.
- Venting from dryer sections (dp or blow through vent valve positions).
- Pulper pump and agitator amps.
- Press section weir flows.

Productivity impact	Can provide higher production rates, improved product quality, reduced downtime, and reduced rates.
Economic benefit	Better profitability due to improved quality, production increase and reduction of waste.
Energy savings	Varies by machine, but can be significant.
Other resource savings	Provides consistent operation for all shifts.
Stage of acceptance	Medium.
Applications and limitations	All operators need to buy in to centerline concept.
Practical notes	Top-performing paper machines have standard operating procedures with all operators following the same guidelines.

PULP MILL BEST PRACTICES

Table of Contents

PU1—Continuous digester

- Evaluate down flow cooking to reduce digester steam.
- Verify winter heat savings. Reduced heat from the digester can increase steam required for stock and hot water heating.
- Optimize series waste heat recovery from all digester waste heat sources.

Productivity impact	Potential increase in wintertime productivity due to digester steam savings.
Economic benefit	Reduced energy costs.
Energy savings	Substantial reduction in energy. Savings varies with fiber species and cooking requirements.
Applications and limitations	Winter reduction in available waste heat may negatively affect project returns.
Resources	• TAPPI TIP 0416-24 Energy checklist: pulp mill Section 2.3 Digester area • HW1—Hot water generation.

PU2—Pulp mill screening

- Optimize feed consistency and minimize feed pressure with VFD pump speed control. Shut down excess capacity when demand drops.
- Optimize screen plates. Consider use of high-efficiency multifoil rotors.

Productivity impact	Improves yield and reduces rejects.
Economic benefit	Reduced energy costs.
Energy savings	Potential reduction in fiberline power requirements.
Stage of acceptance	Medium.
Applications and limitations	Capital costs and rejects handling.
Practical notes	Must evaluate options for rejects handling.
Resources	TAPPI TIP 0416-24 Energy checklist: pulp mill Section 4 Screening

BD1—Batch digester blow heat recovery

When a batch digester cook is completed and the blow valve is opened, liquid in the digester pressure vessel flashes to atmospheric pressure. The flash steam is condensed in a Blow Heat Accumulator (BHA) tank heat recovery system. While batch digesters require considerably more steam (lb/BDt) than continuous digesters, efficient BHA waste heat recovery will substantially offset the difference in total mill steam use. An efficient and properly tuned batch digester BHA heat recovery system can generate hot water at 190°F or higher.

Design considerations:

- Minimum required BHA tank volume is 1.5 times the heat released by a digester blow.
- Control the BHA top temperature using flow rate to the direct contact primary condenser (top temperature range 205°F to 212°F).
- Control the BHA bottom temperature with a heat exchanger that controls the return condensate temperature to the bottom of the BHA tank.
- BHA controlled bottom temperatures range from 120°F to 185°F (small accumulator tank volumes require cooler bottom-controlled temperature).
- Control the primary condenser cooling water flow with a VFD on the primary condenser pump (instead of a circulation control valve).
- An additional final blow heat condensate return heat exchanger is required if multiple water sources are heated using hot BHA condensate in multiple heat exchangers.
- Digester heat release rate to the primary condenser is dependent on blow valve size/type/CV, digester pressure at the start of blow and the height of the blow tank. Typical flash steam flow rates to the primary condenser range from 140,000 to 200,000 lb/hr. BHA condensate flow to the blow heat exchangers should be relatively constant and match the actual production rate (let the BHA tank volume dampen heat removed from the BHA tank.) This is accomplished by setting the hot condensate flow rate to the heat exchangers at a fixed rate equal to the average heat released by the digesters at the actual production rate. For example; if the current production rate is 1.5 digester blows/hr and the digester heat released is 40 mmBtu/blow, the required heat removed by the heat exchanger is 40 mmBtu * 1.5 blow/hr = 60 mmBtu/hr. At a controlled BHA top temperature of 210°F and return condensate temperature of 140°F, the BHA condensate flow rate to the heat exchanger is 60 mmBtu/hr/8.34 lb/gal/60 min/hr/(210°F - 140°F) = 1,713 gpm. The average temperature of the BHA tank temperature probes is used to compensate for small changes in production rate. If the average of the tank temperature probes increases to 195°F (15°F less than top temperature), the BHA condensate flow rate is automatically increased by 15% to 1,970 gpm and maintained at the rate until the average temperature falls below 195°F. Conversely, if the average tank temperature falls below 155°F (15°F hotter than the bottom temperature), the BHA condensate flow rate is reduced and maintained at 1,456 gpm (85% of normal flow) until the average tank temperature increases to 155°F.
- Use the average of the BHA tank temperature probes to control heat rejection. This regulates the flow and temperature of both the hot water and BHA condensate returned to the accumulator. The flash steam heat released by the digester blow is typically 3 to 5 times greater than the heat rejection to the BHA heat exchanger. Thus, the average temperature of the BHA probes increases significantly when blowing and decreases significantly between blows. This control strategy does not fully utilize the BHA tank volume and continually swings the BHA flow rate to the heat exchangers.

- Control the BHA tank level by removing condensate at the return condensate temperature.
- The indirect secondary condenser can generate hot water in the range of 140°F to 185°F. Outlet temperature can be used to send the water to the warm or hot water tank.

Productivity impact	Potential increase in wintertime productivity due to steam savings for high temperature BHA waste heat to bleach plant, paper machine, caustic plant, and boiler feedwater make-up.
Economic benefit	Efficient batch digester blow heat recovery can offset the steam required for batch digester cooks.
Energy savings	Large energy savings for entire mill.
Water savings	See HW1 section.
Other resource savings	See BP1 section.
Stage of acceptance	Medium.
Applications and limitations	Heat rejection must match blow schedule to prevent large swings in hot water temperature.
Practical notes	Process controls and tuning are critical to maximize savings and prevent venting during digester blows.
Resources	TAPPI TIP 0416-24 Energy checklist: pulp mill Section 2.2 Digester area. HW1—Hot water generation. BP1—Bleach plant operation.

BS1—Brown stock operation

- Use combined/stripped condensate as final stage washer/decker shower water to minimize fresh water use.
- Maximize final stage wash water temperature while preventing flashing in washer drop legs.
- Implement dilution factor shower water control to minimize black liquor flow to evaporator and minimize soda loss from final stage washer. As production rates change, dilution factor control continuously minimizes evaporator steam while maintaining consistent brown stock washing efficiency.
- Eliminate wire cleaning and water doctor flow. Use combination doctors and airlifts instead of water/steam for stock take-off.
- Eliminate filtrate bypass around individual washer stages.
- Eliminate level control make-up into filtrate tanks especially last stage.
- Use double mechanical seals with tank systems on filtrate pumps to eliminate water infiltration to liquor.
- Use level transmitters not requiring water purge.
- Routinely monitor washer mat consistency and soda loss to optimize dilution factor control.
- Monitor conductivity of combined and stripped condensate.
- Evaluate replacing poorly performing washers with wash press.

Productivity impact	Maximize washing, minimize liquor flow to evaporators and maximize liquor solids to evaporator.
Economic benefit	Maximize recovery boiler steam generation and minimize evaporator steam.
Energy savings	Varies with washer consistency, black liquor solids, and evaporator economy.
Water savings	Reduction in fresh water to brown stock washers and liquor cycle.
Stage of acceptance	Medium.
Applications and limitations	Divert high-conductivity condensates from shower water during evaporator upset conditions.
Practical notes	Monitor level control make-up to filtrate tanks and by-pass water to filtrate tanks.
Resources	TAPPI TIP 0416-24 Energy checklist: pulp mill Section 3.

BS2—Brown stock high density dilution

- Brown stock High Density (HD) tank dilution to unbleached paper machine:
  - If paper machine chemistry permits, use paper machine whitewater as unbleached HD dilution water.
  - If whitewater cannot be used, use temperature-controlled warm/hot water as HD dilution (5 °F hotter than wire pit temperature to compensate for paper machine Fourdrinier cooling effect).
- Brown stock HD tank dilution to bleach plant:
  - Use $D_2/D_1/D_0$ filtrate as bleached HD dilution (See BP1 for D_1/D_2 filtrate to D_0 filtrate pump).
- If HD bottom-dilution cone is not tile lined for acid filtrate, consider tile lining (otherwise, use combined/stripped condensate for HD dilution).

Productivity impact	Potential wintertime productivity increase due to hotter stock to paper machines.
Economic benefit	Minimize water use with potential for chemical savings if D_1/D_2 washer filtrate is used for HD dilution to bleach plant.
Energy savings	Potential energy savings at E_0 steam mixer if hot D_1/D_2 washer filtrate used for HD dilution to bleach plant.
Water savings	Reduction in fresh water to brown stock HD dilution.
Stage of acceptance	Medium.
Applications and limitations	Specialty products and color grades may prevent use of whitewater.
Practical notes	See BP1 for D_1/D_2 filtrate to D_0 filtrate pump.

CS1—Caustic area

- If using a precoat filter for mud and dregs washing, maximize shower water temperature to these washers to at least 175°F.
- If using a lime kiln scrubber, maximize warm water make-up to the suction of scrubber pump to reduce total solids in the scrubber recirculation system. Maximize hot water removed from scrubber recirculation tank and use this hot water countercurrent as dilution water to precoat filter dilution and mud mix tank. This will minimize Total Dissolved Solids (TDS) and reduce scale buildup in the scrubber recirculation system. It will improve washing and minimize both Total Reduced Sulfur (TRS) and particulate emissions. The kiln exhaust gas will produce hot water in the scrubber recirculation system. The pre-coat filter filtrate and vacuum pump water must be excluded from the scrubber recirculation system to minimize kiln TRS emissions.
- Measure and control lime kiln exhaust O_2 gas concentration (internal measurement within kiln before any in-air leakage) to minimize fan horsepower; use VFD to control fan speed.
- An O_2 concentration >1% is required to prevent a reducing combustion atmosphere and minimize TRS emissions.

Productivity impact	Improved washing and reduced TDS in kiln feed from scrubber recirculation system.
Economic benefit	Reduced energy costs and potential increase in lime kiln capacity.
Energy savings	Reduced kiln fuel.
Other resource savings	Reduced TRS from kiln.
Stage of acceptance	Low.
Applications and limitations	Capital costs.
Practical notes	Water, sodium, soluble sulfide, and TDS balance required for caustic plant (including scrubber recirculation system).
Resources	TAPPI TIP 0416-24 Energy checklist: pulp mill Section 8 Caustic area, Section 9 Lime reburning HW1—Hot water generation.

EV1—Evaporator area

Black liquor evaporation is one of the biggest consumers of steam and cooling water.

- Evaluate value of additional evaporator effects to minimize steam use. (Winter energy balance must verify energy savings due to reduced volume and temperature of surface condenser warm water).
- Eliminate water intrusion in pulp mill and evaporator area with pump mechanical seals, brown stock washer combination doctors or airlifts.
- Incorporate internal steam stripping column or consider hard piping contaminated condensates to waste treatment to eliminate stripper column requirement.
- Maximize evaporator primary surface condenser (SC) cooling water outlet temperature to warm or tepid water tank (within vacuum constraint).
- Evaluate primary SC series operation with another tepid water heat exchanger to maintain controlled inlet temperature to primary SC (wintertime operation).
- Evaluate cooling water recirculation system to maximize outlet warm water temperature at reduced winter inlet cooling water temperature.
- Evaluate pulp mill black liquor cooler if liquor temperature to evaporators is greater than 210°F per TAPPI TIP 0416-24 Energy checklist: pulp mill, Section 6.1.
- Measure boiling point rise between effects, monitor overall evaporator and condenser efficiency.

Productivity impact	• Minimize evaporator constraint. • Reduce foul condensate generation.
Economic benefit	Reduced energy costs and improved heat recovery.
Energy savings	Steam savings with increased evaporator economy.
Water savings	See HW1 and HW2.
Other resource savings	Increased recovery boiler steam generation with increased liquor solids.
Stage of acceptance	Medium.
Applications and limitations	Capital costs.
Practical notes	Mill water and energy balance required.
Resources	TAPPI TIP 0416-24 Energy checklist: pulp mill, Section 6 Evaporator Area. EV2: Evaporator external stripping column. HW1—Hot water generation. HW2—Heat exchanger hot water optimization. Focus on Energy may have assistance available for process assessments. AH Lundberg Associates. Valmet.

EV2—Evaporator external stripping column

- Use effective steam ratio to control steam flow to column and maximize methanol-stripping efficiency (typical—0.18 lb. steam/lb of feed condensate required for 92% methanol-stripping efficiency).
- Maximize feed condensate temperature and primary reflux temperature to column to minimize stripping steam required and maximize methanol-stripping efficiency.
- Measure U-factor of feed heat exchanger to determine if heat exchanger is fouled and requires cleaning.
- If feed heat exchanger requires frequent cleaning to maintain 92% methanol stripping efficiency and the required effective steam ratio is ≥0.22 lb steam/lb feed condensate, consider eliminating feed heat exchanger and installing additional primary reflux condenser with feed to column flowing through primary reflux condenser. This significantly increases both feed and reflux temperature to column and reduces required effective steam ratio to maintain stripping efficiency.
  - Without a feed heat exchanger, the stripped condensate from column will be at the column operating temperature.
  - Stripped condensate at 190 °F has been used as bleach plant D_0 washer-shower water (replacing hot water) to eliminate E_0 steam mixer steam requirement.
  - Existing feed heat exchangers can be repurposed and used with hot stripped condensate as heat source to heat boiler feed water makeup and/or produce high temperature hot water to further reduce mill energy requirements.
  - Net effect is a significant reduction in stripping steam required and all heat to stripping column efficiently recovered to reduce energy. Two stripper column systems have been modified to by-pass the feed heat exchanger and heat the column feed in the primary reflux condenser. The secondary reflux condenser must have ~ the same surface area as the primary reflux condenser. The latest modified stripper column operates at effective steam ratio 0.13 lb steam/lb feed condensate and 95% methanol stripping efficiency. Hot stripped condensate from column is used to heat boiler feedwater makeup and heat white liquor to the batch digester creating additional energy savings.

Process	Evaporator area—external steam stripping column.
Productivity impact	Potential increase in productivity during winter months due to energy savings.
Economic benefit	Reduced energy costs and improved heat recovery.
Energy savings	Steam savings with lower effective steam ratio. Additional bleach plant steam savings if stripped condensate used at D_0 bottom shower bars.
Water savings	Hot water savings if stripped condensate used at D_0 washer. See HW1 and BP1.
Other resource savings	Reduced BOD_5 to waste treatment.
Stage of acceptance	Low.
Applications and limitations	Capital costs.
Practical notes	Stripping column energy balance and process hot water balance required.
Resources	TAPPI TIP 0416-24 Energy checklist: pulp mill Section 6 Evaporator Area. BP1—Bleach plant operation. HW1—Hot water generation. HW2—Heat exchanger hot water optimization.

BP1—Bleach plant operation

Bleach plant shower water distribution, hot water temperature and dilution factor control are used to maximize energy and chemical savings. Recommendations for various stages are shown below.

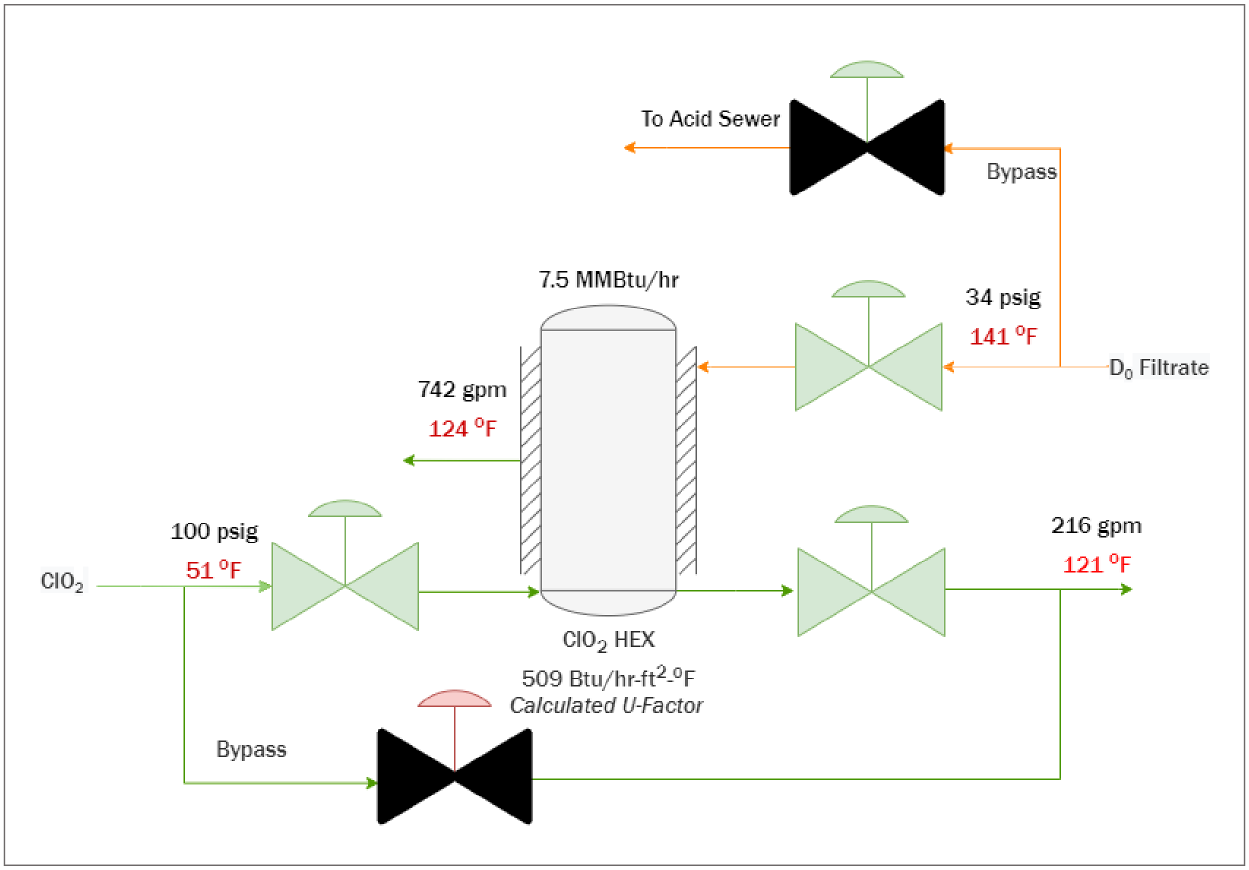
- D_0 Washer:
  - Control shower flow rate at dilution factor of 1.0.
  - Use hot water or high temperature stripped condensate on bottom showers (50% of total flow) and E_0 filtrate on top showers.
  - Use E_0 filtrate for repulper dilution.
- E_0 Washer:
  - Control shower flow rate at dilution factor of 0.0 to 0.5.
  - Use hot water on bottom showers (35% to 50% of total flow) and D_1 filtrate on top showers
  - Use D_1 filtrate for repulper dilution.
- D_1 Washer (three-stage bleach plant):
  - Control shower flow rate at dilution factor of 0.0 to 0.5.
  - Use hot water on bottom showers (35% to 40% of total flow) and warm water or paper machine whitewater (chemistry permitting) on top showers.
  - Control stock temperature leaving bleach plant/high density tanks > 5 °F hotter than paper machine wire pit temperature (compensates for paper machine Fourdrinier cooling).
  - Use warm water or paper mill whitewater (chemistry permitting) for repulper dilution to high density.
  - Pipe excess D_1 filtrate to suction of D_0 filtrate pump supplying high density dilution water to bleach plant (reduces CLO_2 demand and improves washing).
- E_1 Washer (five-stage bleach plant):
  - Control shower flow rate at dilution factor of 0.0 to 0.5.
  - Use hot water on bottom showers (30% to 40% of total flow) and D_2 filtrate on top showers.
  - Use D_2 filtrate for repulper dilution.
- D_2 Washer (five-stage bleach plant):
  - Control shower flow rate at dilution factor of 0.0 to 0.5.
  - Use hot water on bottom showers (25% to 40% of total flow) and warm water or paper machine whitewater (chemistry permitting) on top showers.
  - Control stock temperature leaving bleach plant/high density tanks > 5 °F hotter than paper machine wire pit temperature.
  - Use warm water or paper mill whitewater (chemistry permitting) for repulper dilution to bleached high density tank.
  - Pipe excess D_1 & D_2 filtrate to the suction of D_0 filtrate pump supplying dilution water to both the brown HD tank and the stock feeding the D_0 tower (reduces ClO_2 demand and improves washing).
  - Reduce % hot water to D_1, E_2 and D_2 bottom showers to maximize hot water temperature (180 °F or hotter is objective).
  - Minimize wire cleaning shower flow, and use warm water instead of hot water for source.

Productivity impact	Potential increase in productivity during winter months due to energy/chemical savings and reduced stock conductivity.
Economic benefit	Reduced process steam demand to heat water and stock at bleach plant and paper mill. Reduced bleach plant chemical use.
Energy savings	Best practice total bleach plant steam reduced to < 200 lb/Bone-dry ton (BDt) with 185± °F hot water temperature to washers.
Water savings	Hot water savings using next stage filtrate for repulper dilution and using warm water for wire cleaning showers and water doctors. Hot water savings if use stripped condensate on D_0 washer bottom shower.
Other resource savings	Chemical savings with high temperature shower water and dilution factor shower water flow control.
Stage of acceptance	Medium. Many mills use "jump stage washing" with D_1 stage filtrate used as shower water on the D_0 washer. Piping excess D_1 filtrate to the D_0 stage filtrate pump suction that supplies dilution water to both the brown stock HD tank and the stock feeding the D_0 stage takes advantage of the hotter and cleaner filtrate that contains residual ClO_2 and reduces caustic demand at the E_0 stage. The excess D_0 filtrate can be used for ClO_2 heating. See BP2.
Applications and limitations	Savings and benefits are hot water temperature dependent.
Practical notes	See HW1 and BP3 for requirements to maximize volume and temperature of hot water.
Resources	TAPPI TIP 0416-24 Energy checklist: pulp mill, Section 5 Bleaching and bleach plant washing. BP3—Bleach plant washer hot water. HW1—Hot water generation.
Synergies	Increased stock temperature and reduced conductivity to paper mill.

BP2—Chlorine dioxide (ClO_2) heating

- Preheating cold ClO_2 (~ 55 °F) used at D-stage bleaching towers.
- Preheat ClO_2 to ≤ 130 °F using bleach plant filtrate.
- Use D_0 stage bleach plant filtrate as heat source (E_0 stage filtrate is too hot and increases the potential for a ClO_2 decomposition).
- Use all titanium-welded plate and frame heat exchanger with dimple or smooth plates (herringbone plates increase fouling).
- Provide strainer on filtrate side to minimize fouling.
- Provide pressure relief on ClO_2 side and relieve to bleach plant ClO_2 scrubber or to elevated vent away from employee work areas.
- Provide automatic ClO_2 and filtrate by-pass around heat exchanger.
- Measure ClO_2 flow, temperature in and out, and filtrate temperature in and out.
- Provide heat exchanger U-factor calculation in DCS or Process Book to identify cleaning requirement.

Figure 5: DCS example of U-factor calculation



Economic benefit	Reduced steam mixer process steam demand.
Energy savings	Steam savings equivalent to heating ClO_2 flow from 55 °F to 130 °F.
Water savings	Reduced boiler feedwater make-up flow.
Other resource savings	Deaerator steam savings.
Stage of acceptance	Medium—high U-factor, reduced surface area and increased ClO_2 outlet temperature for all titanium plate and frame heat exchanger have increased energy savings resulting in a simple project return ≥50%.
Applications and limitations	Savings vary with final ClO_2 temperature from heat exchanger. Must evaluate impact of effluent heat recovery on wastewater treatment plant (WWTP) influent temperature (summer and winter).
Practical notes	Heating ClO_2 for the first stage D_0 tower may not be required if existing stock temperature is already at desired D_0 tower operating temperature.
Resources	TAPPI TIP 0416-24 Energy checklist: pulp mill, Section 5 Bleaching and bleach plant washing. HW2—Heat exchanger hot water optimization. See Figure 5: DCS example of U-factor calculation.

BP3—Bleach plant washer hot water

- Produce hot water using series heat exchanger operation (fresh water heated to tepid, tepid heated to warm and warm heated to hot).
- Heat hot water (with waste heat) to 10°F > than E_0 Tower operating temperature.
- Maximize waste heat recovery to prevent direct or indirect heating of hot water with steam for bleach plant use.
- Minimize bleach plant hot water use to maximize temperature of hot water generation.
- Incremental hot water Btu utilization efficiency is ~85% when temperature is 180°F or higher (increased utilization efficiency with presses); incremental hot water Btu utilization efficiency decreases with cooler hot water temperature.
- Use warm water (minimize flow) for wire cleaning showers and water doctors to maximize hot water temperature.
- Use next stage filtrate instead of hot water for repulper dilution (use high temperature hot water for washer showers only).
- Reduce percent hot water to bottom shower bars on bleach plant washers to reduce volume and maintain high temperature. Start with final stage washers working backward to reduce volume and maximize hot water temperature.
- Use dilution factor to control shower water flow (maintain 50% hot water or stripped condensate on D_0); see BP1 for recommended shower water dilution factor control.

Productivity impact	Potential increase in productivity during winter months due to energy/chemical savings and reduced stock conductivity.
Economic benefit	Reduced steam mixer process steam demand.
Energy savings	Best practice total bleach plant steam reduced to < 200 lb/BDt with 185±°F hot water temperature to washers.
Water savings	Reduced boiler feedwater make-up flow.
Other resource savings	Deaerator steam savings.
Stage of acceptance	Medium. Savings vary with final hot water temperature.
Applications and limitations	Available waste heat sources and final approach temperature limit of high temperature heat sources.
Practical notes	See HW1.
Resources	TAPPI TIP 0416-24 Energy checklist: pulp mill; Section 5 Bleaching and bleach plant washing. BP1—Bleach plant operation.

BP4—High-density dilution

Control stock temperature from last-stage washer to HD at least 5 °F hotter than paper machine wire-pit temperature (compensates for paper machine cooling effect).

If paper machine chemistry permits, use whitewater from paper mill as HD dilution water; use temperature-controlled warm/hot water (at least 5 °F hotter than wire-pit temperature) as bleached HD tank dilution if whitewater cannot be used.

Economic benefit	Minimize water use and minimize paper machine wire pit steam.
Energy savings	Wintertime wire pit steam savings due to hotter stock from bleach plant.
Stage of acceptance	Medium. Whitewater dilution is normal practice except for specialty products.
Applications and limitations	Specialty products and color grades may prevent use of whitewater.
Practical notes	May require reconfiguration of hot and warm water generation to achieve energy savings.
Resources	HW1—Hot water generation. BP1—Bleach plant operation.

HW1—Hot water generation

Waste heat recovery sources can be stacked to maximize volume of 190°F water available year-round for pulp mill, bleach plant, caustic plant, or tempered for paper mill use.

Prioritize high temperature heat sources based on Btu utilization efficiency.

- Use dedicated warm and high temperature heat sources (prior to hot water generation) in series based on Btu utilization efficiency to maximize energy savings.
- High temperature heat sources used for boiler feedwater (bfw) heating include flash steam condenser, primary reflux condenser, blow heat accumulator heat exchanger, etc.
- Use dedicated medium and high temperature sources for series heating of bfw make-up (100% Btu recovery).
- High temperature hot water used for bleach plant shower water can be 100% Btu recovery due to steam mixer direct steam condensate loss and increased deaerator steam required for boiler feedwater makeup.

Tepid water system.

- Have a dedicated tepid water tank.
- Use fresh water for low temperature heat sources (turbine condensers, NCG coolers, evaporator secondary condensers, etc.) to tepid tank.
- Use tepid water as cooling water for medium temperature heat sources.
- Overflow or pipe excess tepid water to fresh water system (especially important during wintertime operation).

Warm water system.

- Have a dedicated warm water tank.
- Use tepid water for medium temperature heat sources (evaporator primary condensers, turpentine condensers, cold blow coolers, etc.) to warm water tank.
- Overflow excess warm water tank to tepid tank.
- Use tepid water as level control make-up to warm water tank (minimize).
- Recover waste heat from effluent heat exchangers during wintertime into warm or tepid water tanks (use recirculation pump to maximize U-factor and heat recovery).
- Use warm water as cooling water source for high temperature heat sources.

Hot water system.

- Use remaining warm and high temperature heat sources in series to generate hot water for pulp mill, bleach plant, caustic plant, and paper mill.
- Dedicated hot water tank.
- Maximize hot water temperature by controlling hot water demand (See BP1).
- Use recirculation pump to maximize heat exchanger/condenser U-Factor and hot water temperature (especially important during wintertime operation—see HW2).

Heat Exchangers and Hot Water

- Prioritize use of hot water based on Btu use efficiency.
- Use warm water for level control make-up to hot water tank (minimize make-up to maximize energy savings).
- Overflow excess hot water to warm water tank.
- Export excess warm and hot water to paper mill.

Productivity impact	Increased wintertime production capacity at mills with steam generation limitations.
Economic benefit	Reduced process steam demand to heat water and stock at pulp mill and paper mill. Improved washing and reduced chemical use. Reduced steam required at deaerator due to increased heating of boiler feedwater make-up and reduced bleach plant steam mixer steam use.
Energy savings	Varies with available waste heat sources and water conservation. Best practice bleach plant steam reduced to < 200 lb/BDT with 185± °F hot water temperature to washers. Wire pit steam use for stock heating minimized/eliminated with exported hot water from pulp mill to paper machine. Boiler feedwater make-up heated to >190 °F with optimized series heat recovery.
Water savings	See BP 1, 2, 3 and 4 for examples.
Other resource savings	Reduced chemical use and reduced flow and temperature to non-contact outfall.
Stage of acceptance	Medium. Detailed energy audits that include flow and temperature measurements typically find many high-return projects with > 50% simple return.
Applications and limitations	Limitations due to available heat sources and piping distance required for stacking heat recovery.
Resources	HW2—Heat exchanger hot water optimization.

HW2—Heat exchanger hot water optimization

- Countercurrent stacking of low temperature heat source in series with higher temperature heat source heat exchangers will maximize volume and temperature of hot water generated.
- Include recirculation system to maintain design flow to heat exchangers to offset impact of cold wintertime water temperature. See Figures 6 and 7 for example U-Factor calculation for systems with and without recirculation. The system with recirculation has increased U-Factor and heat output compared to the single pass system. The design criteria used for Figures 6 and 7 are summarized in Table 6.
- Design specification sheets, including surface area, design flows and temperatures of existing heat exchangers and condensers for major heat sources are required to optimize heat recovery.
- Heat exchangers/condensers are typically designed for peak heat load at maximum summer inlet cooling water temperature (oversized design).
- Wintertime heat transfer is inefficient if cooling water flow decreases due to colder inlet cooling water temperature. To maximize wintertime energy savings, increase number of stages of series operation to maintain warm water temperature to hot water heat exchangers or install a recirculation pump to maintain constant flow (at design rate) to heat exchanger/condenser (see HW1). Wintertime inlet and outlet hot water temperature will increase with a recirculation pump system.

Productivity impact	Improved stock washing at bleach plants and reduced equipment downtime to clean heat exchangers and condensers due to increased flow rate/scouring velocity. Increased wintertime production capacity at mills with steam generation limitations.
Economic benefit	Reduced process steam demand to heat water and stock at pulp mill and paper mill. Reduced water and heat to non-contact sewer outfall.
Energy savings	Varies with available waste heat sources and water conservation. Best practice total bleach plant steam reduced to < 200 lb/BDt with 185± °F hot water temperature to washers. Wire pit steam use for stock heating minimized/eliminated with exported hot water from pulp mill to paper machine. Boiler feedwater make-up heated to > 190 °F with optimized series heat recovery.
Water savings	Reduced warm/tepid water to non-contact outfall, reduced boiler feedwater make-up and reduced bleach plant hot water use.
Other resource savings	Bleach plant chemical savings due to washing stock with higher temperature hot water. Increased consistency from washers.
Stage of acceptance	Medium—limited integration of total mill heat recovery to maximize energy savings. Limited heat recovery from process area effluents to maximize energy savings.
Applications and limitations	Must evaluate summer and winter impact of heat recovery on WWTP and mill water treatment plant. Piping cost limitations for stacking waste heat recovery.
Practical notes	Heat exchanger/condenser U-factors are primarily dependent on flow rate and velocity at the tube/plate surface. Flow rates need to operate near the design for efficient heat recovery and hot water generation. A recirculation heat recovery system should be evaluated for wintertime operation to maximize energy savings.
Resources	HW1—Hot water generation. Heat exchanger condenser suppliers. Focus on Energy representatives. “Heat Exchanger Sizing for Pulp & Paper Mill Applications”, Lake States TAPPI Energy Forum, Nov. 7, 2017.
Synergies	Maximized energy savings and water conservation with total integration and stacked heat recovery of entire mill heat sources.

Table 6: Reflux condenser peak design criteria

CRITERIA	DESIGN
Vapor Temp In (°F)	204
Vapor Temp Out (°F)	140
CW Flow to Reflux Condenser (gpm)	1,090
Condenser CW Temp In (°F)	100
Condenser CW Temp Out (°F)	155
Condenser Heat Removed (MMBtu/hr)	30.00
GTD (°F)	49.0
LTD (°F)	40.0
ΔT (LMTD) (oF)	44.3
Required Surface Area (ft^2)	3,007
Design U-Factor (Btu/hr/ft^2/°F)	225

Figure 6: Reflux condenser, winter condition minimum heat single pass

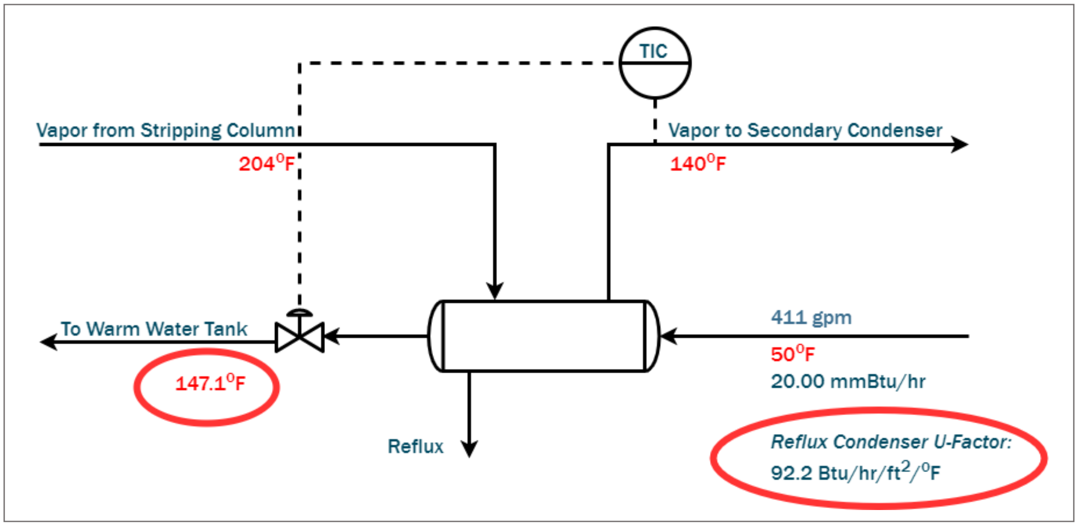
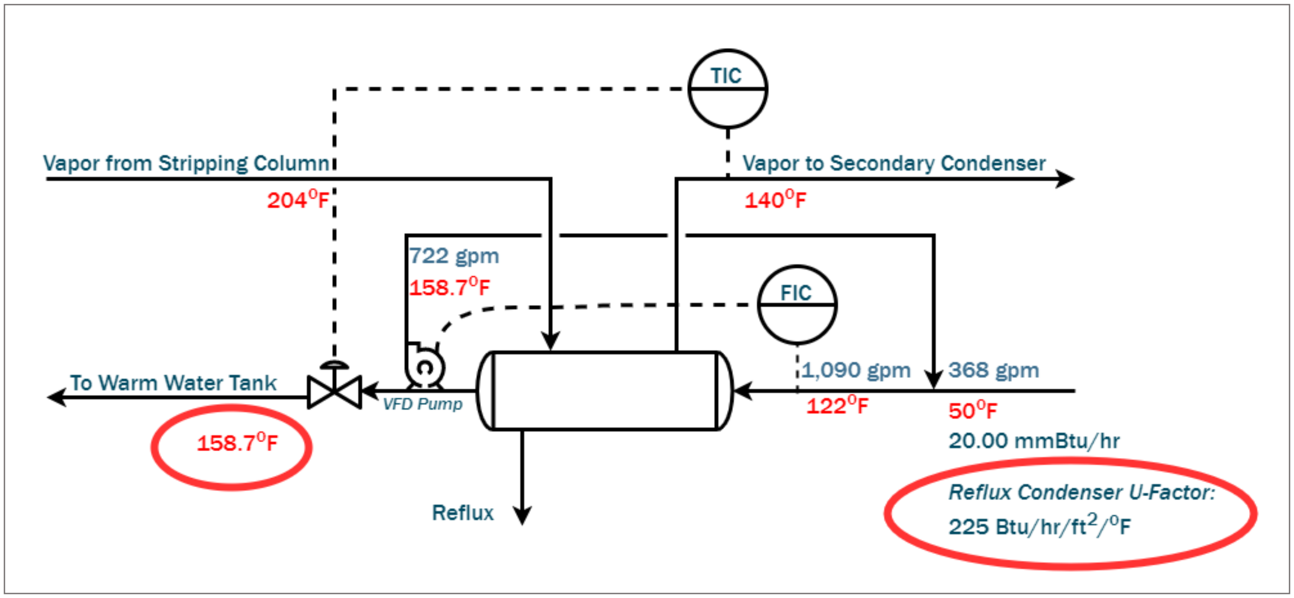


Figure 7: Reflux condenser, winter condition minimum heat with recirculation



HW3—Heat exchanger U-factor calculation

- Heat exchangers are widely used.
- Operating efficiencies vary with process conditions.
- Calculation of heat exchanger efficiency (U-factor) provides a key metric for heat exchanger performance.
- Calculate, display and monitor operating heat exchanger performance and optimize accordingly.

To calculate the U-Factor for a condenser, use the inlet and outlet vapor and water temperatures on both sides of the condenser plus the cooling water flow rate measured in the data historian or the DCS. To calculate the U-Factor for a HEX, use the inlet and outlet water temperatures on both sides of the HEX plus the cooling water flow rate (or hot fluid flow rate) measured in PI or the DCS.

The U-Factor is calculated by the equation: $U = Q/(A*T)$

Where

U = heat transfer coefficient, $\mathrm{Btu/hr/ft^2/°F}$

Q = heat transfer, Btu/hr = $(T_{in} - T_{out}) * gpm * 500.4$

A = condenser surface area, ft^2

T = log mean temperature difference (LMTD)

LMTD =(GTD)-(LTD)/ln((GTD)/(LTD))

GTD = greatest temperature difference, $(T_2\text{-}T_3)$

LTD = least temperature difference, $(T_1\text{-}T_4)$

Set the PI calculation for at least a 15 min average of actual PI data. If you set it up for a shorter time frame, you can get negative numbers (causing an error in the LMTD calculation) due to quick changes in flow rates and temperatures. Please remember that the flow rate on the water side of a condenser and the flow rate on both sides of a HEX affect the U-Factor. This understanding is needed to determine if the HEX is fouled or the low U-Factor is due to reduced flow rates.

Sample Heat Exchanger U-Factor Calculation

Q = 800 gpm x 8.34 lb/gal x 60 min/hr x (180°F – 85°F) = 38.03 MMBtu/hr (based on cooling water)

A = 7,161 ft^2

T_1 = 195°F

T_2 = 120°F

T_3 = 85°F

T_4 = 180°F

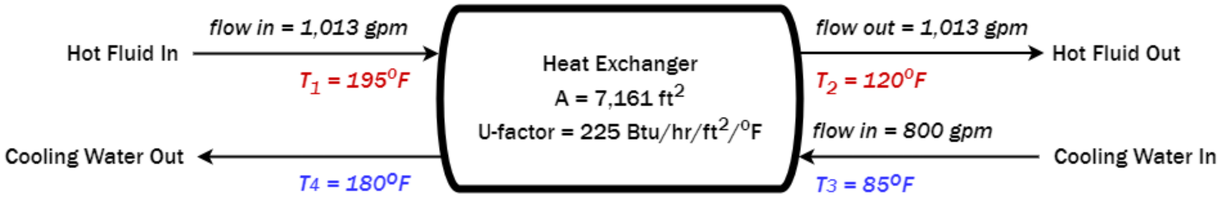
$GTD = T_2 - T_3 = 120^\circ F - 85^\circ F = 35^\circ F$

$LTD = T_1 - T_4 = 195^\circ F - 180^\circ F = 15^\circ F$

$T = LMTD = (GTD) - (LTD)/\ln((GTD)/(LTD)) = (35 - 15)/\ln(35/15) = 20/0.85 = 23.6^\circ F$

$U = Q / A \times T = 38.03\ MMBtu/hr \times 1{,}000{,}000\ Btu/MMBtu / (7{,}161\ ft2 \times 23.6^\circ F) = 225\ Btu/hr/ft^2/{}^\circ F$

Figure 8: Example U-factor calculation



Productivity impact	U-Factor measurement is directly related to fouling. Excessive fouling can be a source of process issues. Measurement can provide an early warning.
Economic benefit	Optimizing heat exchanger efficiency has a direct energy recovery benefit, and an indirect process benefit.
Energy savings	Energy savings will vary depending upon the application. Optimization requires measurement.
Water savings	Water savings will vary depending upon the application. An optimized heat exchanger will maximize the benefit of cooling water use.
Other benefits	Heat exchanger optimization has no down-side. Benefits to process, quality, and runnability can be side benefits.
Stage of acceptance	Heat exchanger efficiency measurement is not widely applied. With the proper measurements, it can be calculated and displayed on existing process historian platforms.
Applications and limitations	Multiple applications exist. Heat exchangers are widely used in the pulp and paper process.
Practical notes	Heat exchanger sizing is critical for optimization. Size appropriate to the “normal” operation and do not oversize.
Resources	There are many qualified Trade Allies who can assist with heat exchanger application.

NO- AND LOW-COST OPERATIONAL BEST PRACTICES

Table of Contents

EM1—Energy monitoring

Accurate metering and display of Energy Key Metrics elevate the visibility of energy consumptions and costs:

Recommend display of energy metrics using the cost it represents for maximum impact.

- Fuel Purchased (real time daily total):
  - Natural Gas.
  - Biomass.
  - Solid fuel.
  - Other.
- Water systems key energy metrics:
  - Daily usage and current rate.
  - Process water discharged.
  - Fresh water daily total.
  - Fresh water flow rate.
  - Steam flow for water heating.
  - Fresh water and warm water flow and temperature to each paper machine.
  - Action plan.
- Steam system key metrics:
  - Overall boiler steam efficiency. Display fuel units per 1,000 lb steam produced.
  - Condensate return flow and temperature by area.
  - Combined condensate return temperature.
  - Boiler make-up flow and integration.
  - Vent rates and totalization.
  - Paper machine steam supply; Flow, pressure, and temperature for each header.
  - Dryer condenser cooling water vent rates.
  - Steam flow by area.
- Heat recovery system key metrics:
  - Final exhaust temperatures.
  - Heat recovery rates by recovery sections.
  - Monitor performance of each energy recovery system.
  - System status.
  - Standard Operating Procedure (SOP) action plan.
  - Annual checklists.
- Electrical consumption key metrics:
  - Purchased electricity. Instantaneous and daily total.
  - Internal generation. Instantaneous and daily total.
  - Internal generation efficiency (kW per 1000 lb of steam produced)
  - Total electricity consumption on each paper machine.
- Compressed air:
  - Total daily compressed air and average daily flow.

  - System pressure.
  - Compressed air system delivery efficiency (kWh per 100 scfm).
  - Compressed air pressure and flow to each paper machine.
  - Air dryer dewpoint.
- System in place to calibrate key energy metering at least annually.

Productivity impact	Supports higher production rates.
Economic benefit	Permits energy management. Reduces total energy cost.
Energy savings	Varies by application but can be significant.
Water savings	Better monitoring of water use.
Other resource savings	Reduces process upsets, stock spills, and other operating problems.
Stage of acceptance	Medium.
Applications and limitations	• Some capital required. • The most advanced energy managed sites bill utilities to the area according to utilities consumed, and not on an assumed energy assignment.
Practical notes	• “You cannot manage what you do not measure.” • Key energy metrics allow communication of improvement and readily identify areas which need to be addressed.
Resources	TAPPI TIP 0404-63 Paper machine energy conservation.

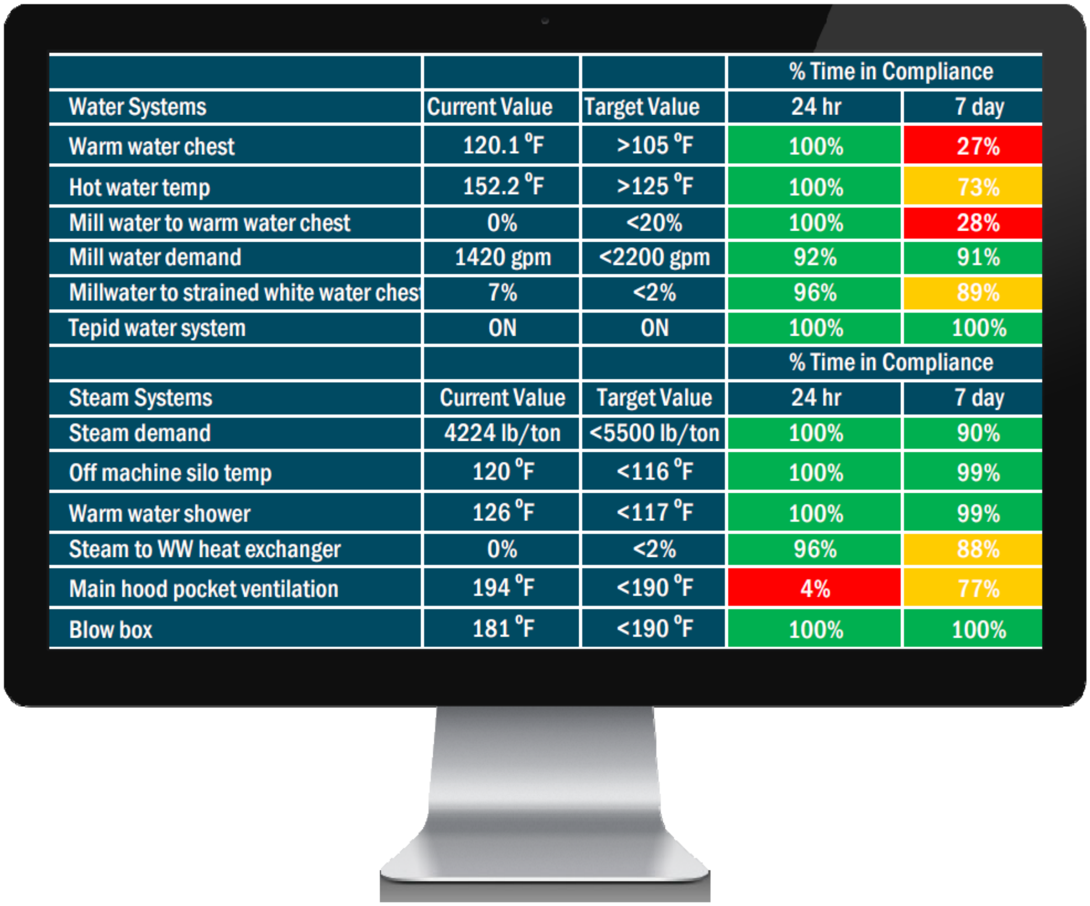
EM2—Energy displays

Good energy displays are required to effectively monitor energy use. Recommended displays include:

- Area specific key energy metrics, in units easily understood by operators.
- Green/yellow/red “stoplight” indicators for each of the key areas. The sample energy display in Figure 9 shows key performance indicators on a stoplight scale.
- Process diagrams of key energy systems.
- Live readout of lbs steam/ton production.
- Fixed trends to review with other paper machine variables.
- Prioritize what is displayed using the following:
  - What is important?
  - What is accurately measured?
  - Actions taken when deviation from excellence occurs.
  - Declutter any display item which distracts from the priority.
  - Integrate an overview screen to quickly link to a more detailed screen which identifies the opportunity.

Productivity impact	Good monitoring provides better management of processes.
Economic benefit	Can lead to higher productivity.
Energy savings	Energy measurements and displays are the foundation for energy management which results in improved energy efficiency.
Water savings	Provides better water system monitoring.
Stage of acceptance	Medium.
Applications and limitations	Some capital required.
Practical notes	Makes operators more aware of energy applications. Good calibration is required to provide reliable indications. Helps make operators aware of key energy variables.
Resources	TAPPI TIP 0404-63 Paper machine energy conservation.

Figure 9: Sample energy display with stoplight indicators



			% Time in Compliance	
Water Systems	Current Value	Target Value	24 hr	7 day
Warm water chest	120.1 °F	>105 °F	100%	27%
Hot water temp	152.2 °F	>125 °F	100%	73%
Mill water to warm water chest	0%	<20%	100%	28%
Mill water demand	1420 gpm	<2200 gpm	92%	91%
Millwater to strained white water ches	7%	<2%	96%	89%
Tepid water system	ON	ON	100%	100%
			% Time in Compliance	
Steam Systems	Current Value	Target Value	24 hr	7 day
Steam demand	4224 lb/ton	<5500 lb/ton	100%	90%
Off machine silo temp	120 °F	<116 °F	100%	99%
Warm water shower	126 °F	<117 °F	100%	99%
Steam to WW heat exchanger	0%	<2%	96%	88%
Main hood pocket ventilation	194 °F	<190 °F	4%	77%
Blow box	181 °F	<190 °F	100%	100%

EM3—Energy reduction discovery

Even though implementation of energy efficient practices is one of the most controllable costs in a facility, energy waste takes many different forms, and can be prevalent throughout an operation. Though difficult, forming the habit of identifying and reducing, or eliminating energy waste is translatable throughout a facility. Continuing to implement processes and practices without periodic evaluation can lead to stagnant, inefficient, and wasteful practices.

Foundations:

- Understand energy costs. Real costs, both fixed and incremental. Sites implementing energy reduction should be able to see a 3%-5% reduction year over year with implemented improvements.
- Track and manage energy used: electricity (kWh), process natural gas (therms), building natural gas (therms), water supply, and compressed air. Record effluent flow and temperature.
- Establish key metrics to serve as a baseline from which to measure success.
- Ensure all impacted departments within a company are engaged to provide input before, during, and after process improvements. For example, operators, maintenance staff, and field supervisors all play roles and interact differently with a process. Input from these parties is valuable in making sound decisions and ensuring no aspect of the project is overlooked.
- Identify an energy champion who feels passionate about spearheading energy-saving projects. Finding the right person can move stalled projects forward and serve as a source for new ways to save energy. For the right person, taking this on is not an assignment; it is a passion and drive to improve.
- Equip the observation team with a simplified setpoint-flow-temperature to economics chart to easily assess economic value.
- Engage assured support from the site manager and the site financial controller. The site controller will provide an unbiased economic value to improvements, which the site manager can present.
- Make flow sheets readily available in reproducible sizes (e.g., 11” x 17”) for use by the field team. Flow sheets should be created for process, water, steam, condensate, compressed air. Make corrections as discovered.
- Basic tools required are: high-intensity flashlight, non-contact and contact thermometer, bucket with hose, and stopwatch.

Energy Management

Productivity impact	Stable control of energy usually results in a stable process. Productivity implications need to be monitored and best economic choices made. All tons are not equal for value add.
Economic benefit	Improved energy efficient practices are able to result in 3%–5% energy reduction on an ongoing yearly basis.
Energy savings	Energy savings of 3% or more is possible on an ongoing annual basis. Look at the energy consumption seasonal profile. High cold weather usage most likely represents significant fresh water heating.
Water savings	Identify any water source going to the sewer, including excess process water. Identify and measure flows on all sources of fresh water entry. On machine maintenance days, perform a sewer walk to observe the amount of water still going into the sewer. Document the source.
Stage of acceptance	Energy efficient practices are accepted by the workforce when they know their input is considered and is making a difference. Communicate the wins, be hasty to share credit. Know and promote the value of the team.
Applications and limitations	Limitations to what can be done with minimized resources is usually limited by the knowledge of what's going on and what it is costing. Simplifying the answers to those questions will build the mindset amongst team members.
Practical notes	Focus on Energy resources are available to support your team. • Do a regular roof walk: Look for and document any visible steam venting. Find its source. Observe vent fan exhausts, and air make-up operation. • On outages, listen for air and steam leaks. Identify and fix the sources of the leaks.
Resources	Focus on Energy provides resources to perform site paper machine and pulp mill audits. These will provide a higher level assessment and recommendations. Process Assessment Incentives are available to uncover opportunities within identified energy processes such as compressed air or steam systems. The site utility may provide energy assessments addressing additional opportunities.
Synergies	Maintenance reliability can be improved with energy improvements, which reduce oversized systems and subsequent vibrations. Reduced utility cost and maintenance reliability spend can provide the cost support for the energy improvements.

E1—Paper machine improvements

- Maintain accurate flow sheets for steam and condensate, process water, and fresh water.
- Identify and monitor fresh water/process water crosstie valve positions.
- Preferably install fresh water meters on wet end process entry branch supply lines and create a daily metric of fresh water entry.
- Eliminate use of fresh water for foam knockdown, trim knockdown, or sheet knockoff.
- Create an energy recovery equipment checklist and verify these systems are operating.
- Check your roof heat economizers for proper operation.
- Establish a winter exhaust operation and shut down those building exhausts not needed to operate.
- Create a simple cost of waste reference including commonly wasted utilities like heated water, steam leaks, air leaks, and water. The reference should be simple enough for operators to understand the cost and implications of wasted energy.
- Use ultrasonic, infrared, and/or thermography to detect failed steam traps.
- Conduct regular compressed air leak surveys.
- Discourage use of poly tubing for air lines. Heat deterioration of poly causes leaks.
- Perform a roof walk weekly to look for steam venting. Identify the cause.
- Replace any incandescent, high-intensity discharge (HID), and fluorescent light fixtures with light-emitting diode (LED) fixtures. While lighting replacements have an upfront cost, comprehensive retrofits can provide the long-term benefit of reduced maintenance costs in addition to energy savings.
- Monitor dryer drainage vent rates. When out of limits, have operators check differential pressure setpoints or proper cascading of the system.
- Engage the mill personnel in a facility-wide energy management program. An empowered energy-reduction culture is beneficial on a company-wide level.
- Create an energy scoreboard, so progress is known and communicated.

Economic benefit	Payback should be tracked at a high level. Energy savings, when seen at the utility bill, supports the low-cost resources necessary. Communicate the wins to the team.
Energy savings	Savings is dependent upon the completed actions, not the items discussed. Monitor and encourage change.
Water savings	Water savings are typical outcomes of energy-reduction efforts.
Other benefits	Establishing a culture of awareness of energy waste.
Stage of acceptance	The frontline workforce will readily accept improvements they identify and are given credit for. Be sure to promote the team and its successes.
Applications and limitations	Application fits any industry at any site.
Practical notes	All levels need to support, or at least not stand in the way of, attaining culture change. Energy improvements can be accomplished by a small group of people with determination to improve.
Other resources	TAPPI TIPs are available to help identify areas of opportunity. Subject matter expert presentations are available. Focus on Energy resources may be available to come alongside the energy team.

E2—Pulp mill

- Maintain accurate flow sheets.
- Improve control of batch digester gas-off flow rate (reduced and consistent flow vs. large swings in gas-off flow).
- Maximize heat removed by batch digester BHA primary condenser by minimizing gas flow to secondary condenser during a blow.
- Reduce flow to the BHA primary condenser to the minimum flow rate at the end of a digester blow when the pressure of blowing digester reaches ~35 psig. This prevents creating a vacuum at the end of the blow and sub-cooling the top temperature.
- Improve control of heat removal from BHA to fully use the volume of the BHA tank and maintain a top temperature >205°F between digester blows.
- Eliminate pad steam to BHA system during digester blows.
- Maximize white and black liquor temperature to continuous and batch digesters.
- Maximize use of warm water as make-up to lime kiln scrubber system to minimize solids in kiln scrubber recirculation system, recover heat from kiln stack, and reduce hot water demand.
- Use dilution factor control of shower water to bleach and brown stock washers.
- Minimize wire cleaning shower flow to bleach and brown stock washers.
- Control use of combined and stripped condensate on last stage brown stock washer and eliminate make-up to filtrate tanks.
- Minimize hot water usage to maximize temperature of hot water used as bleach plant shower water. This includes using filtrate for repulper dilution instead of hot water, using warm water instead of hot water for wire cleaning showers and dilution factor control of both hot water flow to the bottom shower bars and next stage filtrate to the top shower bars on bleach plant washers.
- Maximize inlet and outlet water temperature for all heat exchangers and condensers supplying tepid, warm, and hot water tanks. A mill concern is always vacuum control at condensers (for example, evaporator surface condensers). Control vacuum better by maximizing cooling water flow to a condenser at or near the design flow rate, especially during the winter.
- Control last stage bleach plant washer stock outlet temperature to at least 5°F hotter than paper machine wire pit to minimize wire pit steam.

Productivity impact	Listed best practices have minimal effect on productivity.
Economic benefit	Payback is significant, with no or minimal implementation cost.
Energy savings	Energy savings should be tracked and communicated. Focus on Energy resources can assist in energy savings projection.
Water savings	Fresh water elimination results in water supply and waste treatment savings.
Stage of acceptance	Practices have been proven and are used in the industry.
Applications and limitations	Applications are site specific. Focus on Energy resources can assist with site audits.
Other resources	TAPPI TIP 0416-24 Energy checklist: pulp mill.

E3—Steam and utility department

- Maintain accurate steam and condensate flow sheets to assist in system training, repairs, and improvement.
- Measure and display energy key metrics in a manner most useful to the operator to initiate actions on deviation from excellence.
- Optimize boiler blowdown (boiler water conductivity as high as possible within established requirements).
- Regularly check pressure reducing valves for condition and proper operation.
- Maintain and use dew point demand systems on desiccant air dryers.
- Use high performance sootbloower nozzles to achieve desired cleaning performance, using less steam.
- Monitor condensate return percentage to identify and correct causes for poor performance.
- Do not keep boilers on hot backup or operate more boilers than needed just in case.
- Audit compressed air system for leaks/repair leaks.
- Monitor differential pressure on compressed air system filters/replace as needed.
- Operate compressed air system at lowest pressure required. Do not operate extra compressors.
- Optimize operation of sootblowers in solid fuel boilers.
- Regularly check temperature of sootblower poppet valves to ensure they are not leaking (do this at least 1 hour after sootblower has run). Leaking poppet valves represent steam loss and can also damage boiler tubes.
- Regularly check sootblower operating pressures to ensure proper cleaning without excessive steam usage. Excessive pressure can also result in boiler tube damage.
- Pressure reduce as much steam as possible in the most efficient turbine if multiple options are available.
- Calculate costs on a regular basis to determine if it is economical to condense steam in turbine(s).
- Identify the causes of steam venting and develop a plan to eliminate.
- Regularly survey steam traps and repair/replace those that have failed.
- Measure “U” factor of energy recovery heat exchangers on a regular basis and clean as needed.
- Model the steam balance operating the steam driven equipment in lieu of electrical driven equipment where the overall balance allows.
- Keep turbine condenser vacuum systems in good condition to maintain design vacuum levels. Every 1.0” Hg increase in condenser pressure results in 2.5% efficiency loss.
- Create a department operation model to identify the most cost-effective operation strategy. This should consider fuel choices, generation choices, time of day generation and equipment operation choices. Use it.
- Condensing steam in turbine condenser typically does not offer good economics (fuel cost is greater than value of electricity produced).
- Establish an overall utility scoreboard to capture the impact of the actions.

Productivity impact	These practices do not affect productivity, only efficiency of operation.
Economic benefit	Payback requires investment of time and process knowledge with significant return economically.
Energy savings	Energy savings are immediate.

Water savings	Water savings are an indirect result of specific measures, but usually increased energy efficiency is also reflected in increased water use efficiency.
Other benefits	Engaging multiple operators and levels creates an energy efficient culture.
Stage of acceptance	Listed practices are accepted practices.
Applications and limitations	Application specifics will be site-dependent. Listed actions have a wide range. Utility range of “normal” operations can limit certain actions.
Practical notes	Many utility department operators do not have a good understanding of energy-efficient operating parameters.
Resources	DOE steam best practices and Inveno Engineering steam best practices.

UTILITIES AND BUILDINGS BEST PRACTICES

Table of Contents

SS1—Combined heat and power (CHP)

Maximize system potential for electrical generation using combined heat and power.

- Measure and record electrical generation and electrical generation efficiency.
- Replace pressure reducing valve with back pressure steam turbine (see DOE steam Tip Sheet #20).
- Steam turbine drives for rotating equipment (see DOE steam Tip Sheet #21).
- High-pressure boiler with back pressure turbine (see DOE steam Tip Sheet #22).
- Combustion turbine with heat recovery steam generator (HRSG) https://www.epa.gov/chp/what-chp
- Use low-pressure steam coil air heaters to increase steam/electric cycle efficiency.
- Use of closed feedwater heater to increase steam/electric cycle efficiency.
- Utilize low-pressure steam in mill processes to increase steam/electric cycle efficiency.
- Install high efficiency thermocompressors to reduce motive steam use.

Economic benefit	• Electricity typically costs 3 to 5 times as much as steam on a Btu basis. The economics of converting steam energy to electricity are very good. • This is an energy cost savings project. It does not decrease the amount of energy needed by plant, only the cost. From a global perspective, combined heat and power is a very efficient method to produce electricity.
Energy savings	Combined heat and power exhibits excellent utilization of the total steam cycle efficiency.
Stage of acceptance	Medium.
Applications and limitations	This is a very capital-intensive project. Existing operations may limit value.
Practical notes	• Time of day generation, while not saving energy, reduces the overall cost of electricity and helps balance the grid. • Site should work with the utility supplier, as to benefit both parties.
Resources	Department of Energy (DOE) Steam Tip Sheets. Inveno Engineering Steam Engineering Best Practices.

SS2—Steam distribution and condensate return

Condensate can represent 16% of the thermal value of the steam system. Maximize condensate return.

- Maintain accurate condensate flow sheets.
- Measure overall condensate return. Target 90%.
- Inspect and repair steam traps (see DOE steam Tip Sheet #1).
- Insulate steam distribution and condensate return lines (see DOE steam Tip Sheet #2).
- Use vapor recompression to recover low-pressure waste steam (see DOE steam Tip Sheet #11).
- Flash high pressure condensate to generate low-pressure steam (see DOE steam Tip Sheet #12).
- Use vent condenser to recover flash steam energy (see DOE steam Tip Sheet #13).
- Use low-grade waste steam to power absorption chillers (see DOE steam Tip Sheet #14).
- Install removable insulation on valves and fittings (see DOE steam Tip Sheet #17).
- Use steam ejector to reduce venting of low-pressure steam (see DOE steam Tip Sheet #29).
- Return pressurized condensate direct to the deaerator (DA).
- Implement an internal steam trap management program. Target less than 3% failure rate.
- Low temperature condensate will create water hammer when mixed with high temperature condensate unless proper piping practices are integrated.
- Eliminate condensate leaks or condensate discharge to the sewer.
- Identify location and monitor all atmospheric condensate collection tank venting.
- Install taps on each return line to test condensate quality to quickly identify sources of contamination.
- Typical condensate measurement includes pH, hardness and conductivity. High conductivity usually represents contamination of condensate. This can be the result of contamination in the condensate return system or solids carryover from a boiler.
- Hardness indicates contamination by river, well water, or other source of contamination. (Volume of contamination can be determined by hardness titration of mixture, compared to titration of contaminating water.)
- Lower pH can result from contamination of condensate, or exposure of condensate droplets to air (example: air in-leakage to paper machine dryer piping under vacuum). NOTE: Condensate pH should be greater than 8.8 to 9.2 to prevent corrosion of carbon steel and copper components.

Economic benefit	Reducing condensate losses will result in less purchased fuel. Site will burn less.
Energy savings	Maximizing amount and quality of return condensate results in overall energy savings. Reduced loss of heat to buildings and atmosphere.
Stage of acceptance	Medium.

Practical notes	• Most facilities can benefit from improvement in these areas. • Accurate condensate flow sheets go a long way to system maintenance, understanding, and identification of overall improvements. • Improving steam line insulation reduces ambient temperature in buildings.
Resources	Department of Energy (DOE) Steam Tip Sheets. Inveno Engineering Steam Engineering Best Practices.

SS3—Steam generation

Integrate best practices to maximize the thermal and electrical efficiency for steam generation.

- Maintain accurate steam and condensate flow sheets.
- Establish the following key steam and condensate measurements. Report daily, act on deviation from standards.
    - Steam production.
    - Fuel consumption.
    - Steam production energy efficiency. Calculate boiler efficiency using ASME PTC 4.1.
    - Electrical consumption.
    - Internal electrical generation.
    - Internal generation efficiency.
    - Condensate return as a percentage of steam production.
    - Measure any controlled steam venting.
- Use feedwater economizer (see DOE steam Tip Sheet #3).
- Improve boiler combustion efficiency (see DOE steam Tip Sheet #4).
- Minimize boiler blowdown (see DOE steam Tip Sheet #9). Automate system.
- Install boiler blowdown heat recovery (see DOE steam Tip Sheet #10).
- Minimize short-cycling loss (see DOE steam Tip Sheet #16).
- Install automated blowdown heat recovery system (see DOE steam Tip Sheet #23).
- Upgrade boiler with energy efficient burners (see DOE steam Tip Sheet #24).
- Install condensing economizer (see DOE steam Tip Sheet #26A).
- Improve boiler combustion efficiency (see DOE steam Tip Sheet #4). Display efficiency using PTC 4.1.
- Perform regular combustion efficiency testing.
- Find alternatives to keeping boiler on hot backup.
- Install VFD on boiler fans.
- Install VFD on boiler feedwater pumps.
- Measure, integrate, and display system venting.

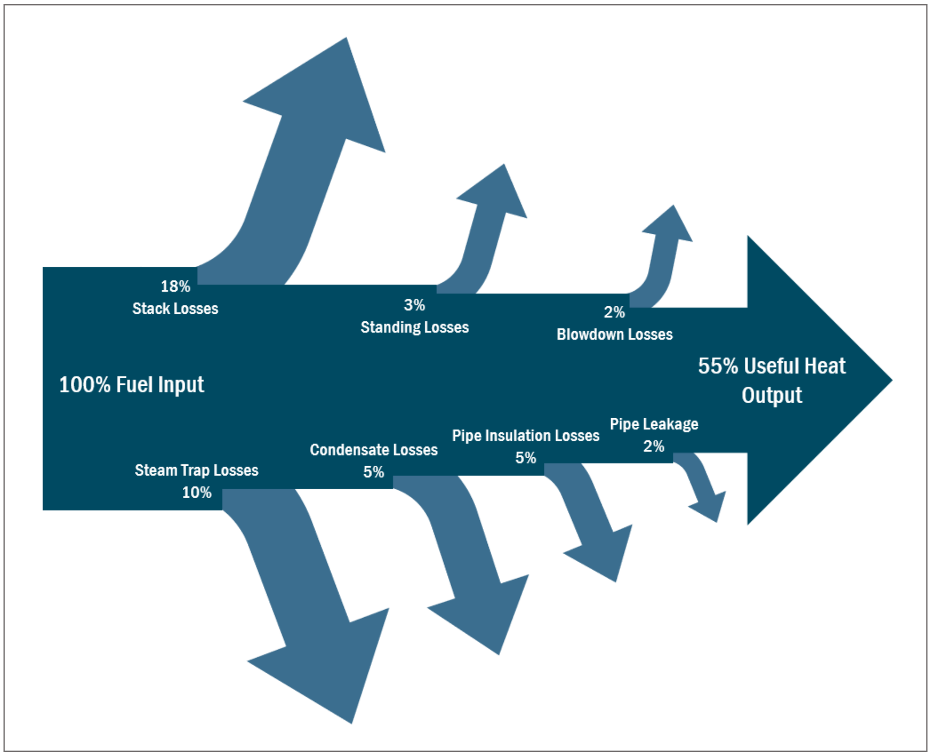
Economic benefit	Reduced cost to produce steam.
Energy savings	As boiler efficiency increases, it requires less fuel to produce a given amount of steam.
Other resource savings	Increased equipment life.
Stage of acceptance	Medium.
Applications and limitations	Most facilities can benefit from improvement in these areas.
Resources	DOE Steam Tip Sheets. Inveno Engineering Steam Engineering Best Practices. Steam system audits may be funded by Focus on Energy.

SS4—Thermal cycle

Implement steam system best practices to reduce steam system thermal losses. Amount of energy reduction is specific to the site steam design, operations, and current condition.

- Steam Thermal Cycle Summary (steam systems exhibit energy losses reducing useful heat output). Each category has a group of measures which can be implemented to reduce losses:
  - Boiler flue gas: 16.4% to 18%
  - Boiler outer shell or casing: 0.5%
  - Continuous blowdown (boiler): 1.5%
  - Bottom blowdown (boiler): 0.2%
  - Insulation (steam and condensate): 6.4%
  - Steam leaks/Steam loss to atmosphere: 7.5%
  - Steam trap station failures: 3.6%
  - Condensate losses: 3.8%
  - Potential thermal cycle energy losses: up to 45%
  - Note: Incremental energy losses must be considered with steam system improvements, when standing losses remain.
- Create a steam system road map:
  - Accurate flow sheets.
  - Eliminate all steam venting to atmosphere.
  - Install vent condensers.
  - Eliminate steam leaks. Target three or fewer leaks per year.
  - Proper steam and condensate piping methods.
  - Elimination of two-phase flow, and water hammer.
- Insulate any exposed surface for steam and condensate piping with temperature >140°F.
- World class condensate return benchmark is 90%. All direct steam use should be measured and recorded to account for those condensate losses.
- Optimize boiler efficiency.
  - Combustion testing.
  - Blow down heat recovery.
  - Economizers.
- Return pressurized condensate direct to the DA.
- Implement an internal steam trap management program. No more than 3% failure rate.
- Replace steam powered condensate pumps. They are difficult to maintain, leading to condensate losses, and require high pressure motive steam use.

Figure 10: Steam system losses



Productivity impact	Indirect.
Economic benefit	Vented steam results in both thermal and condensate loss.
Energy savings	10 pounds of steam per hour represents over 1100 therms of heat per year. Note: 60°F make-up water, including boiler efficiency, 8700 hours/year. Reclaimed heat can be used for boiler feedwater make-up or process water heating.
Water savings	Vented steam also vents the condensate. This must be made up by a fresh water source.
Other benefits	Piping insulation improves safety, reduces ambient temperature, two phase flash steam erosion, building preservation.
Stage of acceptance	Best practice heat recovery methods are widely received within the industry. Solutions are proven.
Applications and limitations	Boiler feedwater preheating or heated fresh water preheating. Limitation of boiler feedwater heating is seen with reduced feedwater make-up requirements with excellent condensate return.
Practical notes	Reasonable energy payback compared to other energy reduction projects. Many papermakers do not have a good understanding of steam and condensate systems. Training can be beneficial.
Resources	Inveno Engineering steam system best practices 1, 2, 3, 25, 26, 43, 51, 52, 53, 54, and 58. Steam thermal cycle summary reference: Swagelok Steam System Best Practices document 33 and Thermal Energy.

CA1—Compressed air system

- Document your compressed air system and identify major air consumers. Include all compressors, air dryers, storage tanks, filters, and branch supplies with shut offs. Identify major air consumers.
- Meter and record compressor power, individual compressor flows, system pressures and branch flow.
- The average facility has 30%-35% leakage if no recent action has been taken to identify and repair leaks. Target leakage rate of less than 10%.
- Install a flow controller to operate plant pressure at minimum acceptable pressure. Every 2 psi reduction represents a 1% compressor efficiency improvement.
- Become familiar with and use ultrasonic leak detectors as part of normal maintenance actions.
- Discourage use of poly tubing or piping practices that do not have robustness of life expectancy.
- Install no-loss air drains for condensate removal.
- Identify the most critical process consumers, whose design establishes supply air minimum pressures or dew points.
- Install engineered nozzles instead of drilled pipes.
- Minimize use of venturi coolers for component cooling. Know the cost and value of the air being consumed.
- Install point-of-use air storage to reduce system disruption or elevated pressures.
- Fix the filter/regulator/lubricators. Verify the following:
  - Filter bowls are not cracked or leaking.
  - Manual drains are closed.
  - Gauges are readable and in good working order.
  - Regulators are set to correct end-use specification.
- Identify and limit misuse of compressed air such as cooling personnel or equipment or cleaning floors.
- Install low-pressure blowers instead of using compressed air.
- Every 8 hp of electrical energy produces 1 hp of work with compressed air. Replace compressed air powered motors and tools with electric powered wherever possible.
- Implement good piping practices, which keep air velocities below these guidelines:
  - Compressor: 15 fps.
  - Distribution: 30 fps.
  - Point of Use: 45 fps.
- Debottleneck supply, using loops or increased pipe sizing or point-of-use storage.
- Super air knives require much less air volume than drilled pipes and flat air nozzles, operate at lower sound level, and have lower operating cost.
- Alternatives to compressed air should be investigated for some applications (e.g., reel turn ups).

Compressed Air

Productivity impact	Compressed air delivery of necessary volume at necessary pressure is critical. Systems tend to operate at excess pressures to address special cause events.
Economic benefit	• Reduced electricity use. • Reduced variation in the compressed air supply reduces process variation in equipment using the compressed air supply.
Energy savings	Energy savings are possible with system optimization, but system optimization is not able to take place without measurement and an understanding of the compressed air system. Accurate flow sheets are a requirement.
Water savings	If air cooled there is no water savings. If water cooled, the cooling water can be reclaimed and reused. Cooling water should be controlled.
Other benefits	Compressed air reliability is a complementary benefit.
Stage of acceptance	System understanding is key to gaining acceptance of system improvements.
Applications and limitations	Certain processes dictate levels of air pressure and air quality. Identify them, so those key processes can be met in the most efficient delivery manner.
Practical notes	Levels of compressed air system optimization.: • Level 1: Reliable pressure, flow, and quality. Documenting all users, suppliers, and ancillary equipment of compressed air. • Level 2: Supply-side optimization which includes KPIs. • Level 3: Demand reduction. Actions are based on measurement and a system understanding. STA-COLM: • Storage: Sufficient quantity in the best place. • Appropriate uses: Eliminate misuse-substitute. • Controls. • Leaks and maintenance.
Resources	Compressed Air Challenge is a training resource https://www.compressedairchallenge.org/. There are many quality compressed air vendors who can assist a site with the improvement of their air system. Focus on Energy provides prescriptive incentives for compressed air leak surveys and repair and ancillary equipment.
Synergies	Heat recovery for air cooling or water cooling.

CA2—Compressed air supply

- Integrate compressed air supply and consumption as a daily reported key energy metric. Act on deviation from excellence.
- Each 2 psi of plant air supply represents 1% compressor electrical load.
- Know and operate compressor(s) at the optimal efficiency point.
- Install VFD or variable slide valve compressors for system pressure trim. Review part-load efficiencies of each compressor.
- Target 3-5 ft^3 storage capacity per cfm supply.
- Optimize multiple compressor controls to maximize compressor efficiency.
- Require CAGI documentation from the vendor for any compressor under consideration.
- Recover compressed air heat for displacement of building heating requirements.
- Use flow controllers for distribution of air to the facility.
- Install no-loss air drains for condensate removal.
- Check the filters. Pressure drop across a filter rises rapidly as it reaches the end of its service life.
- Identify the most critical process consumers, whose design establishes supply air minimum pressures or dew points.
- Inlet air temperature matters. Use outside air when possible. Allow inside air use as backup if inlet filters or inlet screen begin to plug. The table below captures the efficiency gain of using outside air vs. inside air.

Table 7: Air compressor power savings vs. Intake air temperature

AIR INTAKE TEMP, °F	POWER SAVINGS
30	7.5%
50	3.8%
70	0
90	-3.8%
110	-7.6%

https://www.buildings.com/articles/28298/easy-steps-save-energy-compressed-air-systems

Productivity impact	Compressed air delivery of necessary volume at necessary pressure is a critical, but often misunderstood and thus, misused utility.
Economic benefit	• Reduced electricity use. • Reduced process variation with stable equipment operation.
Energy savings	Significant energy savings are possible with system optimization. System optimization requires measurement, reporting, and understanding of the compressed air supply and distribution system.

Water savings	Water-cooled compressors can have significant water flows and present opportunity for beneficial reuse of tempered water. Reduce to minimum requirement and consider installing cooling towers or glycol heat transfer to reduce discharges to the sewer.
Stage of acceptance	Compressed air improvements addressing reliability are readily accepted. Improvements based on measured values demonstrating predicted improvements are usually accepted. Lack of measurement holds back acceptance.
Applications and limitations	Existing air systems, which have evolved over time, limit practical approaches within economic boundaries.
Practical notes	Energy costs are approximately 80% of 10-year life cycle cost for an air compressor. Efficiency should always be the primary concern when selecting new compressors or selecting new equipment.
Resources	Focus on Energy can provide audit incentives and incentives for compressed air system efficiency improvements. The Compressed Air Institute and DOE are resources that provide excellent support.

CA3—Compressed air dryers

- Install efficient compressed air-drying systems, which consider the level of drying required, and the means to accomplish it, including operational costs.
- Identify level of air dewpoints required. Do not dry to -40°F if none of the air supplies equipment located outside, or if equipment requires this level of dryness.
- Install dewpoint demand control on desiccant dryers to reduce overdrying.
- Most energy-efficient to least energy-efficient air dryers:
  - Heat of compression.
  - Cycling refrigerated.
  - Vacuum purge desiccant.
  - Heated desiccant with blower purge.
  - Heated desiccant compressed air purge.
  - Heatless air purge.
- Consider point-of-use dryers for process-specific areas such as outside equipment vs. whole system solution to meet the need of a few specific consumers.
- Routinely check purge valves for leakage and purge rates where purging does occur. These systems tend to be in less-traveled areas.
- Minimize use of heatless air dryers, due to purge air requirement.

Productivity impact	Compressed air delivery of necessary quality at necessary pressure is critical. Air dryers serve an important role in air quality.
Economic benefit	Most efficient use of the available compressed air supply. Reduced parasitic losses in the air-drying process.
Energy savings	Energy savings from the most efficient selection of air drying, with controls, minimize parasitic losses. For example: parasitic purge losses of heatless desiccant drying can require 15% purge air. This dryer, without any dewpoint control, has a continuously established air leak to the system that the compressor must supply.
Other benefits	Compressed air system stability.
Stage of acceptance	Newer technologies of air drying have proven applications.
Applications and limitations	Heat-of-compression air dryers can only be used with oil-free compressors. Each dryer must be properly applied to the compressed air system.
Resources	Compressed Air Challenge is a training resource. There are many quality compressed air vendors who can assist a site with the improvement of their air system. Focus on Energy can provide financial and technical assistance for more efficient compressed air dryers.

P1—Pumping and pump selection

In mills of most sizes and types, pumping represents 25-40% of the mill's electrical consumption. Average pumping efficiency is below 40%. Over 10% of pumps run below 10% efficiency.

- Major factors affecting pump efficiency are throttled valves and pump motor over-sizing.
- Seal leakage causes the highest downtime and cost.
- Check for multiple parallel pumps when number of operating pumps is seldom changed. In some cases, one or more may not be pumping at all.
- Check batch or cyclical start/stop system with frequent pump cycling.
- Listen for significant cavitation noise.
- Select pumps which operate at optimal efficiency vs. oversizing.
- Trim impellers where the control element consistently restricts flow. Pumps supplying a headbox must be hydraulically balanced to reduce pulsations after trimming the impeller.
- Consider VFDs in process applications with varying flow requirements.
- Eliminate flow/pressure recirculation loops whenever possible.
- Slower rpm pumps tend to last longer and demonstrate higher pump efficiencies than higher-speed pumps of similar head and capacity.
- More than 80% of pump lifecycle costs result from energy and maintenance expense. Less than 15% are initial purchase costs.
- Target system improvement in any process case where the control element is less than 30%-40% open.
- Specifically review all high head pump applications for operating design efficiency. Consider vertical multistage as an alternative.
- For positive displacement pumps, consider rotary lobe instead of progressive cavity.

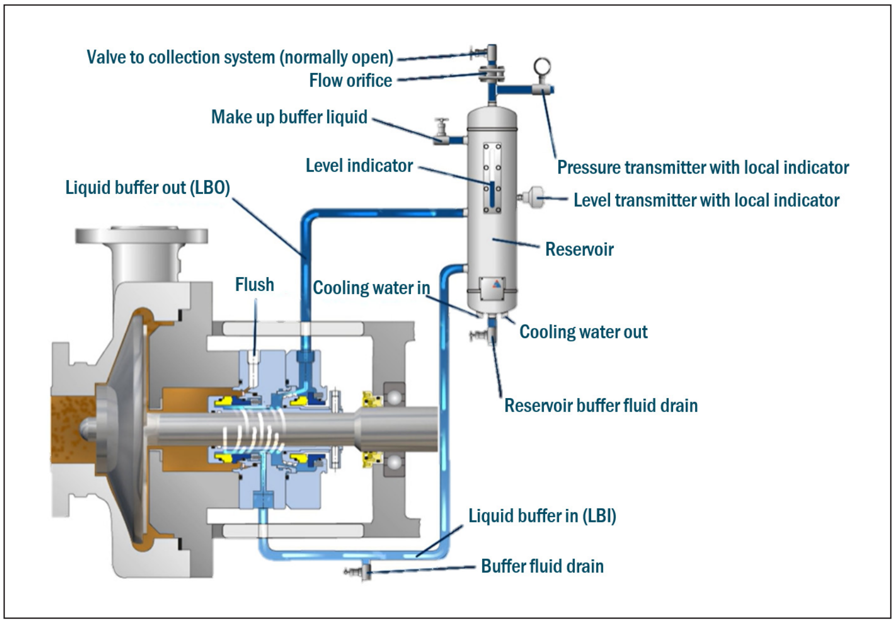
Productivity impact	There are hundreds of pumps in pulp and paper mills and good performance is required to achieve optimum production.
Economic benefit	• Reduced electricity use. • Pumps operating at their best efficiency point reduce ongoing maintenance and reliability costs.
Energy savings	Energy savings of 20% or more are possible with system optimization.
Water savings	See Pump Sealing.
Other benefits	• Longer pump and seal life with proper pump application. • Piping components have longer life with reduced vibration when eliminating oversized pump systems. Transmitters, piping flanges, control valves, etc.
Stage of acceptance	Pump system improvements are widely accepted once system design is understood. VFD's have improved reliability and are also widely accepted.
Applications and limitations	Multiple pumping applications in the pulp and paper industry. Each process is unique requiring specific solutions.
Practical notes	There are several pumping system resources. Choose a pump vendor who knows pumps and pumping systems.
Resources	Focus on Energy can provide prescriptive incentives for VFD for pumping applications.

P2—Pump sealing

Install pumps with sealing practices that eliminate or reduce fresh water entry with minimized impact on pumping energy.

- Pump shaft seals are one of the significant fresh water infiltrations to the process.
- Failure of pump seal systems are the leading cause of pump mechanical failures.
- Loss of quench water is the leading cause of pump seal failure. Do not run a seal dry.
- Leaking seals create environmental, safety, and energy impacts.
- Quality seal suppliers are available to assist in the proper application of the supplied seals.
- For fresh water or minimally contaminated pumping service where the pump is always flooded when operating:
  - Select pump with a larger seal chamber and a mechanical seal that does not need seal flushing.
  - Consider using a double mechanical seal with a tank system, in applications where a pump can run dry.
- For condensate:
  - Use a seal piping plan that uses condensate for seal flushing.
  - Make sure the seal quench is on the pump side before any check valve or shut off.
  - If the condensate is too hot for the seal, or if there is any chance of the pump running dry, install a double mechanical seal with a tank system.
- To minimize fresh water entry for pumping system with solids:
  - Best Practice is the double mechanical seal with a tank system. The tank system should automatically refill with an indication of refill rate.
  - Lesser alternative is to control seal water flow with a reliable flow meter, which provides a rate of flow at the manufacture's recommendation.
- Application of a shaft seal restriction bushings serve to reduce fresh water infiltration.
- Pump using a repeller can also be used. This design does not require seal water but does increase pumping hp by about 3%.
- Overtightening packing usually results in an increase of energy and results in shaft wear. Superior packing performance products can be an alternative for those applications where the cost of a tank system/mechanical seal is not able to be supported.
- Use of clarified process water or tempered water are ways to reduce heating costs of pump seal water.

Figure 11: API Plan 52



Productivity impact	Process pumping failures reduce productivity. Reliability matters.
Economic benefit	Payback is primarily driven from reduced heating of fresh water. Mechanical failure and loss of product are also significant costs incurred when a seal fails.
Energy savings	Energy due to water infiltration heating can be calculated. An average flow of an unmetered single mechanical seal was measured at about 2.7 gpm, based on measurement of more than 200 pumps at paper sites. Average annual heating value of the seal water is well over $3,000 per year for 2.7 gpm.
Water savings	Pump seal water reduction directly reduces water consumption and reduces excess process water.
Other benefits	Excellent sealing practices results in improved system mechanical reliability.
Stage of acceptance	Practices are accepted by the best in the industry.
Applications and limitations	Application of the proper seal is important. Seal suppliers can support the proper selection and application of the seal.

P3—Optimize Pump System Efficiency

The site should determine the optimum operational conditions for each pump and perform a system analysis. This analysis should include the startup flows (present low flows) and evolution toward the design-flow capacity. Design flow is the system capacity based on a 20-year forecast of flow. An estimated peaking factor indicates the range of flow(s) and head conditions required to meet the conditions and specifications of the system design.

The site should select the pump or combination of pumps providing a peak efficiency operating point relative to the common operation condition of the pump. Consider operating a single pump, multiple pumps, multiple pumps of different capacities, and VFDs. The site can confirm the equipment-system selection by calculating the wire-to-water efficiency of each equipment system option under consideration.

Productivity impact	Optimizing pumping systems can reduce unscheduled downtime, reduce seal replacement costs and improve process-treatment efficiency and effectiveness.
Economic benefit	The payback period depends on site specifics and whether this practice is applied to a new design or retrofit. With a new facility, the payback period should be less than two years; in retrofit conditions, payback typically ranges from three months up to three years.
Energy savings	The energy saved will vary with the installation; 15% to 30% is typical, with up to 70% possible in retrofit situations where a service area has not grown as forecasted, or projected operating conditions have not been met.
Applications and limitations	No limitations.
Practical notes	Many computer models can help with the analysis. The model should address both static and dynamic conditions and present and future pumping conditions.
Other benefits	Generally, improved pumping systems provide better treatment-system control.
Stages of acceptance	The technologies used to analyze pumping systems are readily available, and their use is widely accepted.
Resources	M2—Variable frequency drive applications. P4—Reduce pumping flow. P5—Reduce pumping head.

P4—Reduce pumping flow

Facility operators should actively manage and reduce, where possible, pumping flow rates. Because the energy use of a pump is directly proportional to the pump-flow rate, operators should compare the facility's design-flow rate with current flow rate and evaluate whether or not system conditions have changed in a way making it feasible to reduce pumping rates.

In some applications (e.g., pumping to a storage tank), it is possible to pump at a lower flow rate over a longer period, allowing the pump to operate at a point on the pump curve optimal for energy efficiency.

Water conservation measures, such as the reduction of infiltration and inflow or leak detection and repairs to the water distribution system, can also reduce the required flow rate.

Productivity impact	No impact.
Economic benefit	The estimated payback will vary with improvements and comparison against a base alternative. While load shifting and demand flattening (pumping at a lower rate over a longer period) do not necessarily result in reduced energy use, they do result in reduced electricity bills (peak demand savings).
Energy savings	The potential savings will vary with the type of modifications being considered.
Applications and limitations	This applies to all pumping systems.
Practical notes	A detailed evaluation should be completed to identify the potential energy savings for each installation.
Stages of acceptance	While the concept is understood, implementing this practice often requires measurement and analysis not immediately practicable for some sites.
Resources	P3—Optimize pump system efficiency.

P5—Reduce pumping head

Operators should aim to reduce the total system head losses, which include static-head and friction head losses (due to velocity, bends, fittings, valves, pipe length, diameter, and roughness). Energy use in a pump system is directly proportional to the head, and the facility can take the following steps to analyze and improve pump efficiency:

- Plot the system curve at the time of installation.
- Compare output on the certified curve for pump model and size.
- Calculate the system efficiency and save for future reference.
- Avoid throttling valves to control the flow rate.
- Run higher wet-well level on the suction side, if practical.
- Increase pipeline size and/or decrease pipe roughness.
- Modify header configuration to minimize fittings.
- Install VFDs to reduce pumping head at low process flow conditions.
- Trim impeller when no operating condition requires the available head.

Productivity impact	No impact.
Economic benefit	The estimated payback will vary with the extent of the improvements and the comparison against a base alternative.
Energy savings	The potential savings will vary with the type of modifications being considered.
Applications and limitations	This best practice is applicable to all pumping systems. Note reducing the head too much may result in the pump running to the far right of the best efficiency point on the pump curve, which could result in inefficient operation and/or cavitation.
Practical notes	A detailed evaluation should be completed to identify the potential energy savings for each installation.
Other benefits	Additional benefits of this practice include reduced pump wear, longer service life and less required maintenance.
Stages of acceptance	Reducing the head on pumping systems is widely accepted in the water and wastewater industry.
Resources	P3—Optimize pump system efficiency. P6—Avoid pump discharge throttling.

P6—Avoid pump discharge throttling

The facility should modify the operation of a pumping system to eliminate the use of discharge valve throttling to control the flow rate from pumps. As an alternative, the facility may consider energy efficient VFDs – or the uses of a low capacity pump.

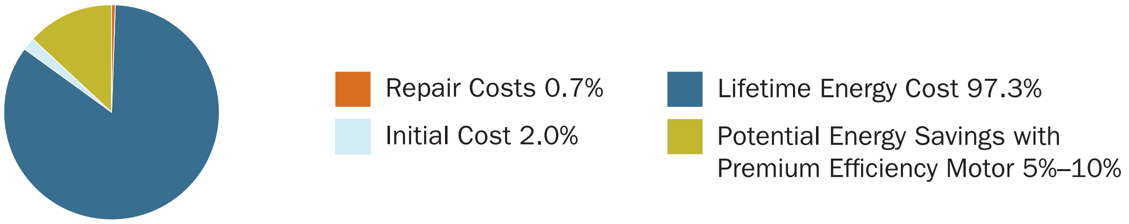
Productivity impact	No impact.
Economic benefit	Payback varies by application and may be less than one year if the pump run time is high and valve closure is significant. However, the savings can be as low as 15% of total energy consumption if the pump has low hours of operation and the throttling valve is minimally closed.
Energy savings	Energy savings can exceed 50% of pumping energy in some cases. Actual energy savings depends on the amount of closure of the throttling valve.
Applications and limitations	Applied to all locations currently using valves to control flows.
Practical notes	A detailed evaluation should be completed to identify the potential energy savings for each installation, giving some consideration to the use of a VFD and/or smaller-sized pumps.
Other benefits	Additional benefits of VFDs are reduced pump wear, longer service life, less required maintenance, and the ability to quickly and easily adjust flow as changes occur in the system.
Stages of acceptance	The water/wastewater industry accepts the use of VFDs to replace throttling valves to reduce energy consumption and provide improved control of the pump.
Resources	M2—Variable frequency drive applications.

M1—High efficiency motors

Facility personnel should survey existing motors for possible replacement with new premium efficiency motors and specify the most energy efficient motors on all new installed and inventoried equipment. The facility should establish an emergency motor replacement program specifying energy efficient motors. As a backup measure, facility personnel should identify a local motor supplier with inventory of the most energy efficient motors for all process installation conditions.

Productivity impact	Facility operation managers should expect minor impact due to the brief shutdown for removal and replacement of the existing motor.
Economic benefit	The simple payback is generally short, often less than two years, if the motor operates continuously. However, if the equipment's annual hours of operation are minimal, the simple payback period may be longer.
Energy savings	Savings will range between 5% and 10% of the energy used by the motor being replaced.
Applications and limitations	The physical characteristics and ambient conditions of the existing motor must be considered when replacing a motor. For example, the new motor may have to be explosion-proof, spark-resistant, or have immersion capability (flooding conditions). This practice can be applied to all electric motors, especially on pumps with high annual operating hours and for those operating during peak hours. These include blowers, pumps, and constant torque equipment.
Practical notes	Typically, when an existing motor is replaced or needs to undergo major repairs, a premium efficiency motor is used. Often, such as under conditions of high annual operating hours, it may be worthwhile to replace a working motor. In any case, facility management should determine if it is economically justifiable to replace older motors instead of repairing them. The size of the existing motor should be assessed to determine if it has the operating range to be energy efficient. Often, a system may be oversized to meet maximum design flow even if the system may never reach that flow. Adding a smaller pump or fan to process average or low flow while keeping the large machine in place to meet maximum design flow requirements may be advantageous. When planning a motor replacement, the project team should keep in mind a premium efficiency motor may require a longer delivery time than a standard or high efficiency motor of the same size and should allow adequate time in the project schedule.
Other benefits	An additional benefit to this practice is a reduction in emissions from the power source (electric utility).
Stages of acceptance	Energy efficient motors are a well known, proven, and accepted technology.
Resources	M2—Variable frequency drive applications.

Figure 12: Lifecycle motor costs



M2—Variable frequency drive (VFD) applications

VFDs match motor output speeds to the specific load and avoid running at constant full power, thereby reducing energy usage. The equipment must be designed so it can operate at peak flows. Peak load designs often do not allow for energy efficient operation at average or low-flow conditions. Operators should assess variations in facility flows, including organic loading, and apply VFDs, particularly where peak process demands are significantly higher than average or low demand and where the motor can run at partial loads.

Productivity impact	The impact should be minimal with interruption of service only during installation, startup, and fine-tuning.
Economic benefit	VFDs are more available and affordable than in previous years with paybacks usually ranging from six months to five years. The payback period will vary with the application depending on the size of the drive, hours of operation and variation in load. Large drives, long hours, and high load variability yield the highest savings.
Energy savings	Savings vary with application and technology. Many VFD retrofits result in savings of 15% to 35%. In some installations, particularly where throttling is used to control flow, savings of 10% to 40% are possible.
Applications and limitations	Applications for VFDs include controlling pressure, process flows, stuff box and tank levels, and process fans. VFDs apply to most processes in pulp and paper systems where loading conditions fluctuate. They can replace throttling valves on discharge piping, control the pumping rate of a process pump, control airflow rates from blowers, and control the speed of constant torque equipment.
Practical notes	Energy-saving calculations accounting for load variation can demonstrate the benefit and help justify the cost. The system should be assessed by an expert before selecting and installing the VFD to ensure system compatibility and cost-effectiveness.
Other benefits	Associated benefits include better control of system flow rate and pressure, more consistent supply and increased flexibility to meet demand requirements with minimum energy use. Matching drives to loads puts less stress on equipment and may reduce maintenance. Better control of process flows can also reduce chemical usage. In addition, reduced emissions from the power source can be directly related to the reduced consumption of electrical power.
Stages of acceptance	VFDs are widely accepted and proven effective in the pulp and paper process industry. New and upgraded water and wastewater systems are commonly equipped with VFDs for most system applications.

PM1—Precision maintenance

Precision maintenance of fans, pumps, and other rotating equipment can reduce electricity use up to 10%. Key factors are:

- Proper assembly, alignment, and machinery balance.
- Electric motor analysis.
- Optimum lubrication.
- Maintenance reliability and energy-reduction benefits are additive.
- Consider using wireless vibration sensors and other process sensors for monitoring of equipment.
- Implementation of precision maintenance practices as a mill culture will take 3-5 years and relies on continual improvement.
- Use vibration sensing as a foundation for process proactive optimization.

Productivity impact	Higher equipment uptime.
Economic benefit	Lower maintenance cost. Higher uptime increases profitability and reduces energy cost per ton.
Energy savings	Up to 10% reduction in electricity use for equipment.
Other resource savings	Longer equipment life.
Stage of acceptance	Medium.
Practical notes	Requires special training of maintenance personnel. Applies to all rotating equipment.
Resources	Preventive maintenance practices by IDCON.
Synergies	Excellent maintenance uptime contributes to excellent process uptime, which, in turn, results in overall site energy efficiency per unit sold.

WASTEWATER BEST PRACTICES

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WW1—Optimize aeration system

The site should assess the aeration system to determine if it is operating as energy efficiently as possible for the required level of treatment. This assessment should compare the present loading conditions and system performance in kWh per million gallons and other KPIs with those of similar facilities. The site should consider the potential benefits and costs of improvements such as fine bubble aeration, dissolved oxygen control and variable airflow rate blowers.

Primary area/process	This practice is primarily implemented in the secondary treatment processes of activated sludge, aerobic digestion, channel aeration and post aeration systems.
Productivity impact	Modified aeration systems may result in different types of savings for other treatment unit processes. For example, in biosolids processing, this practice may lead to a reduction in the polymer dosage requirements for biosolids thickening and dewatering. This practice has also led to increased treatment capabilities at most facilities. In some locations, final effluent quality has improved.
Economic benefit	The payback period is generally three to seven years for retrofits and about one year for new construction.
Energy savings	Savings of 30% to 70% of total aeration system energy consumption are typical.
Applications and limitations	This practice can be applied to all aerated treatment systems.
Practical notes	This best practice should be implemented at all facilities with aeration opportunities.
Other benefits	This practice often results in improvement in other unit treatment processes and reduced maintenance at some facilities.
Stages of acceptance	Fine bubble aeration methods are widely accepted as are dissolved oxygen monitoring and control systems and various methods of controlling the flow rate of air to the treatment process.
Resources	WW2—Fine bubble aeration. WW3—Variable blower airflow rate. WW4—Dissolved oxygen control.

WW2—Fine bubble aeration

Sites with activated sludge treatment facilities should assess the feasibility of implementing fine bubble aeration, which provides energy efficient treatment of wastewater. Fine bubble aeration can be installed in new systems or retrofitted into existing systems. The technology usually improves operations and increases the organic treatment capability of a facility. For optimum performance, the site should combine this practice with dissolved oxygen monitoring and control and a variable capacity blower and should monitor blower pressure. A facility installing fine bubble aeration should plan for periodic diffuser cleaning (in place gas cleaning system or scheduled drain and manual cleaning), as diffuser fouling influences system pressure, oxygen transfer efficiency and energy efficiency. To this end, it is usual practice to periodically "bump" the diffusers to maintain proper pressure drop and maximize oxygen transfer capability.

Primary area/process	The primary application for this best practice will be on aeration tanks, aerobic digesters, channel aeration and post aeration.
Productivity impact	Minor impact during installation.
Economic benefit	Economic benefits vary between new facilities and retrofit applications. A new system may pay back in as little as one year while payback on a retrofit will vary depending on the inefficiency of the existing system and the amount of new equipment required.
Energy savings	Energy savings range from 20% to 75% of the aeration or aerobic digestion unit's energy consumption.
Applications and limitations	This practice applies to all aeration systems. A limit exists for aerobic digestion; if the system operates at a solids concentration of 2.5% or greater, further review should be done first.
Practical notes	Fine bubble technologies have applications for all sizes of wastewater treatment facilities. The percentage range of energy savings will be similar regardless of facility size. Fine bubble can replace mechanical aerators, but the facility should consider the ability to maintain proper mixing when assessing this modification.
Other benefits	Most sites that have implemented this practice report improved biosolids management, reduced polymer usage, better clarification, and better overall effluent quality.
Stages of acceptance	This technology has gained a high level of acceptance in the industry.
Resources	WW1—Optimize aeration system. WW3—Variable blower airflow rate. WW4—Dissolved oxygen control.

WW3—Variable blower airflow rate

The site should require that the aeration system and aerobic digester blowers have variable air supply rate capability such as multistage or single stage centrifugal blowers with VFD, positive displacement blowers with VFD, inlet guide controlled single stage centrifugal blowers and/or turbo blowers with a VFD. The range of variability should respond to the specific requirements a site needs to precisely match system demands. The blower system should be able to supply either the minimum airflow required to meet existing low load conditions or the minimum airflow rate to meet mixing conditions of the aeration system and to meet the high loads of design conditions. The site should avoid airflow discharge throttling and unnecessary backpressure, assess the application properly to ensure the correct delivery pressure, and avoid delivery at a pressure higher than the process requires.

Primary area/process	This practice applies to all aeration systems, including aerated grit, activated sludge aeration tanks, aerobic digestion systems, channel aeration, and post aeration systems.
Productivity impact	Interruption in production should occur only during installation.
Economic benefit	Payback is usually under three years.
Energy savings	Energy savings depend on site conditions and which parameter, mixing or organic loading, dictates the lesser amount of airflow required by the system. Savings will range from 15% to 50% of the energy consumed by this process.
Applications and limitations	This practice can be applied wherever blowers are installed.
Practical notes	Variable airflow rate blowers should be integrated with fine bubble aeration as well as dissolved oxygen monitoring and control for optimum energy efficiency. The site should consider the potential advantages of staging loads and replacing two blowers with three, four, or five smaller units able to meet both current and future demands.
Other benefits	When teamed with fine bubble diffusers and dissolved oxygen control technologies, effluent quality, and biosolids processing are usually improved.
Stages of acceptance	Technologies for varying airflow rates are well received. Variable speed positive displacement blower arrangements and variable capacity centrifugal blowers are becoming more available, and numerous installations now exist.
Resources	WW1—Optimize aeration system. WW2—Fine bubble aeration. WW4—Dissolved oxygen control.

WW4—Dissolved oxygen control

Automatic dissolved oxygen (DO) control technology will monitor and maintain the DO concentration level of the aeration tank(s) and post aeration systems at a preset control point by varying the airflow rate delivered to the aeration system.

Primary area/process	The primary applications of this practice are on aeration tanks at activated sludge facilities, aerobic digestion, and post aeration systems.
Productivity impact	Installation of most systems can be accomplished without interfering with normal operation.
Economic benefit	Paybacks for using DO control technology are usually two to three years.
Energy savings	Savings vary depending on the efficiency of the present system. Generally, energy savings for an aeration system range from 20% to 50%.
Applications and limitations	Limitations will vary with the characteristics of the waste being treated. If the waste has characteristics able to easily foul a DO probe, the DO system will not be readily feasible. Maintenance of the DO probe to preserve its monitoring capability is the key to achieving maximum energy efficiency.
Practical notes	This control strategy should be employed at post aeration systems and wherever activated sludge is used as the secondary treatment process. Variable flow may be provided using variable frequency drives. Self-cleaning monitoring probes may reduce maintenance frequency and maintain energy efficient operation for extended periods of time.
Other benefits	A DO controlled system can improve the dewatering characteristics of waste biosolids and will have fewer problems treating a fluctuating influent load, compared to systems without DO control technology.
Stages of acceptance	DO control is a well established control methodology. The primary factor affecting acceptance is the concern about the reliability and potential maintenance costs related to DO probes.
Resources	WW1—Optimize aeration system. WW2—Fine bubble aeration. WW3—Variable blower airflow rate.

WW5—Aerobic digestion options

The site should assess the operation of its aerobic digester to determine if better control of airflow could be achieved through either using a separate smaller blower and/or using flexible membrane fine bubble diffusers and equipment with adjustable airflow rates. Many facilities operate aerobic digesters with surface aerators or coarse bubble diffusers with limited ability to modify or control the amount of airflow delivered to the process.

First, the facility should consider flexible membrane fine bubble diffusers, which allow for variable airflow rates in digester applications. Second, the facility should choose equipment and/or controls with adjustable airflow rates. Often, air for the digestion process is bled from the activated sludge blowers within the secondary treatment process, allowing little or no control over the airflow delivered.

Primary area/process	This practice applies to biosolids treatment and management.
Productivity impact	Conversion to flexible membrane fine bubble diffuser technology and a smaller blower may improve the process of reducing volatile solids.
Economic benefit	Payback for this practice varies with the modifications required.
Energy savings	The application of flexible membrane fine bubble diffusers and a separate smaller blower in an aerobic digestion system can reduce energy consumption for the process by 20% to 50%.
Applications and limitations	The key limitation to this practice is the final concentration of total suspended solids (TSS) in the aerobic digester. Operators may wish to be directly involved in the control of the concentration of TSS to maintain applicability of flexible membrane fine bubble diffusers. Mixing can also be a limitation.
Practical notes	This best practice is applicable to most systems but will typically require the diffusers and blowers be replaced. Some piping modifications may also be required.
Other benefits	Application of this practice can yield the following benefits: • Improved biosolids dewatering. • Reduced polymer demand when the digested biosolids are thickened or dewatered. • Less pin floc in the biosolids processing. • Improved reduction of volatile solids. • Improved decanting from the digester. • Reduced volume of biosolids for disposal.
Stages of acceptance	This technology is readily available and widely accepted, except in situations where the solids concentration within the aerobic digester exceeds 2.5% TSS.
Resources	WW1—Optimize aeration system. WW2—Fine bubble aeration. WW3—Variable blower airflow rate. WW4—Dissolved oxygen control.

WW6—Blower technology options

Blower technology is continually evolving, providing more energy-efficient options to select from. This evolution in blowers needs to be continually researched and monitored by the site to identify the most energy efficient technology for the application being assessed. Current research and development and improved controls have brought turbo blowers and new technology screw blowers to wastewater treatment facilities. This technology, along with single stage variable vane blowers, provides options to the designers of wastewater treatment facilities. The value of this evolving technology is blowers are increasingly energy efficient and can now operate more efficiently over a wider range of airflow rates. Sites should research, assess, and use the most current energy efficient blower technology available for a specific application to ensure an energy efficient selection from startup through design and able to be integrated with other elements to make the entire facility energy efficient.

Primary area/process	This best practice applies to all aeration applications, including aerated grit, activated sludge aeration tanks, aerobic digestion tanks, post aeration tanks, aerated channels, and air assisted final filter backwash applications.
Productivity impact	The only interruption in treatment would occur during installation.
Economic benefit	Economic benefits of this practice vary between new facilities and retrofit applications. Payback on a new application may be as short as a year while payback on a retrofit application will depend on the inefficiency of the existing system.
Energy savings	Energy savings will depend on the specifics of the opportunity, but generally range from 15% to 25% based on improved blower energy efficiency.
Applications and limitations	This best practice should be applied wherever blowers are installed. If applying turbo or centrifugal blowers to variable submergence processes such as SBRs or aerobic digesters, the control system must be able to maintain operation of the system within safe limits.
Practical notes	New technology blowers should be assessed for any existing or new design application. The new blowers are often more energy efficient and have an expanded operating range when compared to former technologies at the same airflow rate and pressure conditions. Because capital expense for new blowers may be high, the site should also evaluate the cost effectiveness of adding VFDs to achieve variable capacity with existing blowers.
Other benefits	When new blowers are integrated with other energy efficient modifications, such as fine bubble diffusers and dissolved oxygen control, effluent quality may be improved, and the facility may gain additional overall treatment capability.
Stages of acceptance	Application of new blower technology has gained an increasing level of acceptance.
Resources	WW1—Optimize aeration system. WW2—Fine bubble aeration. WW3—Variable blower airflow rate. WW4—Dissolved oxygen control.

WW7—Improve solids capture in dissolved air flotation (DAF) system

The site should optimize the air-to-solids ratio in a DAF system by adjusting the supply air and/or by feeding the highest possible solids content. Furthermore, the site can reduce energy use by operating the DAF thickener continuously and adding polymers to the biosolids. Alternate technologies should be explored to provide dissolved air using less pumping horsepower.

Primary area/process	DAF thickeners are used in dewatering processes, fiber recovery, and sludge thickening.
Productivity impact	No impact.
Economic benefit	DAF thickeners have high operating costs because they require a significant amount of energy for air pressurization. Payback for this practice will vary depending on the degree of optimization.
Energy savings	Energy consumption can be reduced by improving solids capture. The savings will depend on the application. There may be opportunity to reduce the high head requirements of air chamber designs with air injection pumps or side stream membranes.
Applications and limitations	Continuous operation of the DAF thickener and the addition of polymers can increase the site's O&M and labor costs.
Practical notes	The site should compare the cost of the additional polymer with the avoided energy cost to determine if the polymer addition is worthwhile.
Other benefits	Improved solids capture will benefit other downstream biosolids treatment processes (i.e., thickening and/or dewatering). Improved air flotation using air injection pumps or membranes can reduce flotation chemical usage.
Stages of acceptance	This practice is widely accepted by the industry.

WW8—Recover heat from wastewater

The site should assess the possibility for wastewater heat recovery to provide a feasible and renewable energy source for heating and a heat sink for cooling applications. Heat recovery technology can be installed in new systems or retrofitted into existing systems. The technology can be designed to improve the total energy balance of the wastewater system and can also be paired with heat pumps for heating and cooling.

Primary area/process	This best practice is primarily applied either when the raw wastewater enters the treatment facility or after final clarification. It can also be applied to higher temperature discharges within the collection system. Heat can be removed and added at these points, and the temperature of the wastewater does not have a negative impact on the downstream process or collection system.
Productivity impact	Minimal impact.
Economic benefit	The main economic benefits of this practice are energy efficient heating and cooling. Payback times will vary depending on the extent and location of modifications required. A payback period of one to three years may be possible if only a heat exchanger is required.
Energy savings	Additional energy savings may be available through the inclusion of heat pumps in the system modifications. Including heat pumps may increase efficiency by 20% to 30%.
Applications and limitations	Excess heat in the incoming water supply.
Practical notes	Each opportunity must be assessed on its merits and site specific conditions. The heat exchanger should be equipped with a fully automated, mechanical self cleaning system for minimal maintenance and maximum operational safety. For optimal maintainability, the system can include a bypass.
Other benefits	Application of this best practice provides the additional benefit of cooling down hot wastewater streams hard to treat biologically at higher temperatures.
Stages of acceptance	The technology is well proven with several installations worldwide, but the opportunity is still unrealized by many.

WW9—Anoxic zone mixing options

When it becomes necessary for a wastewater treatment facility to incorporate anoxic zones, the site should determine the best technology and methodology. Many wastewater treatment facilities use their existing aeration system blower to mix their anoxic zones. While this method of mixing does work, other methods should be considered. For example, fractional-to-low-horsepower mechanical agitators can be used to mix the anoxic zones and usually have notably lower energy demands than using the aeration system blower. Mechanical mixing will better manage the concentration of oxygen in the zone because it generally does not incorporate air into the contents being mixed. In addition, avoiding use of the existing aeration system for anoxic zone mixing enables more effective control.

Primary area/process	This practice applies primarily to mixing treatment tanks to remain anoxic.
Productivity impact	Interruption to operations should only occur during installation of the equipment and associated controls.
Economic benefit	Simple payback is usually in the three- to five-year range depending on the size of the anoxic zone(s) to be mixed.
Energy savings	Overall savings will vary depending on the efficiency and size of the existing system to be retrofitted. Generally, the reduction in energy for the anoxic mixing system ranges from 25% to 50%.
Applications and limitations	Limitations will vary with the characteristics of the material being mixed. In general, the higher the concentration of solids being mixed, the greater the savings.
Practical notes	Mechanical mixing should be assessed to account for the level of mixing required for improved process control. The goal of mechanical mixing is to be void of oxygen (anoxic), not anaerobic. It is better to have mechanical mixing because stirring the liquid keeps the solids in suspension. However, many wastewater facilities use their aeration system to mix the anoxic tank. By doing so, air (20% oxygen) is fed into the contents of the tank, making process control more challenging.
Other benefits	This practice reduces the airflow rate required from a blower. In addition, if the air was previously provided by the aeration blower, this practice results in one fewer variable for a DO control system to account for in the aeration tank and thereby improves the efficiency of the overall treatment system.
Stages of acceptance	Anoxic zones are becoming more prevalent at wastewater treatment facilities as nutrient removal limits are being required. As a result, assessing mixing options is an accepted practice.

WW10—Optimize anaerobic digester performance

The site should optimize anaerobic-digester performance and enhance biogas production. The primary ways to optimize anaerobic digestion are:

- Optimization of process temperature: Changing the digester operating temperature from mesophilic (85°F–105°F) to thermophilic (125°F–140°F) increases the rate of destruction of the volatile solids in the biosolids. Two-phased anaerobic digestion and temperature-phased digestion have shown potential benefits in volatile solids reduction and biogas production enhancement.
- Biosolids pretreatment: The hydrolysis step is often the limiting factor in anaerobic digestion. Hydrolysis can be improved by pretreatment to improve the ability of the active microorganisms to digest the biosolids. There are various pretreatment methods available, including biological, physical, and chemical methods. Three of the more promising methods include thermal treatment, ultrasonic treatment and enzyme dosing, respectively.
- Co-digestion of auxiliary feedstock: It is often beneficial to co-digest biosolids with other types of organic waste such as restaurant grease, dairy/cheese wastes, vegetable/fruit waste and municipal organic waste. By doing so, the nutrient and moisture content can be optimized, process stability can be improved, and biogas production can be enhanced.
- Pre-thickening of the biosolids: The site can pre-thicken biosolids being fed to the digester to reduce excess water. This will increase the residence time of volatile solids and lessen the amount of energy required to heat the biosolids fed to the digester.

Primary area/process	This practice affects anaerobic sludge digestion.
Productivity impact	Optimal performance maximizes the productivity of the asset.
Economic benefit	The economic benefit of increased biogas production will be reduced by the cost of biosolids pretreatment and biogas conditioning equipment necessary for biogas use. Acceptance of other waste may generate additional revenue for the wastewater treatment facility.
Energy savings	Energy savings will be proportional to the amount of additional biogas produced for power and/or heat generation.
Applications and limitations	Except for the capital costs of the biosolids pretreatment and the biogas conditioning equipment, this practice has no limitations.
Practical notes	Performance optimization of the anaerobic digester will benefit biosolids quality for downstream biosolids processing, treatment and disposal.
Stages of acceptance	These optimization techniques are currently not widely used but are gaining industry interest.
Resources	WW11—Use biogas to produce combined heat and power (CHP).

WW11—Use biogas to produce combined heat and power

Biogas produced by an anaerobic digester can drive reciprocating engines, which can be directly connected to a pump, blower or electric generator, or can fuel microturbines, turbines, or fuel cells to generate electricity. In addition, the thermal energy generated by these systems can often be captured and used to meet digester heat loads and, where applicable, for building heating. Alternatively, the biogas can be used directly as boiler fuel to produce steam.

Primary area/process	This practice applies to anaerobic sludge digestion.
Productivity impact	Beneficial reuse of conditioned biogas has minimal impact on the operation of the CHP. There may be a limit of co-fired percentage of biogas which is established by the boiler vendor.
Economic benefit	Whether the system generates electricity or heat, or both, the beneficial reuse of the biogas offsets energy costs.
Energy savings	Sites should assess biogas-to-electricity generating systems for treatment facilities with existing anaerobic digesters or are planning to install new ones. Each system needs to be individually assessed for feasibility.
Applications and limitations	The characteristics and quality of the biogas to be used must be assessed on a facility-by-facility basis to determine what level of biogas conditioning (cleanup) is required for the beneficial, reliable and non-harmful use in an engine, boiler, or process to be fueled. The site should also determine the volume of biogas generated to assess the need for incorporating auxiliary feedstock for the digester to make biogas production viable.
Practical notes	Reciprocating engines can be used in most facility sizes. Microturbines and fuel cells are available in smaller capacity sizes for small facilities where emissions are a concern. Combustion turbines can be used for facilities with generating capacities shown to be greater than one megawatt. The site should assess the potential to directly operate pumps or blowers using biogas to identify the most beneficial use option for the site.
Resources	WW10: Optimize anaerobic digester performance. WW12: Assessment of beneficial utilization.
Other benefits	Collecting and using biogas avoids venting and flaring, which release greenhouse gas without benefit. Beneficial use of biogas can also help a facility become self-sustaining.
Stages of acceptance	Beneficial use of preconditioned biogas in CHP is gaining acceptance and being increasingly implemented in the pulp and paper industry. Conditioning and beneficial use of biogas to displace process boiler natural gas combustion represents a proven but emerging technology.

WW12—Assessment of beneficial utilization

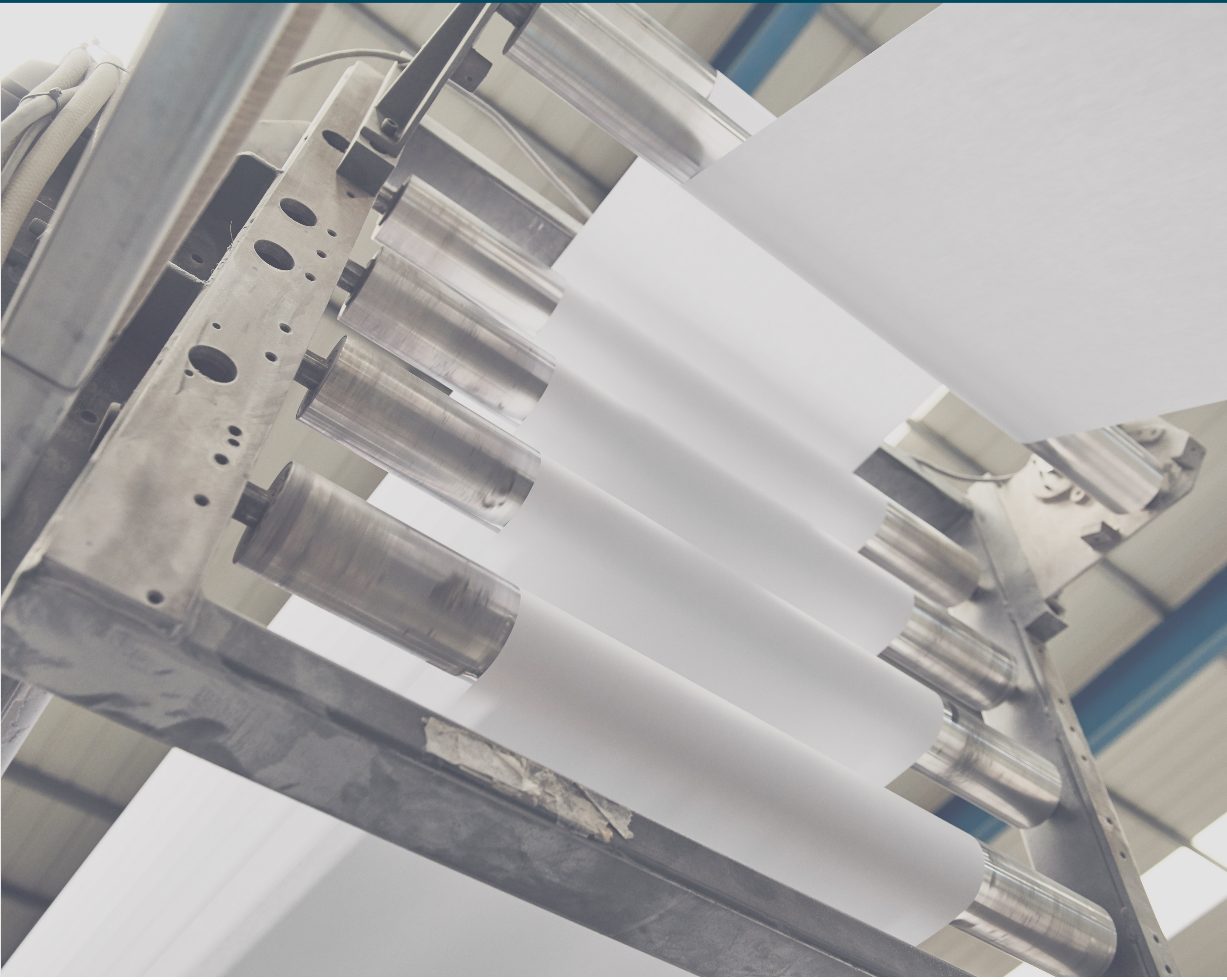
Biogas is a renewable energy resource the site should consider as a source of energy to fuel the facility's boilers, to directly fuel an engine to drive a piece of equipment and/or to generate electricity. Analysis of an anaerobic digestion system's biogas production potential requires a different view—one looking to maximize energy production rather than minimize energy use as with other energy efficiency practices. The assessment should consider biogas production from initial operation through the end of its life cycle, helping site personnel to understand the beneficial utilization over the system's lifetime.

Assuming the system loads grow over the lifetime of the equipment, initial loadings will be less than design conditions. Since the capital investment of the biogas utilization system must be repaid over the design life, an analysis of the projected biogas generation must show the life cycle benefits outweigh the initial cost. An analysis showing how the anaerobic digester will be loaded over its lifetime should show how operation will be optimized on the overall system economics. Once the rate of biogas production has been estimated, the assessment should address options for the lifetime utilization of the biogas. A full analysis will also consider the quality of the biogas available and the potential need for special conditioning equipment. The type and size of gas conditioning equipment should be specified.

The presence of biogas production capable of meeting both the internal electric needs of the facility and process heating needs is not unusual. Biogas used for process heating has a conversion efficiency of 80% to 85%. Conversion to electricity can be done at a rate of 30% to 35%. If both heat and power are generated, the conversion efficiency will generally range from 70% to 75%.

Primary area/process	This practice applies to anaerobic digestion.
Productivity impact	Minimal impact during installation.
Economic benefit	The economic benefit is in the opportunity to offset the facility's electric and natural gas use through the utilization of an otherwise flared renewable energy resource.
Energy savings	The amount of energy savings will depend on the quantity and quality of the biogas and how much can be utilized. At some wastewater treatment facilities, the utilization of internally generated biogas has been enough to eliminate facility's reliance on purchased energy.
Applications and limitations	The beneficial utilization of biogas should be implemented, when feasible, at all wastewater treatment facilities with anaerobic digestion. Many biogas systems have failed due to the improper treatment of the impurities in the biogas, resulting in poor operation and system breakdown. Biogas utilization should always use gas-conditioning equipment.
Practical notes	Biogas utilization must incorporate biogas conditioning to ensure the system being fueled does not become impaired because of varying biogas characteristics.
Resources	WW10: Optimize anaerobic digester performance.
Other benefits	The utilization of biogas can assist the facility in moving toward energy neutrality and help in reducing greenhouse gas emissions (methane and carbon dioxide).
Stages of acceptance	The utilization of biogas is gaining acceptance and being implemented more frequently across the industry.

APPENDICES

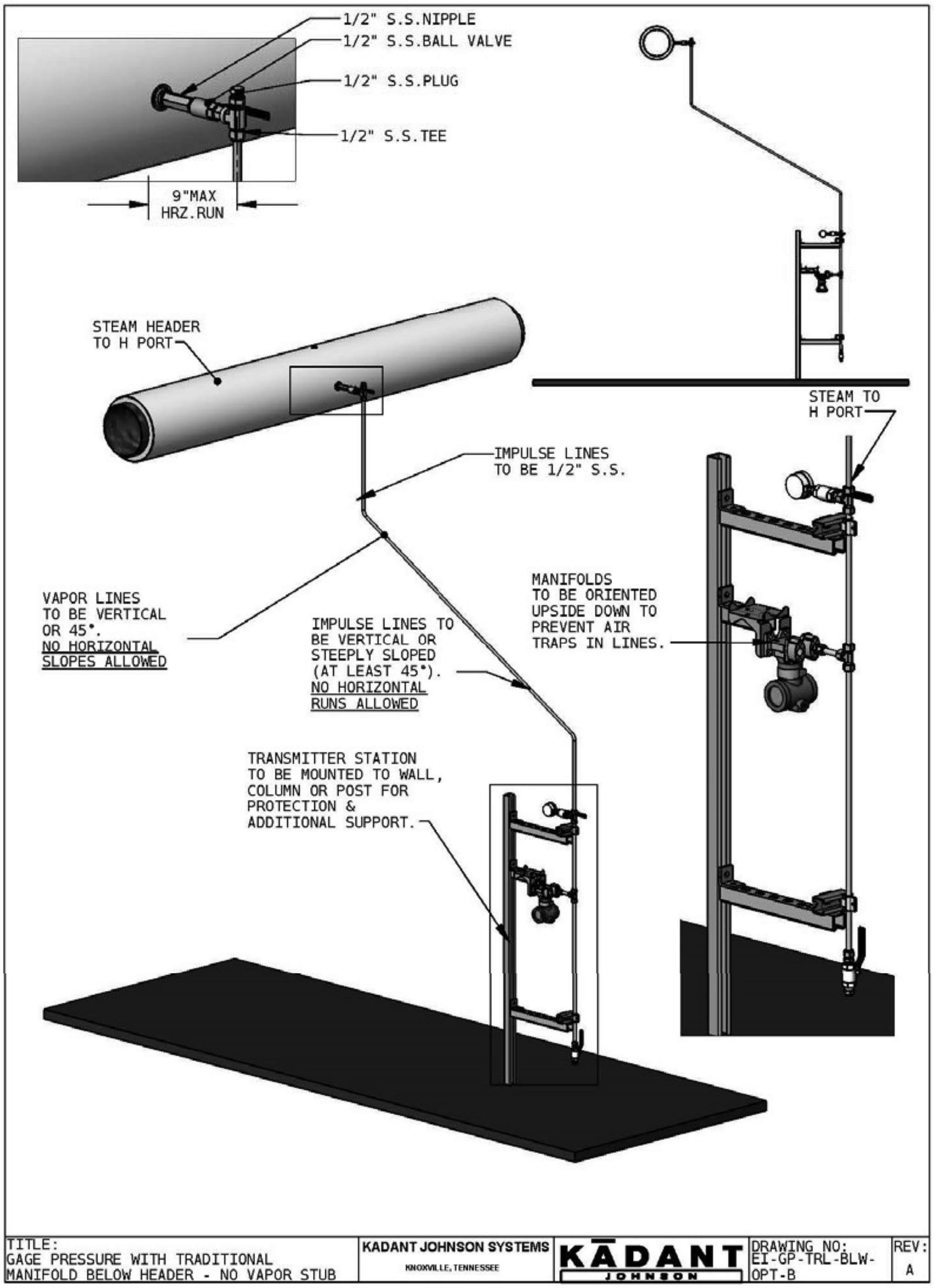


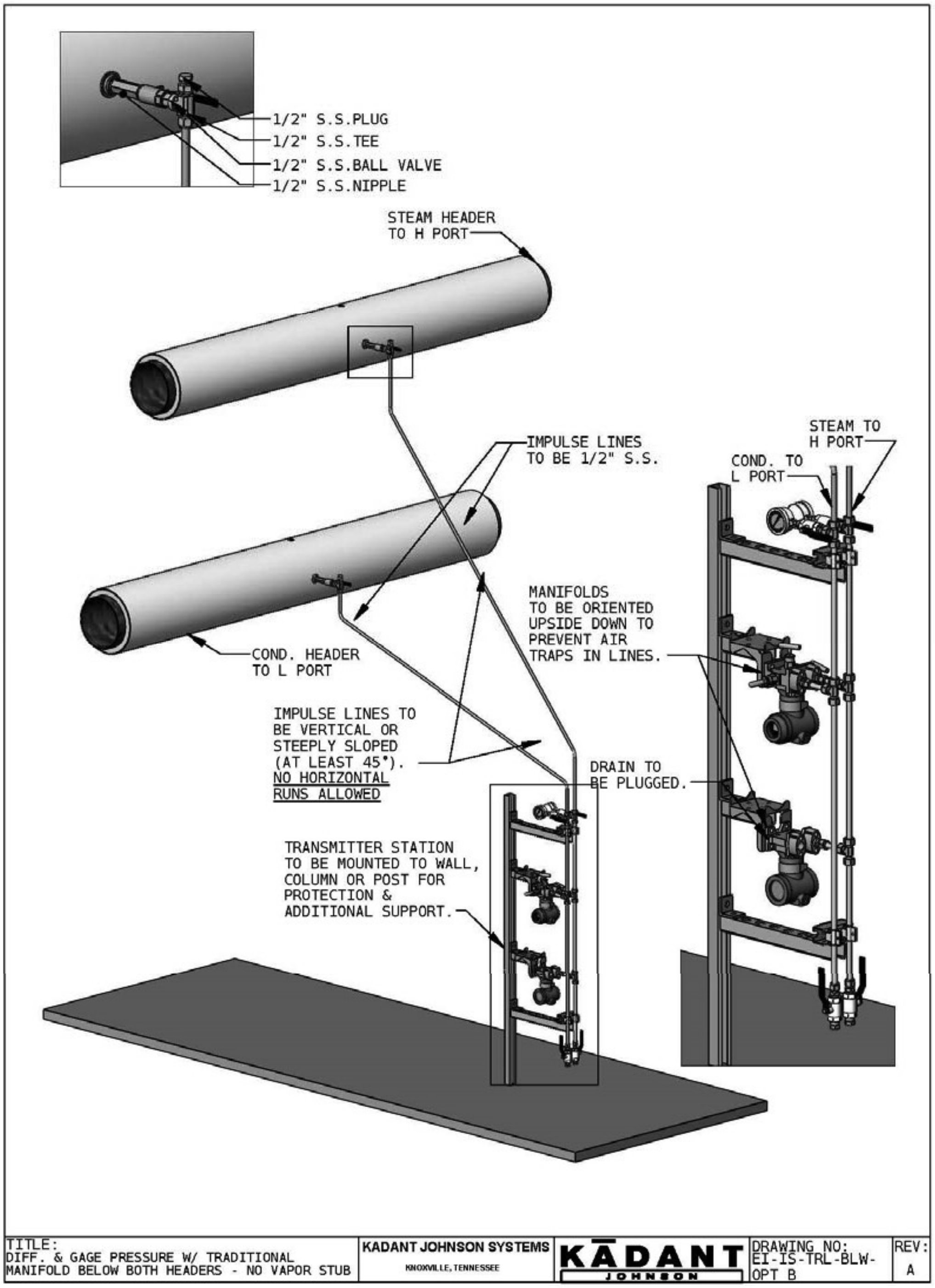
Appendices

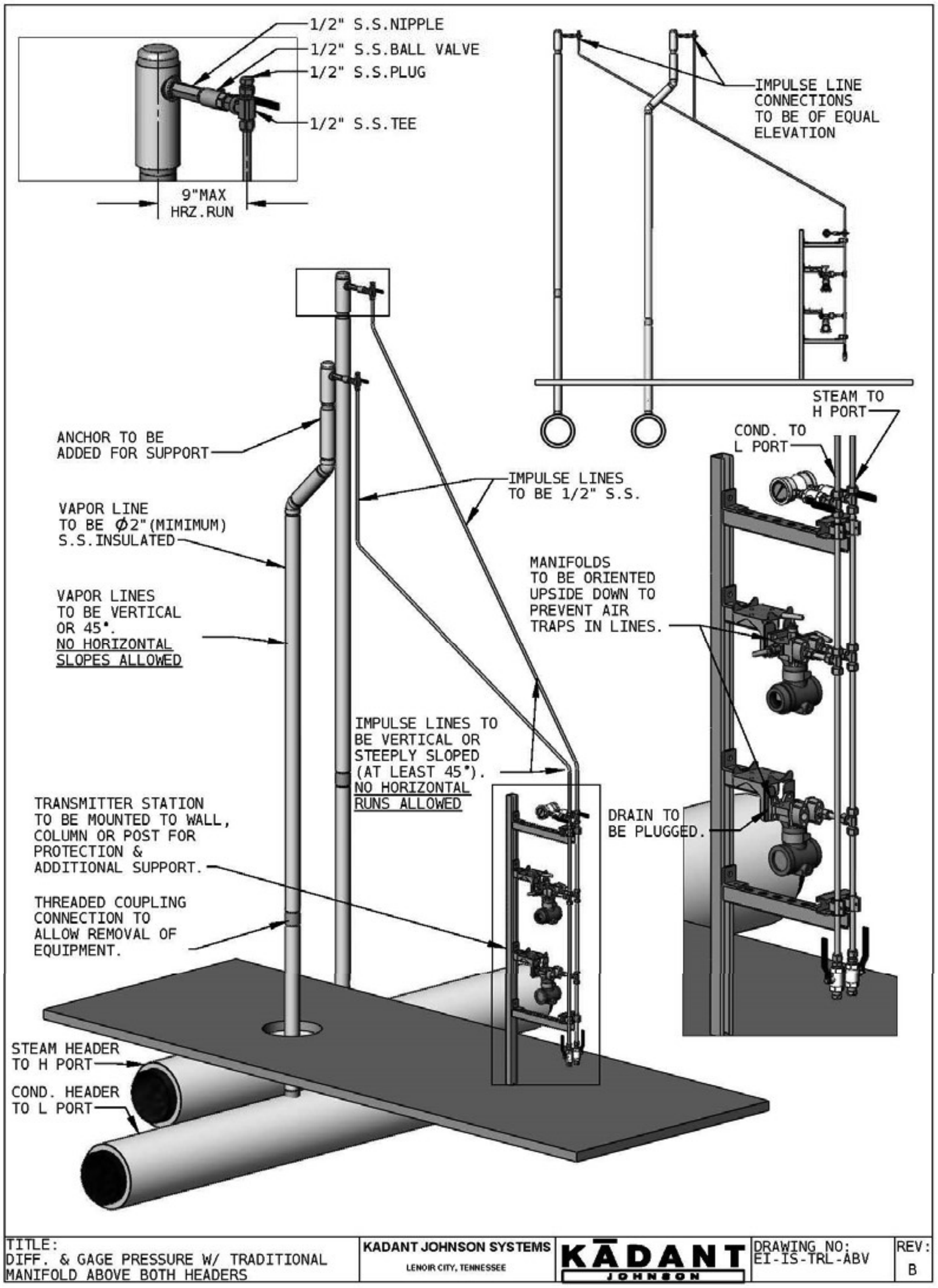
Appendix A—Steam table

PRESSURE psig	TEMP °F	TEMP °C	LATENT HEAT Btu/lb	PRESSURE psig	TEMP °F	TEMP °C	LATENT HEAT Btu/lb	PRESSURE psig	TEMP °F	TEMP °C	LATENT HEAT Btu/lb
0	212	100	970	85	328	164	889	290	419	215	808
1	215	102	968	90	331	166	886	300	422	217	804
3	219	104	964	95	335	168	883	320	428	220	798
5	227	108	960	100	338	170	881	340	433	223	793
8	235	113	956	110	344	173	875	360	438	226	787
10	239	115	952	120	350	177	871	380	443	229	781
15	250	121	945	130	356	180	866	400	448	231	777
20	259	126	939	140	361	183	861	420	453	234	771
25	267	130	934	150	366	186	857	440	457	236	766
30	274	134	929	160	371	188	853	460	462	239	761
35	281	138	924	170	375	191	849	480	466	241	756
40	287	142	920	180	380	193	845	500	470	243	751
45	292	145	916	190	384	195	841	520	474	264	747
50	298	148	912	200	388	198	837	540	478	248	742
55	303	150	909	215	394	201	832	560	482	250	737
60	307	153	906	230	399	204	827	580	485	252	733
65	312	155	901	245	404	207	822	600	489	254	728
70	316	158	898	250	406	208	820	620	492	256	723
75	320	160	895	260	409	210	817	640	496	258	719
80	324	162	892	275	414	212	812	660	499	259	715

Appendix B—Differential pressure transmitter arrangement




1/2" S.S.PLUG
1/2" S.S.TEE
1/2" S.S.BALL VALVE
1/2" S.S.NIPPLE
STEAM HEADER TO H PORT
IMPULSE LINES TO BE 1/2" S.S.
STEAM TO H PORT
COND. TO L PORT
MANIFOLDS TO BE ORIENTED UPSIDE DOWN TO PREVENT AIR TRAPS IN LINES.
COND. HEADER TO L PORT
IMPULSE LINES TO BE VERTICAL OR STEEPLY SLOPED (AT LEAST 45°). NO HORIZONTAL RUNS ALLOWED
DRAIN TO BE PLUGGED.
TRANSMITTER STATION TO BE MOUNTED TO WALL, COLUMN OR POST FOR PROTECTION & ADDITIONAL SUPPORT.
TITLE: DIFF. & GAGE PRESSURE W/ TRADITIONAL MANIFOLD BELOW BOTH HEADERS - NO VAPOR STUB
KADANT JOHNSON SYSTEMS
KNOXVILLE, TENNESSEE
KADANT JOHNSON
DRAWING NO: EI-IS-TRL-BLW-OPT B
REV: A


1/2" S.S.NIPPLE
1/2" S.S.BALL VALVE
1/2" S.S.PLUG
1/2" S.S.TEE
9"MAX HRZ.RUN
IMPULSE LINE CONNECTIONS TO BE OF EQUAL ELEVATION
STEAM TO H PORT
COND. TO L PORT
ANCHOR TO BE ADDED FOR SUPPORT
IMPULSE LINES TO BE 1/2" S.S.
VAPOR LINE TO BE Ø2"(MIMIMUM) S.S.INSULATED
MANIFOLDS TO BE ORIENTED UPSIDE DOWN TO PREVENT AIR TRAPS IN LINES.
VAPOR LINES TO BE VERTICAL OR 45°. NO HORIZONTAL SLOPES ALLOWED
IMPULSE LINES TO BE VERTICAL OR STEEPLY SLOPED (AT LEAST 45°). NO HORIZONTAL RUNS ALLOWED
DRAIN TO BE PLUGGED.
TRANSMITTER STATION TO BE MOUNTED TO WALL, COLUMN OR POST FOR PROTECTION & ADDITIONAL SUPPORT.
THREADED COUPLING CONNECTION TO ALLOW REMOVAL OF EQUIPMENT.
STEAM HEADER TO H PORT
COND. HEADER TO L PORT
TITLE:
DIFF. & GAGE PRESSURE W/ TRADITIONAL MANIFOLD ABOVE BOTH HEADERS
KADANT JOHNSON SYSTEMS
LENOIR CITY, TENNESSEE
KĀDANT JOHNSON
DRAWING NO: EI-IS-TRL-ABV
REV: B

Appendix C—Procedure for pressurizing vacuum piping

1. Raise pressure setpoint in the individually controlled dryers to 10 psig. (Keep differential pressure in automatic.)
2. Increase vacuum condenser setpoint to +2 psig or 220 °F.
3. Turn off vacuum pump.
4. Inspect steam and condensate joints on all individually controlled dryers (looking for steam leaks).
5. Inspect piping, valves, and separators from dryers to heat exchangers.
6. When inspection is complete, return all settings to normal operation.

Appendix D—Additional resources

References

1. American Forest and Paper Association; “2018 Sustainability Report”
2. United States Department of Energy; “Bandwidth Study on Energy Use in U. S. Pulp and Paper Manufacturing”; June 2015
3. Wisconsin Focus on Energy; “Pulp and Paper Energy Best Practice Guidebook”; May 2005
4. TAPPI Technical Information Paper; 0404-63, Paper Machine Energy Conservation; 2020
5. TAPPI Technical Information Paper; 0416-24, Energy Check List; Pulp Mill, 2015
6. Wisconsin Focus on Energy; “Water and Wastewater Industry Energy Best Practices Guide”; 2016
7. “An Assessment of the Economic Contribution of Pulp, Paper, and Converting to the State of Wisconsin”; Wisconsin Institute of Sustainable Technology; August 5, 2019
8. Print and Paper Myths and Facts; www.twosides.info

Publications

1. Reese, Dick; “Practical Strategies to Reduce Pulp and Paper Mill Energy Use”; Paper 360° July/August 2018, page 9
2. Gilbreath, Ken; “Pulp Mill Energy Audit Pays Off”; Paper 360° July/August 2019, page 34
3. Neun, John; “Paper Machine Water Efficiency”; Paper 360° July/August 2020, page 20-25 (Article received 2021 Jasper Mardon award.)
4. Reese, Dick; “DOE Paper Machine Energy Scorecard System”; TAPPI Papermakers Conference; Dallas, TX; May 4-7, 2008
5. Reese, Dick; “How Does Your Paper Machine Rank”; Paper 360°; August 2008: pages 22-24
6. Reese, Dick; “Update on Paper Machine Energy Conservation”; Paper 360°; July/August 2012
7. Reese, Dick, and Deodhar, Subhash; “Using Common Sense and Emerging Technologies to Reduce Energy Use”; TAPPI PaperCon 2018, April 15-18, 2018; Charlotte, NC

TAPPI Technical Information Papers (TIP)

TIP 0404-01 Determination of water removal by wet presses

TIP 0404-02 Measurement of dryer condensing rates (batch method)

TIP 0404-03 Measurement of dryer condensing rates (continuous method)

TIP 0404-04 Recommended tensions in dryer fabrics

TIP 0404-05 Methods of evaluating high velocity dryers

TIP 0404-07 Paper machine drying rate

TIP 0404-17 Recommended minimum dryer pocket air requirements

TIP 0404-18 Measurement of dryer condensing rates (vertical separator method)

TIP 0404-19 Press section monitoring

TIP 0404-20 Physical characterization of press fabrics: basis weight, air permeability, void volume under loading and pressure uniformity

TIP 0404-24 Guidelines for the design, operation, performance evaluation, and troubleshooting of a paper machine hood and air systems

TIP 0404-25 Through drying

TIP 0404-26 Paper machine clothing performance analysis

TIP 0404-27 Press fabric dewatering and conditioning - suction box (Uhle box) design and vacuum requirements

TIP 0404-31 Recommended dryer differential pressures

TIP 0404-33 Dryer section performance monitoring

TIP 0404-35 Application of dryer bars

TIP 0404-38 Dryer fabric cleaning

TIP 0404-39 Dryer surface temperature measurement

TIP 0404-41 Granite roll material and surface requirements

TIP 0404-43 Water permeability of press felts

TIP 0404-44 Sheet handling devices

TIP 0404-46 Techniques for nip impressions

TIP 0404-47 Paper machine performance guidelines

TIP 0404-49 Yankee dryer steam condensing rates

TIP 0404-50 Paper machine room ventilation guidelines

TIP 0404-51 Paper machine clothing cleaning and conditioning for recycled fiber use

TIP 0404-52 Press section optimization

TIP 0404-54 Headbox approach piping guidelines

TIP 0404-55 Performance evaluation techniques for paper machine vacuum systems

TIP 0404-57 Troubleshooting cross-machine direction moisture profile problems

TIP 0404-58 Steam shower applications in the forming and press section

TIP 0404-59 Methods to minimize sheet rewet in the press section

TIP 0404-60 High vacuum sheet dewatering

TIP 0404-61 Paper machine shower recommendations

TIP 0404-63 Paper machine energy conservation

TIP 0404-65 Chemical cleaning guide for press fabrics

TIP 0404-66 Thermocompressor applications for paper drying

TIP 0416-24 Energy checklist: pulp mill

TIP 0502-01 Paper machine vacuum selection factors

TIP 0502-14 Forming section monitoring

TIP 0508-06 Refiner systems, their inspection and maintenance

Websites

1. Office of Energy Efficiency & Renewable Energy / Tip Sheets by System -- https://www.energy.gov/eere/amo/tip-sheets-system
2. Inveno Engineering LLC / Technical Information / Best Practices – http://invenoeng.com/library/
3. Pump System Assessment Tool at the following link: http://www.energy.gov/eere/amo/articles/pumping-system-assessment-tool

Additional Resources

1. Optimizing Pumping Systems: A Guide to Improved Efficiency, Reliability and Profitability: http://estore.pumps.org/guidebooks/ops.aspx

Appendix E: Electrical distribution

Figure 13: Typical electrical distribution, integrated mill

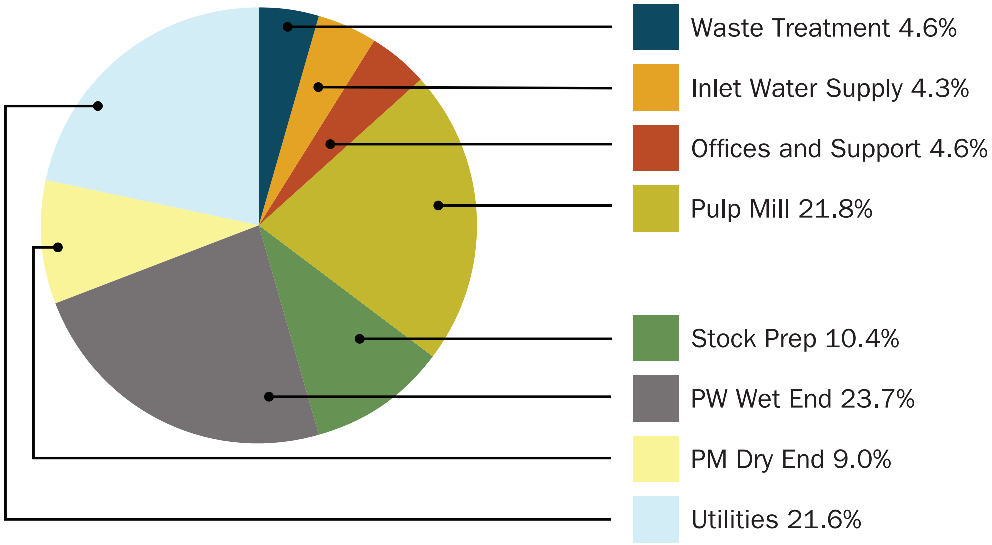
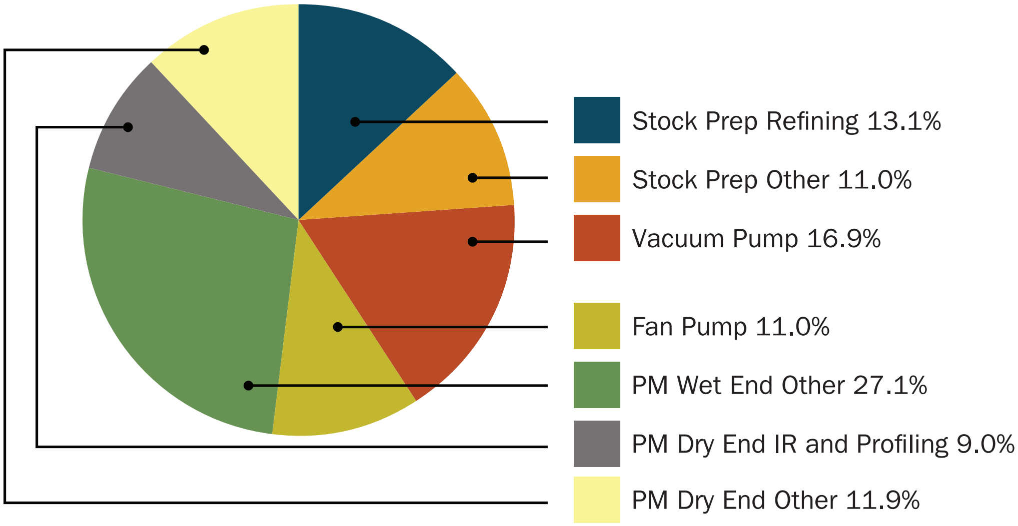


Figure 14: Tpyical electrical distribution, paper mill



Appendix F: Common acronyms and abbreviations

BDT	Bone Dry Tons
bfw	Boiler Feedwater
BHA	Blow Heat Accumulator
BOD5	Biochemical Oxygen Demand (5 Day)
Btu	British Thermal Units
Btu/t	British Thermal Units/ton
CD	Cross Direction
CEM	Certified Energy Manager
cfm	Cubic Feet per Minute
CHP	Combined Heat and Power
Cv	Control Valve flow coefficient
DA	Deaerator
DAF	Dissolved Air Flotation
DCS	Distributed Control System
DO	Dissolved Oxygen
DOE	Department of Energy (US)
DP (dp)	Differential Pressure
EMP	Energy Management Plan
EPI	Energy Performance Index
fps	Feet per Second
gpm	Gallons per Minute
HEX	Heat Exchanger
HD	High Density
hp	Horsepower
hpd/t	Horsepower Day/Ton
HPS	High Pressure Shower
KPI	Key Performance Indicator
lb	Pound
MD	Machine Direction
MMBtu	Million British Thermal Units
O&M	Operation and Maintenance
OME	Overall Machine Efficiency
PI	Brand of Data Historian System
PPI	Process Performance Index
PV	Pocket Ventilation
rpm	Revolutions per minute
SC	Surface Condenser
SOP	Standard Operating Procedure
scfm	Standard Cubic Feet per Minute
TDS	Total Dissolved Solids
TIP	Technical Information Paper
ton	US short ton (2000 lb)
TRS	Total Reduced Sulfur
VFD	Variable Frequency Drive

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