Key Best Practices for Process Energy Use
In Four Energy Intensive Industries

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ABSTRACT

Best Practices has become the model by which most industrial facilities can benchmark their energy efficiency. The Wisconsin Focus on Energy Industrial Cluster Initiative sets forth to identify, develop, and advance Best Practices in manufacturing process energy for Wisconsin's four most energy intensive industries – Pulp and Paper, Food and Dairy, Metal Casting, and Plastics. After almost one year of development, the four separate initiatives have identified and condensed almost 100 process best practices that implementers believe show the most promise for impact.

Each Cluster Initiative is lead by a team of industry experts, industry associations, and Focus on Energy management staff. While Focus on Energy already has partner relationships with almost 2000 of the 12,000 Wisconsin industrial customers through their plant managers and engineers, this approach leverages the strong political and technical connections that team members have to high level executives.

To date, industry in Wisconsin has welcomed this initiative with open arms, especially against a backdrop of escalating energy prices. While ultimate success depends on industry adoption of these Best Practices, the Wisconsin experience may be a microcosm and testing ground for future state and national efforts.

Introduction

Energy rates in Wisconsin, not long ago the lowest in the Midwest and among the lowest in the nation, have climbed to be the most expensive in the region. This phenomenon has created great concern among Wisconsin industries not only for rate relief, but also for any means to reduce the cost of production, particularly through energy efficiency.

Overall, the industrial sector in Wisconsin consumes 35% (over 24 million MWh) of electricity and 36% (1.4 billion therms) of natural gas. Table 1 shows electricity and natural gas consumption for Wisconsin's four most energy intensive industries. Together these industries account for approximately 58 percent of electricity and 79 percent of natural gas consumption of all manufacturing energy in the state. The Major Markets Study (Xenergy, 2001) found a potential savings of 18.9 trillion Btu's for these industries. Since most energy for these sectors is consumed in process manufacturing, these are logical, but difficult targets for program efforts.

Volatile, escalating energy prices are forcing industrial customers to take a closer look at their energy budgets. Knowing that the bulk of energy costs are generated by manufacturing processes, Focus on Energy embarked on an initiative to identify and promote energy efficiency opportunities in manufacturing processes for four key Wisconsin industries. Focus convened a team of industry experts to pursue manufacturing process opportunities to improve energy efficiency and reduce energy costs for these top manufacturing industries. The team concentrates on two types of activities to make this happen:

- Developing and promoting new, informative technical resources to help manufacturing facilities reduce their energy costs.
- Connecting with key large customers and players, such as industry associations and industry business allies to create a credible platform for dissemination of Best Practice information for industry.

Table 1. Wisconsin Manufacturing Energy Consumption and Savings Potential

	Consumption (10^{12} Btu)		**Savings Potential (10^{12} Btu)**	
	Electricity	Natural Gas	Electricity	Natural Gas
Forest Products	18.8	31.5	2.2	4.8
Metal Casting	6.4	59.1	0.2	4.1
Food Processing	7.9	32.4	0.8	4.6
Chemicals/Plastics	3.4	17.8	0.4	1.8
Other manufacturing	26.3	38.4	NA	NA
TOTAL	62.8	179.2	3.6	15.3

Source: Xenergy, 2001.

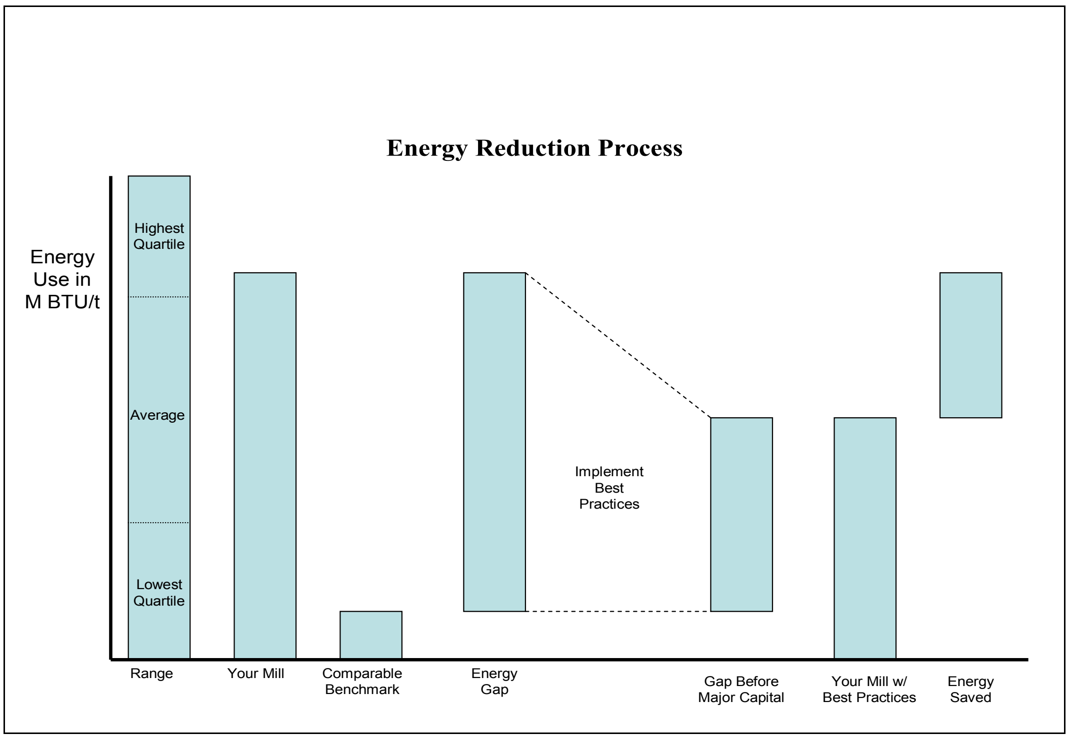
This paper presents a sampling of the first set of Process Energy Best Practices identified by the Focus on Energy Cluster Industry Initiative in Wisconsin. (For a more detailed account of the Focus on Energy Cluster Initiative, see Nicol, 2005.) We define Process Best Practices as those measures and activities which provide the best opportunities for energy efficiency in processes that are necessary for production. According to the United States Department of Energy (USDOE), Industrial Technologies Program (ITP, USDOE, 2005):

> BestPractices brings together the best available and emerging technologies and practices to help companies immediately begin improving energy efficiency, environmental performance, and productivity. … focuses on plant systems, where significant efficiency improvements and savings can be achieved….helps U.S. manufacturers maintain global competitiveness through strategic energy management, including the use of energy-efficient technologies….helps industrial manufacturers cut costs and emissions —and this helps our nation achieve its economic and environmental goals.

While many energy users know about Best Practices for the various ancillary industrial functions, such as compressed air, lighting, motors and drives, Best Practices that affect manufacturing processes have received little attention and have not experienced significant program promotion. Process energy impacts generally do not subject themselves to standardized measures that fit all industry. The usually depend on the unique circumstances of application within a facility. Several energy intensive industries have developed tools that use energy benchmarking to gauge the energy performance of comparable facilities within their industry.

Benchmarking is the process of determining who is the very best, who sets the standard, and what that standard is. In business, many things are benchmarked, for instance, who is best in sales or customer service, or what is the least amount of scrap that others make in the production of their product. For Pulp and Paper, for example, it is how much energy does a mill use per salable ton of paper produced, and how does that compare to the best performance of others making a similar product (Francis, Towers, Brown, 2002). Benchmarking for a plant is a critical tool to minimize energy use. Without being able to compare performance with an industry standard, a plan manager may not be able to see cost threats and savings opportunities. Benchmarking allows a manager to compare his plant or mill with that of the top energy performers, estimate the gap between their plants and his, and set targets and model results for best practice implementation. Figure 1 illustrates the basic procedure for benchmarking industrial facilities.

Figure 1. Potential Energy Saving through Benchmarking and Gap Analysis



Source: Akhtar, et al., 2005

Since processes are specific, even with industries, benchmark data have been developed to help mills and plants make the most direct comparisons possible. For example, in the Pulp and Paper industry, energy benchmarks can be represented as in Table 2. This table shows energy consumption for top energy performing mills- those that would be in the top decile (top 10 percent of performers). Mill configurations, except for market pulp, are typical for Wisconsin. The data for the pulp mill came from The Canadian Industry Program for Energy Conservation and the data for the remainder came from Jaakko Poyry and reconciled with the Institute of Paper Science and Technology techno/economic model. (" **-** " denotes Not-Applicable.)

Table 2. Energy Benchmarks –Gross Thermal/Power Consumption per Ton of Salable Paper

	Market Pulp Mill		**Recycled Linerboard**		**Fine Paper** (purchased Kraft)		**Coated 1-3** (purchased Kraft)		**Coated 4-5** (purchased Kraft and self-produced Ground wood)		**Recycled Tissue**	
Units	**MMBTU**	**kWh**	**MMBTU**	**kWh**	**MMBTU**	**kWh**	**MMBTU**	**kWh**	**MMBTU**	**kWh**	**MMBTU**	**kWh**
Wood/Chip Conveying	0	18	-	-	-	-	-	-	0	15	-	-
Pulping, repulping or recycling	1.5	63	0.8	110	0.6	90	0.6	100	0.2	30	1.8	300
Mechanical Pulping	-	-	-	-	-	-	-	-	1.3	575	-	-
Oxygen Delignification	0.4	68	-	-	-	-	-	-	-	-	-	-
Bleaching	2.0	91	-	-	-	-	-	-	0.1	10	0.5	50
Pulp Making	2.0	128	-	-	-	-	-	-	-	-	-	-
Paper Making	-	-	4.0	310	3.9	410	4.5	590	4.7	600	11.0	581
Black Liquor Evaporation	2.7	27	-	-	-	-	-	-	-	-	-	-
Utilities (includes wastewater)	2.0	138	0.3	30	0.3	30	0.3	30	0.4	30	0.6	30
Kiln & Recausticizing	1.0	46	-	-	-	-	-	-	-	-	-	-
Total	**11.6**	**579**	**5.1**	**450**	**4.8**	**530**	**5.4**	**720**	**6.7**	**1,260**	**13.9**	**961**

Source: Akhtar, et al., 2005

Best Practices has become the model by which most industrial facilities can benchmark their energy efficiency. The Wisconsin Focus on Energy Industrial Cluster Initiative set forth to identify, develop, and advance Best Practices in manufacturing process energy for Wisconsin's four most energy intensive industries – Pulp and Paper, Food and Dairy, Metal Casting, and Plastics.

Of the four sectors, Pulp and Paper is by far the largest energy user, paying almost a half billion dollars annually for energy, almost one-third of all industrial energy costs. Wisconsin leads the nation in papermaking, shipping over $12 billion of product annually. The forest products industry employs over 100,000 people in the state. For these reasons, Focus devoted the largest amount of resources to this cluster. The other three clusters also represent significant energy use in the state as shown in Table 1. (Nicol, 2005.)

In early 2004, Focus Industrial Program management solicited assistance from industry leaders, associations, and state government to identify experts to support the development and dissemination of Best Practices in process manufacturing for the four key industries. We developed a Cluster Team for each, lead by a team of industry experts, industry associations, and Focus on Energy management staff. While Focus on Energy already has partner relationships with almost 2000 of the 12,000 Wisconsin industrial customers through their plant managers and engineers, this approach leverages the strong political and technical connections that team members have to high level executives. The program enlisted a Cluster Leader, with 20 or more years of experience in the industry and familiar with the manufacturing processes, and a Cluster Engineer, who understands energy issues in those industries, for each Cluster team. Each team developed a series of Best Practice descriptions for its respective target industry. Best Practices were derived from literature review, industry roundtables, industry representative interviews, and facility surveys.

After almost one year of development, the four separate initiatives have identified and condensed almost 100 process best practices that implementers believe show the most promise for impact. Each best practice identified is summarized in a report template that includes a Best Practice description; the primary area or process where the Best Practice can be applied; typical energy savings and return on investment; the stage of market acceptance; specific limitations and applications; other benefits, such as productivity and environmental; information sources and resources available to customers; practical notes; and ideas for promotion.

The remainder of this paper discusses a sampling of **Process Energy Best Practices** identified by the Focus on Energy Cluster Industry Initiatives and a brief summary of how this effort has been received by industry in Wisconsin.

Key Best Practices in Four Energy-Intensive Industries

This section provides a sampling of brief descriptions of **Process Energy Best Practices** that we have identified and developed, to date. Once we have validated these Best Practices and estimated benefits and costs, we will synthesize the information into a standard Best Practice sheet format. We will deliver the information to industry stakeholders through Best Practice sheets, case studies, specialized trainings, newsletters, oral presentations, and web pages.

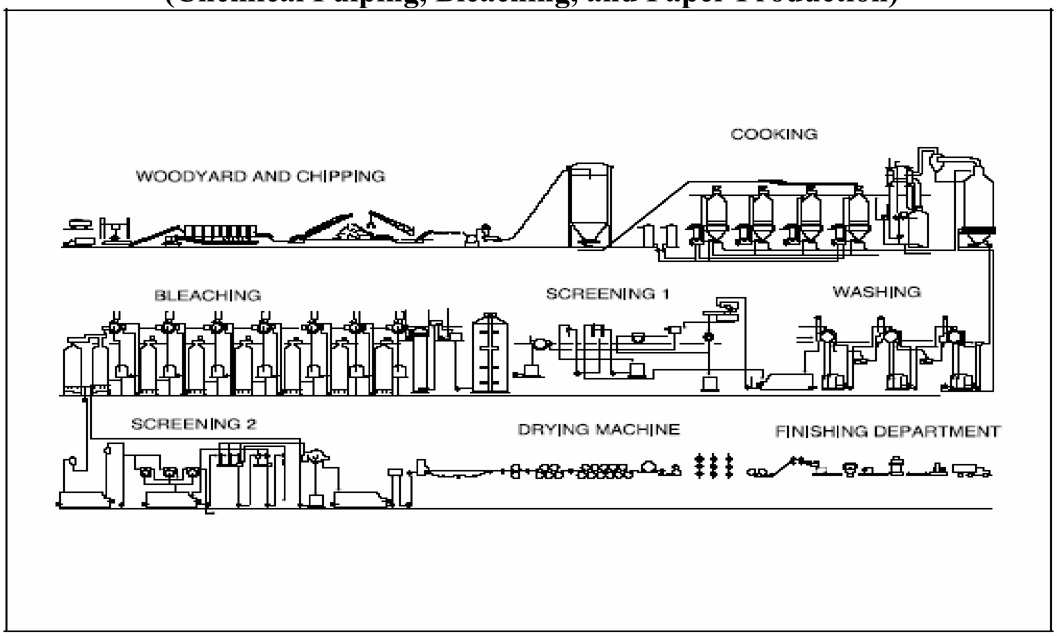
There is a limited number of ways to reduce energy consumption (Akhtar, et al., 2005). Any master plan must focus on these approaches. They include:

1. Eliminate an unnecessary usage (e.g., eliminate or shut off pumps, fans, steam flows where there is no need). This first step is the simplest and can be the most surprising. For each process and function ask the question," Is this process/equipment really necessary to meet the demands of the facility?"
2. Increase system efficiency (e.g., increase black liquor solids and post press solids in papermaking). When equipment, processes and systems cannot be eliminated, increasing efficiency must be evaluated. This step requires knowledge of any new energy saving techniques available. Applying the 80/20 rule, consider first the 20 percent of the equipment, processes and systems that use 80 percent of the energy.
3. Reclaim heat (e.g., return condensate, displace primary heat with secondary heat). After unnecessary equipment and processes are eliminated, and the remaining equipment and processes are made as energy efficient as economically possible, heat recovery must be considered. Recovered heat can be used for process water and to heat make up air.

Pulp & Paper

Processes in paper manufacture occur in three basic steps: pulp making, pulp processing, and paper production. After a stock pulp mixture is digested into its fibrous constituents through chemical or mechanical processes and.fibers have been separated and impurities have been removed, the pulp is bleached to improve its brightness and converted into a form that can be received by a paper-making machine. During paper-making, the pulp may be combined with dyes, strength building resins, or texture adding filler materials. Then the mixture is dewatered, leaving the fibrous material in place that can be rolled and stored. See Figure 2 for a simplified flow diagram of a pulp and paper mill. (EPA. Profile of the Pulp and Paper Industry, 2002.)

Figure 2. Simplified Flow Diagram: Integrated Mill (Chemical Pulping, Bleaching, and Paper Production)



Source: Smook, 1992.

Source: EPA - Notebook Project 22, 2002

Here are four examples of Process Best Practices from a growing list of about 50. These Best Practices that can be applied to 10 different areas of pulp and paper making.

Dryer Management System (DMS). DMS™ control software is an advanced control system for the dryer section of a paper machine (Aue, 2005). Supervisory control of all system set points is used to optimize system operation and provide ease of use for the operators. Steam pressures, flows, and differentials are managed under all machine operating conditions including sheet breaks, tail threading, grade changes, and start-ups.

The control system accomplishes this without the need for operator intervention. Consistent dryer operation is produced over the entire machine operating range and for every machine operating crew. Drying conditions are controlled in a manner that produces consistent machine direction sheet moisture, constant draws, and improved runnability. Upsets such as sheet breaks, grade changes, and wash-ups are handled efficiently by the DMS system.

Establishing the proper system relationships and operating limits minimize venting and steam waste. In addition, steam is conserved during upset and sheet-off conditions. The operation of the dryer section is trouble free as operating parameters are tightly controlled and controller limits are continuously set. This ensures that no dryer flooding or system problems can occur and the energy efficiency of the system is optimized.

Energy savings alone can pay for the installation in as little as nine months; production benefits shorten payback time even more. The first DMS was installed in Wisconsin in 2003 with support from the Focus on Energy program. Three additional DMS control packages were installed on paper machines in Wisconsin by the end of 2004.

High efficiency pulping blade. At the pulping stage, the processed furnish (wood or other fiber source) is digested into its fibrous constituents. The bonds between fibers may be broken chemically, mechanically, or by a combination of the techniques called semi-chemical pulping. The choice of pulping technique is dependent on the type of furnish and the desired qualities of the finished product, but chemical pulping is the most prevalent. Many mills perform multiple pulping processes at the same site, most frequently non-deink secondary fiber pulping and paper grade kraft pulping. (EPA/310-R-95-015, 2002.)

A newly designed energy efficient repulping blade rotor, recently tested in Wisconsin mills, requires 25 to 30 percent less horsepower than conventional pulping blades (Aue, 2005). Of the 425 paper mills currently operating in the United States, less than half make their own pulp to produce paper. The majority of mills must purchase their paper making fibers in the form of dried pulp bales. These mills have at least one repulper installed to make down purchased pulp bales. Applied to one 500 horsepower motor, this blade can save $35,000 per year at Wisconsin energy rates. In retrofits, the energy savings pay for the new blade in about 1 year. In new design the payback is approximately three years. Some testing for stock preparation requirements, wet strength (chemical bonding), and field verification of energy savings is currently being conducted at several Wisconsin mills with Focus on Energy assistance.

Capture whitewater waste heat to pre-heat mill water. Waste heat from whitewater produced in papermaking can be recovered to heat fresh mill water entering the mill thereby reducing steam requirements (Borowski, 2005). White water is the water that carries paper fibers through the paper making process. It is recycled and conditioned, and contains fines and residual paper making chemicals (bleach, sizing, etc.). Experience in one mill reduced steam requirement by one-third. One mill in Wisconsin has already adopted this practice. The plant operators selected spiral heat exchanger technology to avoid the typical whitewater fouling found with shell-and-tube heat exchangers. This technology can handle fluids with suspended fibers and particulate matter. The operators also found that reducing the heat in the white water also benefits the pulping process and allows for easier removal of contaminants during de-inking. All paper mills can apply this technology. Benefits are based on steam cost and the quality of recovered water.

Automated chip handling and thickness screening system. Automated chip handling in the wood yard area of a pulp mill using a first-in/ first-out inventory system provides more consistency in wood chip aging. The chip screening system assures higher uniformity in the raw material feeding the digesters. The more uniform chip and higher yields result in fewer cooks for the same amount of pulp and may also result in reduced energy required to make bleaching compounds.

In a typical mill, digester yield increases by 5-10 percent, produces an estimated energy savings of about $500,000 per year, and can result in a ROI of 15 – 20 percent. This is standard practice in all new mills, but has been slow to catch on in established mills using chip piles and chip pushers. Additional benefits include higher by-product yields and less chip damage due to handling. Since less wood is needed per ton of pulp this technology also supports sustainable forestry practices, eases wood procurement, reduces transportation, handling, and processing costs. (Borowski, 2005).

Metalcasting

While there has been economic improvement, many foundries are still struggling financially, largely due to long-term contract obligations that locked them in to energy and scrap prices when those commodities were less expensive and to competitive overseas labor rates (Bettinghaus, 2005). We have investigated about five different metal casting Process Energy Best Practices, showing mixed results. While we can show savings, some yields are so low as to not warrant further consideration. We will continue to identify and develop additional Best Practices for this industry. One example is provided below.

Coreless furnace tap temperature reduction. Reducing the electric furnace tap temperature to more closely match the final pouring temperature into the mold can yield significant savings in metal casting operations. This can be accomplished by close monitoring of furnace temperature, metal transfer distances and improved ladle insulation. Progressive metal casters are currently trying this with only slight risk to quality. One result may be an increase in molding demand since metal will be brought to the pouring line in more frequent intervals. While this should be a standard practice for all metal casters, they currently lack the proper temperature measuring devices for control.

Table 3. Energy (kWh) Savings from Tap Temperature Reductions

Furnace Size (Tons)	DEGREES (^{o}F) OF TAP TEMPERATURE REDUCTION PER HEAT									
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
4	5	11	16	21	26	32	37	42	47	53
6	8	16	24	32	39	47	55	63	71	79
9	12	24	36	47	59	71	83	95	107	118
10	13	26	39	53	66	79	92	105	118	132
15	20	39	59	79	99	118	138	158	178	197
20	26	53	79	105	132	158	184	210	237	263
25	33	66	99	132	164	197	230	263	296	329

For total kWh per day savings, multiply chart value by number of furnace heats per day.
For furnace sizes other than those shown:
kWh savings = Furnace size (tons) x Degrees tap temp lowered x 0.1315 kWh/Ton

Source: Schifo and Radia, 2004

The use of infrared temperature measurement has been available for many years. However, the cost of the units has been prohibitive. Most metal casters use the "dip stick" method (disposable thermocouple on the end of a rod dipped into metal bath) to determine temperatures. This practice will apply to most metal pouring applications. In cases where there are multiple pouring locations requiring different metal temperatures the practice may not be beneficial due to potential scrap increases. We expect customer acceptance to be high for this technology.

The Best Practice in a facility would be to reduce temperature on all heats. Using an average of 100^{o}F for each tap provides a reasonable estimate of expected savings. For a nine ton furnace at 480 heats per year, we estimate savings to be about 568 MWh per year. See Table 3.

Plastics

Process Energy Best Practices in Plastics provide from five to ten options that can be applied to various plastics processes: thermoforming, injection molding, and blow forming. Here are three practices that can provide significant savings. (Tabrizi, Tucker, 2005)

Free cooling to offset mechanical refrigeration. Process equipment such as injection molding machines sometimes require refrigerant-based chillers to supply cold water for mold cooling. Free cooling utilizes cool outdoor conditions to reject the heat generated during processing. Free cooling can apply to injection molding or other process areas where refrigerant based chillers are used. One side benefit is reduced wearing on chillers. A typical energy payback ranges from two to four years. While free cooling has been used in other industries, the plastics industry has not yet adopted it.

VFD's in cooling systems for injection molding. Any plastics manufacturing process that requires cooling requires pumps to move the cooling water around the plant. Since the full output of the pump is not normally required, the pump can run at a slower that rated speed to meet actual process demands. Since most if not all of the pumps used are centrifugal, significant savings are possible.

This applies to injection molding, thermoforming, and blow molding and wherever else cooling is needed, especially in cases where process needs vary over a wide range of load for a significant number of operating hours. The VFD allows the pump to both follow load and to operate in its highest efficiency range. The ROI for this technology is two to three years. Customers are willing to implement but are especially convinced by metering results.

Plastic heater retrofits. We are in the process of developing case studies with discussions of technical application and energy savings for the following plastic heater retrofits:

- ***Convert electric thermoform to catalytic gas fired*—**Electric oven thermoformers can be retrofitted to operate on natural gas using special catalytic heaters. Efficiency gains come from the fraction of heat that is radiant.
- ***Convert electric calrod thermoform to ceramic/quartz*—**Many thermoformers use the tubular type of calrod oven. Calrod oven elements lose efficiency quickly and can be retrofitted to operate on quartz or ceramic heating elements. Benefits include greater radiant efficiency, lower thermal loss to the building and shorter product cycle times.
- ***Proper radiant heater*—**A proper radiant heater is one whose spectral signature is matched to the spectral features of the plastic used. Using the proper heater will improve radiant energy efficiency and reduce scrap loss.

Food/Dairy

To date, we have reviewed between 10 and 15 dairy/food practices that have potential to become Process Energy Best Practices for promotion. Here are four. (Tucker, 2005)

Recover heat from dryer exhaust stream. Heat in the dryer exhaust stream can be recovered and used to preheat dryer make-up air, reducing overall energy consumption in spray dryer operations. Spray dryers use high temperature air (e.g., 350^{o}F) to transform product from a liquid to solid in the manufacture of several dairy-related products including milk, milk proteins, whey, milk replacers, and infant formulas. The high temperature drives off excess moisture from the product resulting in a bulk solid. The remaining air is exhausted into the environment.

The energy savings depend on the dryer operating temperatures and the load factor on the dryer. Higher temperature dryers offer greater potential savings, reaching 10-30 percent. Paybacks on the heat exchangers and ancillary equipment range from two to four years. Heat recovery technology is well understood and many equipment manufacturers already work with customers to evaluate and develop solutions for this energy intensive process. The technology requires periodic cleaning of the heat exchanger to maintain peak performance.

Reverse osmosis (RO) to dewater/concentrate solutions. RO is a membrane separation process driven by a pressure gradient in which the membrane separates the solvent (generally water) from other components of a solution. In RO, the membrane pore size is very small allowing only small amounts of very low molecular weight solutes to pass through. RO has emerging commercial applications in separation of whey proteins to produce whey protein concentrate; concentrating milk prior to cheesemaking at the farm level; clarification of apple juice and wine; treatment of waste and product recovery in edible oil, fat, potato, and fish processing; clarification and separation of fermentation broths; and ultrafiltration of whole egg and egg white prior to spray drying.

Energy savings will naturally depend on the process that it replaces. Since higher pressures are required, electricity use will likely increase for pumping. RO is widely used by processors that want increased concentration capacity without having to purchase a new evaporator. Pre-concentrating a stream by two to four times results in lower load on the downstream evaporator, allowing a plant to process additional product with minimal capital investment. Membrane systems can often treat wastewater streams to minimize disposal costs and recover water for reuse. The energy from these streams may also be recovered through heat exchange.

Free-cooling for process cooling and product storage areas. Free-cooling makes use of outside air for direct or indirect cooling in medium and low-temperature process cooling applications to avoid compressor-aided refrigeration when outdoor air conditions are appropriate. Depending on the particular process, free cooling can be done through simple control algorithms that allow more outdoor make-up air to enter when enthalpy conditions are appropriate. Free cooling is suited for locations where many hours are below 40 degrees; opportunities increase as temperatures go lower. Estimates for energy savings in some Canadian facilities are as high as 15 percent. Depending on the product and outdoor temperature, savings in the 10-15 percent range are possible. In low or no cost situations requiring a control sequence change (e.g. outdoor makeup air ductwork already exists) the payback can be immediate. More extensive changes or the need for secondary heat exchangers can push the paybacks to two to four years.

Progress and Impact of Best Practice Initiatives

After almost one year of development, the four cluster initiatives have identified and condensed almost 100 process energy best practices that implementers believe show the most promise for impact. While, to date, industry in Wisconsin has welcomed this initiative with open arms, ultimate success depends on industry adoption of these Best Practices. Industry associations and their industrial members, performing in a climate of escalating energy and materials costs, have been more responsive to energy efficiency opportunities than we have seen in the past. These groups include the Wisconsin Paper Council, Lake States TAPPI, the Wisconsin Cast Metals Association, the American Plastics Council, and the Midwest Food Processors Association. Each industry cluster has responded in a cohesive fashion to try to address the threat of high energy costs on their businesses, by lobbying for rate reduction, negotiating better future contracts, developing alternative fuel resources, and, most notably, by revisiting energy efficiency opportunities. Some also see energy efficiency as placing them on better footing in internationally competitive markets. With the economy on the rebound and ensuing opportunities to reinvest in capital improvements, they are eyeing Best Practice investments as a way to lower costs and remain competitive.

The Focus on Energy Industrial program is now positioned to find and provide the most reliable information and technical support for cost-effective, Process Energy Best Practices to Wisconsin's industries. Saving energy through improving the intrinsic operations of these key industries will ensure Wisconsin's long-term economic viability and sustainability.

Over the next few years, the Wisconsin experience may serve as a test tube for future state and national efforts. US DOE (ITP, USDOE, May 2005) estimates that manufacturing process energy accounts for over 24,600 trillion Btu of energy consumption. The break out for key industry process energy discussed here is as follows: Forest Products – 1698 trillion; Plastics and Rubber – 156 trillion; Food and Beverage – 658 trillion; and Foundries – 151 trillion. This totals 2,663 trillion Btu's for process energy, not counting ancillary functions that support processes.

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