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ENERGY

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CONSERVATION

TEN CASE HISTORY STUDIES OF ENERGY EFFICIENCY
IMPROVEMENTS IN PULP & PAPER MILLS

Final Report

Work Performed Under Contract No. AC06-76RL01830

Centec Corporation
Reston, Virginia

and

Battelle Pacific Northwest Laboratories
Richland, Washington

U. S. DEPARTMENT OF ENERGY

Division of Industrial Energy Conservation

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OF
ENERGY EFFICIENCY IMPROVEMENTS
IN PULP & PAPER MILLS

Final Report

U.S. Department of Energy
Assistant Secretary for Conservation & Renewable Energy
Office of Industrial Programs

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INTRODUCTION

In 1977 the pulp and paper industry in the United States purchased 1.3 quads (10^{15} Btu) of fossil fuels and electricity, thus making it the third largest industrial energy user. Since 1976, No. 6 residual fuel oil has risen from \$11.49/bbl to \$35.05 bbl. This is equivalent to an increase of 205 percent or an annual average inflation rate of 41 percent. In the same time span, however, equipment costs have increased a more modest 57 percent or 11.4 percent per year. Because of this large disparity in fuel versus equipment cost increases, technologies to improve energy efficiency in pulp and paper operations are more economically attractive than ever before. Many pulp and paper plants have adopted energy conservation programs to take advantage of the current favorable economics. This report documents ten case history examples of the pulp and paper industry's energy conservation efforts.

To obtain case history studies of energy efficiency improvements in the pulp and paper industry, several tasks were undertaken and completed:

- o Identification of candidate technologies for energy efficiency improvement
- o Prioritization and selection of candidate technologies for case history studies
- o Acquisition of site-specific data through site visits, telephone calls and written correspondence

To identify candidate technologies for energy efficiency improvements in the pulp and paper industry, an extensive review of literature was conducted. The bibliography section of this report references the useful information sources identified in the course of the literature review. In addition to the references cited, many telephone calls were made and letters written in order

to obtain as much information as possible on the candidate technologies. Both DOE-funded and non-DOE funded technologies were identified. Table 1 is a list of the technologies chosen for case history development.

TABLE 1.

1. Sonic sootblowing in boilers
2. Boiler operation on oil-water emulsified fuel
3. Energy efficient motors
4. Excess air control for boilers
5. Boiler control and load allocation
6. Drying of waste-activated sludge by multiple effect evaporation
7. Pre-drying of hog fuel
8. Lime kiln computerization
9. Heat wheel for process heat recovery
10. Organic Rankine bottoming cycle for TMP heat recovery

Once the approval was given by the Department of Energy and Battelle on the candidate technologies for case history studies, additional detailed information was collected on the technologies. This was achieved through correspondence, numerous telephone conversations and site visits (where necessary). To aid in the information collection process, an interview guide was prepared to identify critical, case history related data requirements. Table 2 is the format of the interview guide that was used. After all the necessary information was collected, the case history studies were prepared using the format shown in Table 3.

Table 2 Interview Guide for Case History Documentation

I. General Information

A. Facility:

1. Name _____
2. Address _____

B. Employee Contact:

1. Name _____
2. Title _____
3. Telephone No. _____

C. Description of Process/Technology

1. Old process/technology:

2. New process/technology:

D. Production Specifics (Before process/technology implemented):

1. Products	(Types)	(Annual Production)
-------------	---------	---------------------

a.	_____	_____
b.	_____	_____
c.	_____	_____
d.	_____	_____

2. Energy	(Cost)	(Annual Consumption)
-----------	--------	----------------------

a. Electricity	_____	_____
b. Natural Gas	_____	_____
c. Fuel Oil	_____	_____
d. Coal	_____	_____
e. Other (Explain)	_____	_____

E. Production Specifics (After process/technology implemented):

1. Products	(Types)	(Annual Production)
a.	_____	_____
b.	_____	_____
c.	_____	_____
d.	_____	_____

2. Energy	(Cost)	(Annual Consumption)
a. Electricity	_____	_____
b. Natural Gas	_____	_____
c. Fuel Oil	_____	_____
d. Coal	_____	_____

F. Cumulative Energy Savings Associated With New Process/Technology:

1. Date of installation	_____
2. Net annual savings	_____
3. Cumulative savings	_____

G. Investment Payback Criteria:

1. DCF rate of return, %	_____
2. Return on investment, %	_____
3. Payback, years	_____

H. Actual Process/Technology Payback:

1. DCF rate of return, %	_____
2. Return on investment, %	_____
3. Payback, years	_____

I. Additional Site Specific Benefits:

1. Environmental
2. Product quality
3. Ease of operation
4. Equipment reliability
5. Ease of retrofit
6. Other (Explain)

Table 3 Case History Study Format

Industry

Company name

Company address & telephone number

Employee contact (name and title)

Description of Energy Consuming Processes:

A description of the manufacturing process with emphasis on energy consumed in the manufacturing process will be included in each case history. Items to be described will be Btu's of energy consumed, the process, tools and equipment consuming large volumes of energy. Approximate values will be provided, if available, for the process before and after implementation of the energy conservation technologies.

Profile of Energy Use:

Types of fuel or energy consumed will be identified as will the average volume and unit cost (\$/Btu) of this energy for recent years.

Description of Energy Saving Actions:

A brief description will be provided that identifies modifications to the production process which were implemented to save energy. For example, a description of process modification, equipment installed, and other capital investments made to save energy will be provided. A discussion of the firm's energy management program, why it was started, major accomplishments, etc., will probably be provided.

Identification of Products Produced:

A brief description of products produced, processes used and energy consumed will be provided. These data will be provided as energy consumed per unit of production.

Energy Savings:

A brief discussion will be provided that identifies energy saved (Btu's per unit output), form of energy saved and the dollar value of this energy saved for a year of normal production. If the data allows, an estimate will be provided for the return on investment resulting from the energy savings due to the new technologies installed in these industries.

Decision Process:

A discussion of management's decision process will also probably be provided. For example, were the investment decisions based upon expected return-on-investment, pay back period, energy savings only, etc. This discussion will also describe any institutional or environmental considerations that were a part of the decision to install energy efficient equipment processes or equipment; e.g., does the new process save energy and also reduce an emissions problem?

CASE HISTORY NO. 1

SONIC SOOTBLOWING

CASE HISTORY NO. 1

SONIC SOOTBLOWING

Industry: Pulp and Paper

Company: Crown Zellerbach
P. O. Box 575
Port Townsend, Washington 98368

Contact: Rick Spangler
Assistant Pulp Mill Superintendent
(206) 385-1616

SUMMARY

Crown Zellerbach's Port Townsend plant produces 450 tons per day of unbleached kraft pulp and paper products. A hog fuel boiler at the mill contributes 200,000 - 250,000 lbs/hr of steam for process use. In order to help maintain the hog fuel boiler efficiency, steam lancing is performed to remove ash and other particulates from the outside surfaces of the tubes. To help reduce steam lancing requirements and improve boiler efficiency, Crown Zellerbach installed a sonic sootblower system in their hog fuel boiler in December of 1979. The installation of the equipment resulted in a decrease in steam lancing from twice to once per shift and a net annual fuel savings of \$25,500. Based upon an installed cost of approximately \$12,600, the sonic sootblowers yielded an after-tax payback of 0.8 years.

DESCRIPTION OF ENERGY CONSUMING PROCESS

The hog fuel boiler at the Port Townsend plant generates 200,000 lbs/hr of steam at 400 psig and 625°F when fired with fir and hemlock waste. When the hog fuel firing is augmented with No. 6 fuel oil, the boiler is capable of producing an additional 50,000 lbs/hr of steam. The fuel mix for normal firing is two-thirds hog fuel and one-third oil.

During the combustion of the hog fuel and oil, particulates and condensable compounds are generated. These particulates and condensables deposit on the steam-generating surfaces (including superheater and economizer tubes) and other surfaces within the boiler furnace and flue gas exhaust sections. The insulating properties of these deposits degrade the thermal performance of the boiler and hence its overall efficiency (i.e., conversion of boiler fuel to steam).

In order to help maintain boiler efficiency, Crown Zellerbach lanced the particulate-affected areas with steam to keep the

heat exchange surfaces (boiler tubes) clean and to prevent excessive buildup of ash, soot, dust and saltcake deposits in the exhaust ducts. Prior to the installation of the sonic sootblowing system, lancing was performed twice per shift for a total of six lancements per day. Four steam lances were used for each cleaning. Based upon this and a steam use of 309 lb/min and a lancing duration of 4.5 minutes, the annual steam use was estimated to be 12×10^6 lbs for 360 days of operation as shown below:

$$4 \text{ lances} \times 360 \frac{\text{days}}{\text{yr}} \times \frac{6 \text{ blows}}{\text{day}} \times \frac{4.5 \text{ min}}{\text{blow}} \times \frac{309 \text{ lb}}{\text{min}} = 12 \times 10^6 \frac{\text{lbs}}{\text{yr}}$$

The efficiency for this mixed fuel (wood and oil) fired boiler was estimated to be 75 percent. For boiler feedwater at an enthalpy of 228 Btu/lb and steam at 1,320 Btu/lb, the net heat addition in the boiler is 1,092 Btu/lb of steam (1,320-228). Therefore, the annual boiler fuel use associated with the steam lancements was 17.5×10^9 Btu/hr as follows:

$$12 \times 10^6 \frac{\text{lbs steam}}{\text{yr}} \times 1,092 \frac{\text{Btu}}{\text{lb steam}} \times \frac{1}{0.75} = 17.5 \times 10^9 \frac{\text{Btu}}{\text{yr}}$$

DESCRIPTION OF ENERGY-SAVING ACTION

A widely applicable, relatively new alternative to steam lancing is sonic sootblowing. As of June 1981, fewer than 50 installations were operating in the United States; approximately 100 were operating in Europe as of February, 1978. To help reduce the steam lancing requirements for the hog fuel boiler, Crown Zellerbach decided to install an Acousticlean® sonic sootblower system at a cost of approximately \$12,600. The equipment, manufactured by Kockums, AB of Malmo, Sweden, is distributed in the United States by KVB, Inc., a subsidiary of Research Cottrell. The equipment for this installation consisted of two sonic horns (refer to Figure 1) which weigh 55 lbs each and are approximately two feet long and one foot in diameter; the bells are stainless steel (useful operating environment to 1,900°F) and the diaphragms are titanium. The horns typically operate on compressed air but can also operate on steam or inert gases. The operating gas pressure is 60-75 psi at a flow rate of 40-80 scfm; an automatic timer and 110 volt solenoid valve are used to control operating frequency and sounding period. Air flow at 3-5 scfm per horn maintains the equipment cool in the period between soundings which are performed in compliance with Occupational Safety and Health Administration standards.

Figures 2 and 3 show the location and mounting of the horns in the hog fuel boiler. Operation of the equipment involves the production of low-frequency (250 Hz) sound waves at 145 db. These sound waves help to fluidize particles attached to the boiler tubes, thus breaking the bonds and allowing the particles to fall free. This cleaning action then enables the boiler to operate more efficiently for longer time periods and hence steam lancing frequencies are reduced. For this particular installation, Crown Zellerbach was able to reduce the steam lancing frequency by one-half.

Figure 1 Acousticlean Sonic Sootblower

Figure 2 Generating Section of Hog Fuel Boiler
Showing Locations of Steam Lances and
Sonic Sootblowers

Figure 3 Horn Installation in Access Door of
Hog Fuel Boiler

ENERGY SAVINGS

Since the original steam lancing requirements resulted in a boiler fuel use of 17.5×10^9 Btu/yr, the sonic sootblower system yielded a savings of 8.75×10^9 Btu/yr ($17.5 \times 10^9/2$). Table 1 summarizes the fuel cost saving of \$25,500/yr attributable to this energy saving. Note the small operating cost penalty associated with providing power to the horns. In addition note the bases used for the discounted cash flow analysis which yielded the following after-tax payback values:

o DCF Rate of Return, %	129
o ROI, %	211
o After-Tax Payback, yrs	0.8

DECISION PROCESS

The boiler installed at the plant suffers from a pluggage problem which requires shutdown and wash approximately every two months. The problem stems from the sticky nature of the particulates, mostly CaSO_4 and NaCl or Na_2SO_4 , which have a softening range of 1,600 to 2,600°F (906 to 1,495°C). The problem is aggravated by the relatively tight spacing of the generating tubes (2-1/2" tubes on 3-1/2" centers). The pluggage occurs about midway through the first bank of generating tubes where the currently installed steam lances are ineffective. Crown Zellerbach elected to install sonic sootblowers in an attempt at resolving the pluggage problem. Testing, however, revealed that though the sonic sootblowers may have modestly alleviated the problem, they did not eliminate it. They did, however, prove cost-effective on the basis of but one of the several ancillary benefits they did provide, namely, reduced usage of energy for steam lancing. Based upon a fuel cost saving of \$25,500 in the first year of operation, the horns yielded an estimated after-tax payback of 0.8 years for the \$12,600 approximate installed cost. Additional benefits realized included elimination of the requirement for 800,000 gallons per year of treated (de-mineralized) boiler make-up water and improved regulation of steam temperature. In the payback analysis for the sootblowers, no cost credit was taken for the reduced treated makeup water requirements.

Two alternatives remain under consideration to resolve the pluggage problem: removal of several rows of generating tubes and installation of additional retractable steam lances; and installation of four additional horns at the planned new steam lance sites without removing the steam-generating tubes. Costs and likely effectiveness are currently being investigated.

Table 1. Data Summary for Discounted Cash Flow Analysis

Installed Equipment Costs, Dec. 1979 (\$)	12,600
Length of Depreciation Period (years)	10
Life of Project (years)	10
Fuel Saving for First Year (\$)	25,500 (1)
Escalation of Fuel Saving (%)	15
Taxes and Insurance (% of Equipment Costs)	2
Investment Tax Credit (%)	10
Equipment Cost Eligible for Tax Credit (%)	100
Corporate Tax Rate (%)	46

Notes:

1. Fuel saving based upon the following calculations:

Boiler Fuel Weighted Average Cost

Bark @ \$1.80/10⁶ Btu

No. 6 oil @ \$5.25/10⁶ Btu

$$2/3 \times \$1.80/10^6 + 1/3 \times \$5.25/10^6 \text{ Btu} = \$2.95/10^6 \text{ Btu}$$

Boiler Fuel Savings

$$8.75 \times 10^9 \text{ Btu/yr} \times \$2.95/10^6 \text{ Btu} = \$25,813/\text{yr}$$

Operating Cost Penalty

$$2 \text{ horns} \times 16,500 \frac{\text{kWh}}{\text{Horn-yr}} \times \frac{\$0.009}{\text{kWh}} = \$297/\text{yr}$$

Net Fuel Savings

$$\$25,813 - 297 = \$25,516/\text{yr} \text{ (use } \$25,500/\text{yr)}$$

CASE HISTORY NO. 2

BOILER OPERATION ON OIL-WATER EMULSIFIED FUEL

BOILER OPERATION ON OIL-WATER EMULSIFIED FUEL

Industry: Pulp and Paper

Company: St. Regis Paper Company
Technical Center
West Nyack Road
West Nyack, NY 10094
(914) 578-7000

Installation is at the firm's
Jacksonville, FL plant

Contact: Dr. E. G. Kelleher
Manager, Energy and Process Engineering

SUMMARY

The St. Regis Paper Company mill in Jacksonville, Florida has three fuel oil-fired boilers with a total rated steam capacity of 560,000 lbs/hr. These boilers provide steam for process use and the on-site production of electricity. Energy conservation and the ability to use alternative fuels are two areas of high priority with the St. Regis Paper Company. For this reason the management at the Jacksonville mill investigated and implemented a system to emulsify the boiler fuel oil with water. After trial tests were performed, the equipment was placed in operation in December, 1980 on the No. 1 boiler. The testing of the boiler indicated an improved boiler efficiency of about two percent which resulted in an annual fuel savings of \$170,200 and thus an after-tax equipment payback of 0.6 years for the \$60,000 installed system cost. Because of the initial success with the No. 1 boiler, St. Regis proceeded to retrofit the No. 2 boiler at a cost of \$50,000 and is in the process of retrofitting the No. 3 boiler.

DESCRIPTION OF ENERGY-CONSUMING PROCESS

Three No. 6 oil-fired boilers are used at the St. Regis Paper Company mill in Jacksonville, Florida. The rated steam capacity of the Combustion Engineering No. 1 boiler is 160,000 lbs/hr. Based upon an 80 percent efficiency, this boiler uses approximately 264,000 bbls/yr of No. 6 fuel oil for 8,600 hrs/yr of operation at the normal steam load of 150,000 lbs/hr. The No. 2 and No. 3 boilers are each rated at 200,000 lbs/hr and thus the total plant steam rated capacity is 560,000 lbs/hr. The No. 1 boiler was installed in 1955; the second and third units were installed at about this time also.

DESCRIPTION OF ENERGY SAVING ACTION

To improve the efficiency of the No. 1 boiler, St Regis installed an oil-water emulsion system, Fire-Brite®, and put it in operation in December of 1980 at a cost of about \$60,000. The equipment, manufactured by Hoffert Manufacturing Company, Inc. is comprised of a series of pumps and fluid handling components which are shown schematically in Figure 1 and as an assembled package in Figure 2. The system mixes water with the No. 6 oil prior to admission to the burners. Water droplets in the size range of two to five microns are produced to emulsify (break-up) the fuel. By doing this the fuel oil is combusted more efficiently by the burner thus allowing boiler excess air to be reduced. The ratio of water to oil can be varied to optimize boiler excess air and hence combustion efficiency.

Extensive tests were performed in November of 1980 on the installed system to establish the combustion efficiency improvement due to oil-water emulsified fuel. These tests indicated that the optimum water concentration in the fuel was eight to ten percent. For these emulsion concentrations, boiler excess air was reduced from four percent to 2.6 percent O_2 and the average combustion efficiency was improved approximately 0.6 percent. An additional improvement of about 1.4 percent in boiler efficiency was attributable to reduced boiler sooting and hence cleaner boiler and air preheater tubes. The total net gain was thus about two percent. Tables 1, 2 and 3 summarize the results and test data for the boiler with and without oil-water emulsion and with a clean and fouled air heater.

Besides the above test supported benefits of oil-water emulsified fuel, the manufacturer claims the following ancillary benefits:

- o Reduced down-time for cleaning
- o Reduced steam requirements for sootblowing
- o Reduced emissions and contaminants and hence potential to use less costly, higher sulfur content fuel

These three additional potential benefits were not credited in the evaluation of the energy cost saving for the equipment.

ENERGY SAVINGS

The installation and successful operation of the Fire-Brite system yielded a boiler efficiency improvement from 80 to 82 percent. Although this represents only a two percent change, the energy savings amounts to 20×10^9 Btu/yr of boiler fuel. This savings is based upon the following factors:

- o 150,000 lbs/hr steam production
- o 8,600 hrs/yr of operation
- o 1,029 Btu of energy added per lb of feedwater

Figure 2 System Installation Schematic, Fire-Brite[®]

TABLE I EFFECT OF OIL-WATER EMULSION AND AIR
HEATER FOULING ON BOILER STACK LOSSES

	TOTAL STACK LOSS, % OF FUEL		INCREASE IN COMBUSTION EFFICIENCY WITH EMULSION
	WITH OIL-WATER EMULSION	WITHOUT OIL-WATER EMULSION	
CLEAN AIR HEATER	13.37	13.92	0.55
FOULED AIR HEATER	15.98	16.86	0.88
INCREASE IN BOILER EFFICIENCY WITH CLEAN AIR HEATER	2.61	2.94	

Table 2. Stack Losses for Clean Air Heater Condition

JACKSONVILLE MILL BOILER TEST RESULTS

<u>PARAMETER MEASURED</u>	<u>WITH OIL-WATER EMULSION</u>			<u>WITHOUT OIL-WATER EMULSION</u>		
Test Date:	<u>11/4</u>	<u>11/5</u>	<u>11/7</u>	<u>11/19</u>	<u>11/20</u>	<u>11/21</u>
% WATER IN EMULSION	8.09	7.26	9.60	0	0	0
HEAT LOSS DUE TO DRY GAS, %	6.53	6.59	6.48	7.55	7.53	7.56
HEAT LOSS DUE TO WATER ADDITION, %	0.56	0.49	0.67	0	0	0
HEAT LOSS DUE TO HYDROGEN IN FUEL, %	6.12	6.36	6.32	6.40	6.41	6.30
TOTAL STACK LOSSES, % OF FUEL	13.12	13.44	13.47	13.95	13.94	13.86
AVERAGE STACK LOSSES, % OF FUEL		13.37			13.92	

Bases:

- o Old burner tips
- o Clean air heater
- o Stack temperature = 360°F

Table 3. Stack Losses for Fouled Air Heater Condition

JACKSONVILLE MILL BOILER TEST RESULTS

<u>PARAMETER MEASURED</u>	<u>WITH OIL-WATER EMULSION</u>			<u>WITHOUT OIL-WATER EMULSION</u>		
Test Date:	<u>11/4</u>	<u>11/5</u>	<u>11/7</u>	<u>11/19</u>	<u>11/20</u>	<u>11/21</u>
% WATER IN EMULSION	8.09	7.26	9.60	0	0	0
HEAT LOSS DUE TO DRY GAS, %	8.83	8.91	8.76	10.21	10.19	10.23
HEAT LOSS DUE TO WATER ADDITION, %	0.58	0.52	0.70	0	0	0
HEAT LOSS DUE TO HYDROGEN IN FUEL, %	6.39	6.64	6.60	6.69	6.69	6.58
TOTAL STACK LOSSES, % OF FUEL	15.80	16.07	16.06	16.90	16.88	16.81
AVERAGE STACK LOSSES, % OF FUEL		15.98			16.86	

Bases:

- o Old burner tips
- o Fouled air heater
- o Stack Temperature = 470°F

Figure 1

On-Line Oil-Water Emulsification System, Fire-Brite[®]

Table 4 summarizes the fuel cost saving of \$170,200/yr attributable to these factors. In addition the table provides the bases for the discounted cash flow analysis which yielded the following after-tax payback values:

o DCF rate of return, %	183
o ROI, %	307
o After-tax payback, yrs	0.6

DECISION PROCESS

Energy conservation and fuel switching (to non-critical fuels) are each high priority programs at St. Regis Paper Company. Individual mill managers are encouraged by corporate headquarters to implement conservation/fuel-switching projects with the technical assistance of personnel at the Corporate Technical Center, West Nyack, New York. Consistent with this policy, the manager of the Jacksonville mill arranged on a trial basis to evaluate the potential of an oil-water emulsion system to reduce boiler oil consumption. With the technical assistance of Technical Center staff, the four-week trial was concluded with affirmative results as to cost effectiveness.

The emulsion system tested, Fire-Brite, was manufactured by Hoffert Manufacturing Company, Inc. The quoted system sale price was \$38,000. As a result of the success with the No. 1 boiler, the decision was made to retrofit the No. 2 and 3 boilers with the Fire-Brite system. The decision to proceed to installations on the No's 2 and 3 boilers was based on ease of operation, the ancillary benefits previously described (valued at \$63,000 by Hoffert Manufacturing, but not credited in the cost evaluation), and the 0.6 years after-tax payback for the No. 1 boiler retrofit.

Table 4. Data Summary for Discounted Cash Flow Analysis

Installed Equipment Cost, December 1980 (\$)	60,000
Length of Depreciation Period (years)	10
Life of Project (years)	10
Fuel Savings for First Year (\$)	170,200 (1),(2)
Escalation of Fuel Savings (%)	15
Taxes and Insurance (% of Equipment Cost)	2
Investment Tax Credit (%)	20
Equipment Cost Eligible for Tax Credit (%)	100
Corporate Tax Rate (%)	46
Maintenance (% of Equipment Cost)	6

Notes:

1. Fuel savings based upon the following calculation:

Fuel Consumed Before Modification

$$150,000 \frac{\text{lbs}}{\text{hr}} \times 1,029 \frac{\text{Btu}}{\text{lb}} \times \frac{1}{0.80} \times 8,600 \frac{\text{hrs}}{\text{yr}} = 1,659 \times 10^9 \frac{\text{Btu}}{\text{yr}}$$

Fuel Consumed After Modification

$$150,000 \frac{\text{lbs}}{\text{hr}} \times 1,029 \frac{\text{Btu}}{\text{lb}} \times \frac{1}{0.82} \times 8,600 \frac{\text{hrs}}{\text{yr}} = 1,619 \times 10^9 \frac{\text{Btu}}{\text{yr}}$$

Fuel Savings

$$(1,659 - 1,619) \times 10^9 \frac{\text{Btu}}{\text{yr}} \times \frac{\$26.75}{\text{bbl}} \times \frac{\text{bbl}}{6.287 \times 10^6 \text{ Btu}} = \$170,200/\text{yr}$$

2. No cost penalty assumed for power to operate the oil-water emulsifier system

CASE HISTORY NO. 3

HIGH EFFICIENCY MOTORS

CASE HISTORY NO. 3

HIGH EFFICIENCY MOTORS

Industry: Pulp and Paper

Company: Madison Industries, Inc.
Madison, ME
(207) 696-3307

Contact: James Kirby
Chief Electrical Superintendent

SUMMARY

Madison Industries' new groundwood news plant in Madison, Maine produces 480 tons per day of super-calendered 35 pound news stock (the type used for Sunday newspaper supplements). The plant began operating on a round-the-clock basis on November 1, 1981.

One noteworthy aspect of the plant design is the use of 305 high efficiency motors of various rated capacities. These motors were selected for the new plant based upon previous favorable industry experience. At a total cost premium of \$57,400 over conventional, standard efficiency motors, the high efficiency motors are expected to yield a simple payback of 0.6 years based upon an estimated plant electrical cost saving of \$98,100 for the first year of operation.

DESCRIPTION OF ENERGY-CONSUMING PROCESS

Total installed motor drive capacity in the Madison plant is 50,000 hp. Approximately 11,500 installed hp is comprised of 60 Hz, polyphase 460 volt motors in the size range 3/4 hp to 200 hp. This class of motors has been a major target for energy-efficiency improvements by motor manufacturers and the Federal government for several years. The remainder of the plant's installed motor capacity is made up of DC motors (for paper machines and other applications requiring precise speed control), single-phase AC motors, synchronous motors, and motors with greater than 200 hp capacity, including two 14,000 hp units.

Single-phase motors are generally small in size and used in light duty cycle applications. Large size synchronous motors are used in special applications and already have very high efficiencies on the order of 96-98 percent. DC motors are typically custom made and are used where speed control is required. Standard polyphase AC motors above 200 hp are not considered major energy conservation targets because their efficiencies are already very high (above 94 percent).

polyphase motors in the size range 3/4 hp to 200 hp are used principally for pumps, compressors blowers and fans. In the pulp and paper plant environment, corrosion-duty rated, 1.15 service factor, NEMA Design B horizontal induction units are typically specified. The operating life of these units is nominally 40,000 hours. Table 1 shows the number of such motors of different sizes used in the Madison plant.

PROFILE OF ENERGY USE

The Madison groundwood plant will operate on a continuous basis approximately 350 days per year, with two planned shut-down periods plus unscheduled, brief outages accounting for the down-time. Plant management expects the 3/4 hp to 200 hp polyphase motors to operate continuously at rated capacity, consistent with the 1.15 service factor specification (which permits motors to operate at 15 percent over the rated capacity, if necessary). To minimize down-time, Madison Industries typically inventories one spare motor for every ten motors installed. Redundant motors are maintained in place for some of the larger installed units.

The load profile presented by the 305 polyphase AC motors in the 3/4 hp to 200 hp range is characterized as approximately flat over the 8,400 hr (350 x 24) annual load duration at the 11,500 hp installed capacity. The average cost of electricity for these motors is approximately \$0.044/kWh at the Madison plant.

DESCRIPTION OF ENERGY-SAVING ACTION

Plant management elected to specify "high efficiency" AC polyphase motors in the 3/4 hp to 200 hp size range. Bids to supply these premium-cost motors were received from several manufacturers (see comparison of equipment offerings in Table 2).

The typical cost premium for a high-efficiency motor is 25 percent. A cost summary of the bids received is presented below:

<u>Bid</u>	<u>Motor HP</u>	<u>Standard Motor Cost, \$</u>	<u>High Efficiency Motor Cost, \$</u>
Low	15	489	611
High	15	698	793
Low	50	843	1,030
High	50	1,349	1,500
Low	200	3,716	3,979
High	200	5,357	6,178

The additional cost for a high efficiency motor is for the use of more and higher-quality materials, and tighter manufacturing quality control. There remain no technical or operational reliability

Table 1. Polyphase AC Motor Requirements

<u>Motor Size, HP</u>	<u>Number Motors</u>	<u>Estimated Average Motor Size, HP</u>	<u>Installed Power, HP</u>
3/4 to 7.5	101	4.13	417
10 to 25	80	17.5	1,400
30 to 50	58	40.0	2,320
60 to 100	44	80.0	3,520
125 to 200	23	167.0	3,841
TOTAL	<u>305</u>	<u>37.7</u>	<u>11,498</u>

Table 2. Comparison of High Efficiency vs Standard Motors (1)

HP	<u>Manufacturer A</u>		<u>Manufacturer B</u>		<u>Manufacturer C</u>	
	High Efficiency	Standard	High Efficiency	Standard	High Efficiency	Standard
	<u>-Efficiency*</u>	<u>-Efficiency*</u>	<u>-Efficiency*</u>	<u>-Efficiency*</u>	<u>-Efficiency*</u>	<u>-Efficiency</u>
	%	%	%	%	%	%
1	81.5-84.0	72.0-75.5	81.5 (nom.)	74.0 (nom.)	83.0-84.0	79.0-80.0
1½	81.5-84.0	75.5-78.5	84.0 (nom.)	74.5 (nom.)	83.0-84.0	79.0-80.0
2	81.5-84.0	75.5-78.5	84.0 (nom.)	81.0 (nom.)	83.0-84.0	82.0-83.0
5	88.5-90.2	78.5-81.5	86.5 (nom.)	83.0 (nom.)	85.5-86.5	82.0-83.0
10	88.5-90.2	86.5-88.5	88.9-90.2	82.5-85.5	88.0-89.0	86.5-87.5
25	91.7-93.0	88.5-90.2	92.0-93.0	87.5-89.5	90.5-91.5	88.0-89.0
50	93.0-94.1	90.2-91.7	93.3-94.1	90.2-91.7	91.5-92.5	89.0-90.0
75	93.0-94.1	90.2-91.7	94.3-95.0	90.2-91.7	92.0-93.0	90.5-91.5
100	94.1-95.0	91.7-93.0	94.3-95.0	91.0-92.4	92.5-93.5	91.0-92.0
150	94.1-95.0	91.7-93.0	95.2-95.8	91.7-93.0	--	--
200	94.5-95.0	93.0-94.1	95.2-95.8	92.4-93.6	--	--

* Where a range is given, the lower number is the guaranteed minimum and the higher number is the nominal efficiency, both at full load.

(1) Design bases for comparison : TEFC, NEMA Design B, continuous Duty, 1.15 service factor, 60 Hertz, 460 volts, 40 C ambient, Class F insulation, 1800 rpm, horizontal induction motors, normal starting torque.

issues associated with the high-efficiency units; they are simply higher quality versions of standard motors (see Figure 1). High efficiency motors, as compared to their industrial standard counterparts, have the following characteristics:

- o Longer rotor and stator cores
- o Thinner, lower-loss steel core laminations
- o Decreased air gap between the rotor and stator
- o Increased amount of copper in the stator winding

ENERGY SAVINGS

The operating efficiency of a motor in a plant environment is difficult to measure. The efficiency varies with the degree of loading, operating speed, starting current, frequency of starting, and other operating parameters. "Energy-efficient" polyphase AC motors have typical laboratory dynamometer-tested motor efficiencies approximately two to eight percentage points higher than industrial standard efficiency motors.

The laboratory test recommended by NEMA for this purpose is IEEE Standard 112, Dynamometer Test Method B. A comparison of high efficiency versus standard motors offered by several manufacturers is shown in Table 2.

Table 3 presents the electricity demand reduction estimated for the Madison plant's 305-unit AC polyphase motor group. The 266 kW coincident demand reduction, taken over the group's assumed 8,400 hour annual full load duration, yields an annual electricity savings of 2.23 million kWh. At the average plant cost of electricity (\$0.044 per kWh), the annual cost saving is estimated to be \$98,100 ($2.23 \times 10^6 \times 0.044$).

Based on published list price differentials, the cost premium for the 305 high-efficiency motors, plus 30 spare units, is \$57,376. The simple payback for all the motors (including spares) is thus 0.6 years ($57,400/98,100$).

DECISION PROCESS

Madison Industries' decision to use high efficiency AC polyphase motors at its Madison plant was made for several reasons. First, the favorable anticipated simple payback of 0.6 years for the high efficiency versus standard motors fell within Madison Industries' criteria for plant equipment investment. Second, Jim Kirby had been previously employed at Georgia Pacific's paper mill in Woodland, Maine and was familiar with their decision in 1978 to use high efficiency motors in all new construction and in all instances where an existing standard motor required replacement. Georgia Pacific's decision process was based upon their own cost analysis

Figure 1. Large Polyphase AC Industrial Motor

Table 3. Demand Reduction Calculation

Motor Size, HP	Motor ⁽¹⁾ Output kW	Motor Efficiency		Connected Power Requirement, kW		Aggregate Demand Reduction kW
		Standard	High Eff.	Standard	High Eff.	
3/4 to 7.5	311	79.4	87.3	392	356	36
10 to 25	1,044	88.2	90.9	1,184	1,148	36
30 to 50	1,730	90.3	93.1	1,916	1,858	58
60 to 100	2,625	91.2	93.7	2,878	2,801	77
125 to 200	<u>2,864</u>	92.7	94.5	<u>3,090</u>	<u>3,031</u>	<u>59</u>
TOTALS	8,574			9,460	9,194	266

(1) 1 kW = 1.341 HP

of high efficiency versus standard motors which indicated an after-tax payback of less than two years with electricity at \$0.03/kWh. In addition, GP's decision was based upon the anticipated longer motor life and less frequent motor maintenance achievable with cooler running high efficiency motors. Finally, Madison Industries decision was further supported by E. C. Jordan, a consulting firm retained by Madison Industries, who confirmed that the analyses and conclusions reached by Georgia Pacific were valid using current vendor-quoted performance and cost data. Additional advantages associated with high efficiency motors include improved power factor, which however, was not considered in the Madison investment decision.

Note that the above decision making processes were based upon vendor quoted efficiencies and not actual plant motor tests. Industry accepts and has confidence in these values because of the stringent test requirements, e.g., IEEE standards, which are normally and routinely adopted by motor manufacturers as part of motor production quality control.

CASE HISTORY NO. 4

BOILER EXCESS AIR COMPUTER CONTROL

CASE HISTORY NO. 4
BOILER EXCESS AIR COMPUTER CONTROL

Industry: Pulp and Paper

Company: Crown Zellerbach
P. O. Box 2949
Vancouver, WA 98668
(206) 696-0191

Installation is at the firm's
Wauna Mill near Clatskanie, OR

Contact: Dudley F. Church
Manager Process Control Services

SUMMARY

Crown Zellerbach's Wauna Mill near Clatskanie, Oregon produces 1,100 tons per day of pulp and paper products. The Wauna Mill during the past several years has increased its effort to conserve energy because of the high cost of energy and the significant portion of total product costs which is attributed to fuel costs. Several energy conserving opportunities have been implemented, one of which is computer control for boiler excess air. The control system, manufactured by Econics of Sunnyvale, California, uses a multivariable control strategy that adjusts air flow based on measurements of carbon monoxide, opacity, unburned hydrocarbons and stack temperature.

In July 1980, the Wauna Mill installed the excess air control system on its B&W power boiler which is rated at 420,000 lbs/hr of steam. The average load is 275,000 lbs/hr. Boiler efficiency increased from 85.7 percent to 86.3 percent after installation of the system. This equates to the conservation of 2,864 bbl of No. 6 oil. At a cost of \$24/bbl in 1980, this resulted in a \$84,000 annual saving. Based on this energy saving and a total installed cost of \$75,000, the system had an after-tax payback of 1.3 years.

DESCRIPTION OF ENERGY-CONSUMING PROCESS

The power boiler at the Wauna Mill is a Babcock and Wilcox balanced draft boiler with six burners. The boiler was installed in 1965 and burns natural gas, No. 4 fuel oil, or No. 6 fuel oil depending on current cost and availability. Steam from the power boiler is generated at 600 psi and 750°F. Prior to installing the new excess air control system, the Wauna Mill operated at 14.2 percent excess air (2.5 percent excess O₂) with a boiler efficiency of 85.7 percent. Based upon an average steam flow of 275,000 lbs/hr at this efficiency, the boiler used $3,036 \times 10^9$ Btu of fuel for 8,600 hrs/yr of operation.

DESCRIPTION OF ENERGY-SAVING ACTION

Although the power boiler at the Wauna Mill had a high efficiency, Crown Zellerbach decided to improve the efficiency by installing a computer control system to trim excess air. After discussions with Econics Corporation of Sunnyvale, California, an Econics 700 boiler fuel optimization system was purchased and installed. This boiler modification reduced the excess air from 14.2 to 6.4 percent (equivalent to a reduction in excess O_2 from 2.5 to 1.2 percent, a 50 percent improvement).

The Econics 700 System incorporates uniquely designed, state-of-the-art sensing and control equipment. To optimize boiler fuel use, air is maintained very close to stoichiometric (zero percent excess air) conditions. This is achieved by a multi-variable control strategy involving the measurement of four parameters:

- o CO concentration
- o Unburned hydrocarbon concentration
- o Stack opacity
- o Stack temperature

For this application, Crown Zellerbach monitors unburned hydrocarbons and stack temperature, but does not control boiler operation using these measured inputs. Only CO concentration, and stack opacity are measured and controlled. To achieve this, an analyzer is mounted in the boiler stack. Beams of infrared and visible light are transmitted through the flue gas as it passes through the purge tube portion of the analyzer. CO concentration is measured by comparing the infrared absorption of a known CO sample concentration with that of the flue gas. Stack opacity is measured in a similar fashion except with visible light. Low noise fiber optics are used to transmit these measurements to a packaged computer console in the control room.

In the computer, stack opacity and CO concentration are compared to preprogrammed target values. The error signals thus generated are linearized and relayed to a boiler model in the computer memory. Depending upon whether the error signals are based upon measurements above or below the target values, a bias signal is generated to open or close the boiler draft to control excess air. If the plant wishes to include the potential for control of the boiler operation based upon stack temperature, for example, several simple commands are easily entered into the computer by the boiler operator. Then if the CO and stack opacity control create an excess air condition that violates the stack temperature target value (say $<250^{\circ}F$), the stack temperature then becomes the dominant control variable. Similarly, unburned hydrocarbons can be simply included in the control scheme when and if desired by the boiler operator. In any case, the target values for CO and stack opacity are set as close to stoichiometric conditions as possible in order to minimize excess air and thus improve boiler efficiency.

The Econics 700 System has several advantages over other boiler excess air control systems, namely:

- o Ability to accurately measure CO concentration in flue gases
- o Ability to precisely control excess air very close to stoichiometric conditions

Conventional O₂ based control systems may sense incorrect O₂ values in induced draft type boilers due to air intrusion after the burners. The measurement of CO in the flue gases, however, is essentially independent of air leakage because air normally only contains 0.03 percent CO. Accurate measurement of CO in the Econics 700 System is possible because of freedom of interference from electrical noise in signal wiring and thermal noise due to flue gas background energy. Electrical noise is essentially eliminated by using fiber optics for signal transmission from the analyzer to the computer. Thermal noise, i.e., the background infrared energy which affects the measurement of the CO concentration, is compensated for by the analyzer and computer.

Precise control of excess air close to stoichiometric conditions is achievable largely because of the relationship of CO concentration and stack opacity to excess air. Figure 1, for example, shows the approximate relationship between CO concentration and excess air. Experimental data established that a target value of about 150 ppm CO in flue gas corresponds to a nearly stoichiometric burner combustion process. The CO concentration curve is relatively steep in the stoichiometric air region, thus allowing precise control. For example, a computer target value of 100 ppm CO would correspond to a five percent excess air rate. Stack opacity varies in a similar fashion with excess air, thus both parameters are used in the multivariable control scheme of the Econics 700 System.

Installation of the system required three working days. No boiler downtime was attributed to the installation since it occurred during a general plant shutdown. To date the equipment has operated reliably and has been very well received by the boiler operators who required only moderate training for the new system.

ENERGY SAVINGS

The installation and successful operation of the Econics 700 System have yielded a boiler efficiency improvement from 85.7 to 86.3 percent. Although this represents only a 0.6 percent change, the energy saving amounts to 22×10^9 Btu/yr of boiler fuel. This savings is based upon the following factors:

- o 275,000 lbs/hr steam production
- o 8,600 hrs/yr of operation
- o 1,100 Btu of energy added per lb of feedwater

Figure 1. Approximate Relationship Between CO Concentration and Excess Air.

Table 1 summarizes the fuel cost saving of \$84,000/yr attributable to these factors. In addition the table provides the bases for the discounted cash flow analysis which yielded the following after-tax payback values:

o DCF rate of return, %	82
o ROI, %	114
o After-tax payback, yrs	1.3

DECISION PROCESS

Although the Wauna Mill power boiler had an existing high operating efficiency of 85.7 percent, discussions with Econics led Crown Zellerbach management to believe that they could still cost effectively improve their boiler efficiency by installing a new, state-of-the-art excess air computer control system. Crown Zellerbach, therefore, purchased and installed the econics 700 system. Their trust in the investment was well rewarded as boiler efficiency was further improved to 86.3 percent. The large boiler load (275,000 lbs/hr) and many operating hours (8,600 hrs/yr) thus yielded a fuel savings of \$84,000/yr and an attractive after-tax payback of 1.3 years for the investment.

Table 1. Data Summary for Discounted Cash Flow Analysis

Installed Equipment Cost, July 1980 (\$)	75,000
Length of Depreciation Period (years)	10
Life of Project (years)	10
Fuel Savings for First Year (\$)	84,000 (1)
Escalation of Fuel Savings (%)	15
Taxes and Insurance (% of Equipment Cost)	2
Investment Tax Credit (%)	20
Equipment Cost Eligible for Tax Credit (%)	100
Corporate Tax Rate (%)	46
Maintenance (% of Equipment Cost)	6

Notes:

1. Fuel savings based upon the following calculation:

Fuel Consumed Before Modification

$$275,000 \frac{\text{lbs}}{\text{hr}} \times 1,100 \frac{\text{Btu}}{\text{lb}} \times \frac{1}{0.857} \times 8,600 \frac{\text{hrs}}{\text{yr}} = 3,036 \times 10^9 \frac{\text{Btu}}{\text{yr}}$$

Fuel Consumed After Modification

$$275,000 \frac{\text{lbs}}{\text{hr}} \times 1,100 \frac{\text{Btu}}{\text{lb}} \times \frac{1}{0.863} \times 8,600 \frac{\text{hrs}}{\text{yr}} = 3,014 \times 10^9 \frac{\text{Btu}}{\text{yr}}$$

Fuel Savings

$$(3,036 - 3,014) \times 10^9 \frac{\text{Btu}}{\text{yr}} \times \frac{\$24}{\text{bbl}} \times \frac{\text{bbl}}{6.285 \times 10^6 \text{ Btu}} = \$84,000/\text{yr}$$

CASE HISTORY NO. 5

BOILER CONTROL AND LOAD ALLOCATION

CASE HISTORY NO. 5

BOILER CONTROL AND LOAD ALLOCATION

Industry: Pulp and Paper

Company: Union Camp Corporation
Franklin Mill
Franklin, VA 23851

Contact: Frederick Y. Thomasson
Sr. Process Control Engineer

SUMMARY

The Union Camp Corporation produces approximately 650,000 tons/year of various paper and paperboard products at its Franklin Mill. A sophisticated computer control system, manufactured by Measurex Corporation, was installed just over four years ago at the Franklin Mill. This system controls and/or monitors such equipment and systems as the power boilers (excess air control and boiler selection), recovery boilers, steam distribution system, and utility tie-line. The computer control system cost approximately \$1,600,000 installed. As a result of the improved boiler efficiency and optimized on-site electrical generation, the equipment reduced energy costs by approximately \$2,000,000 in 1980 when oil cost an average of \$26.75/bbl.

DESCRIPTION OF ENERGY-CONSUMING PROCESS

The Franklin pulp and paper mill manufactures printing and writing grades of paper, coated and uncoated bleached paperboard, and bleached packaging grades of paper. There are six paper machines with related facilities producing in excess of 1,800 tons of first grade paper and board per day (approximately 650,000 tons per year). The operation runs 24 hours per day seven days per week.

For the mill the energy requirements, both process heat and electrical, are enormous. The mill's energy complex is shown in Figure 1. The electrical power requirement for the Franklin mill is about 85 megawatts. About 60 megawatts is generated by the mill's turbine-generators and 25 megawatts is purchased for the utility company.

The following processes are responsible for most of the heat consumption in the Franklin mill:

A. Pulp Mill

- Digestors
- Bleach Plant
- Evaporators
- Recovery Boilers

Figure 1. Steam Network

B. Paper Mill

- Paper Machines - Drying
- Heating of Process Air

C. Power Plant

- Sootblowing
- Feedwater Heating
- Auxiliaries

PROFILE OF ENERGY USE

The Franklin mill consumes about 23.0×10^{12} Btu's of energy per year. This amounts to 35.4×10^6 Btu per ton of paper. The mill generates 70 percent of this energy requirement via combustion of waste by-products (woodwastes and black liquor solids). Approximately 30 percent of the energy requirement (11.3×10^6 Btu per ton of paper) is purchased.

PURCHASED ENERGY (1980)

Energy Source	Btu's	Cost
Oil	57.9%	53.3%
Coal	32.6%	19.0%
Electricity	9.5%	28.7%

The estimated cost of the purchased energy in 1980 was \$34,000,000.

DESCRIPTION OF ENERGY SAVING ACTIONS

Union Camp's mill at Franklin has in operation one of the most sophisticated computerized Energy Management Systems in the world; see Figure 2. Provided by Measurex Corporation, the system consists of a network of computers which controls four power boilers, three recovery boilers and four turbine generators. The primary objective of this system is to operate the mill's energy complex so that the energy demand (electrical and heat) is met at the minimum cost. A second objective is to produce a daily management information report as shown in Figure 3. This report contains data on:

- Energy consumption (steam and electrical)
- Process operation
- Fuel usages
- Alarm summaries
- Air quality (opacity)
- Water usage
- Control utilization
- Peak demands (steam and electrical)
- Equipment performance

september, 1978 • pima

Figure 2. Franklin Mill Energy Management System

Figure 3. Management Information Reporting System

One of the computers depicted in Figure 2 continuously controls the power boilers so that they produce the required process steam at a minimum cost. To accomplish this task there are three things the computer does. First, it makes sure that each boiler operates at its maximum efficiency so that the minimum amount of fuel is used for a given steam demand. This is accomplished by controlling excess combustion air to a minimum. Oxygen in the stack gas is used as the index for excess air. Second, it maximizes the amount of wood waste that is burned in power boilers (PB) No. 6 and No. 7 and recovery boiler (RB) No. 3. This is done by a fuel allocation algorithm which selectively loads up the coal fired boilers, No. 5PB and No. 6PB, while maintaining oil usage in No. 7PB and No. 3PB at the minimum necessary level fixed by steam demand.

Purchasing large amounts of electrical energy for short periods of time is extremely costly. The basic functions of the steam distribution control system depicted in Figure 2, is to supply process steam while maximizing cogeneration power (minimizing the electric utility power bill)¹. This requires utility tie-line control and optimal allocation of steam flow to the low pressure steam headers from the four turbine-generators, two of which have condensing stages. It is cheaper to purchase electrical energy (up to the demand target) from the utility than it is to generate it by increasing the forced condensing in one of the turbines. The reverse is true if the purchased power exceeds the demand target. The steam distribution system tie-line control computer (refer to Figure 3) controls the amount of power that is purchased and eliminates expensive peak demands by controlling the steam flow through the condensing stage of the least efficient of the condensing turbines. When demand for power is reduced, the computer holds the condensing flow at a minimum value. This allows the mill to purchase the maximum amount of incremental energy at the minimum cost (so long as the demand limit separating high and low purchase rates is not exceeded). The computer also routes the extraction steam through the most efficient turbines so that the maximum amount of electrical power is cogenerated, further reducing the amount of power that must be purchased.

ENERGY SAVINGS

This system has been in operation for over four years and is responsible for a five to seven percent annual saving, approximately \$2,000,000 ($0.06 \times \$34,000,000$) in purchased energy. Since purchased energy savings result from preferential use of bark and coal and from control of condensing turbine steam flow at minimum levels (condensing turbine steam requirements are met by oil burning), energy savings are directly recognized as oil savings. At \$26.75/bbl for oil, oil savings are approximately 74,000 bbl/year ($2,000,000 / 26.75$).

The installed cost of the boiler control and load allocation system was approximately \$1,600,000. Note that the installed cost is approximate because other plant modifications were concurrently made to increase capacity by 200 TPD, therefore, precise attribution of cost to the appropriate achieved objective, i.e., capacity increase or unit energy savings is difficult.

A simple payback computation indicates the payback period for the energy saving system to be $\$1,600,000 / \$2,000,000 = 0.8$ years.

DECISION PROCESS

Fuel costs at the Franklin mill had soared a staggering 230 percent² in the five years prior to Union Camp's decision in 1975 to approach a process controls supplier to attempt obtaining of a joint development contract for design and turn key supply of digital computer control fuel-optimization system applied to the Franklin multiple boiler, multiple turbine-generator energy complex. Fuel costs were continuing to rise; a study had revealed that the hardware required to handle the job existed. Because, in this environment, an opportunity existed for recovery of development costs on future sales of systems hardware to an expanding market, Measurex Corporation agreed to the joint development contract concept. The mill had projected savings of \$2 million in the first full year of operation and close to a 2-year payback under the agreed contract terms. With that rather substantial incentive and a ready industry leader as partner, the decision to proceed was made.

(1) PIMA, September 1978

(2) Business Week, October 9, 1978

CASE HISTORY NO. 6

DRYING OF ACTIVITATED SLUDGE BY MULTIPLE
EFFECT EVAPORATION

CASE HISTORY NO. 6

DRYING OF ACTIVATED SLUDGE BY MULTIPLE EFFECT EVAPORATION

Industry: Pulp and Paper

Company: ITT Rayonier, Inc.
1177 Sumner Street
Stamford, CT 06904

Installation is at the firm's
Port Angeles, WA plant

Contact: Ronald C. McCarty, Director, Energy Systems
(203) 348-7000

SUMMARY

ITT Rayonier, Inc. began operating a secondary treatment facility at their Port Angeles, Washington plant in 1979. The activated sludge from this facility was originally disposed of by partial dewatering and trucking to a interim landfill site for disposal. In an attempt to reduce the cost of disposal and to create a valuable pulp mill byproduct, ITT Rayonier installed a sludge recovery system in December of 1980. This system utilizes a 3 million dollar multiple effect evaporator (manufactured by Carver-Greenfield) to dehydrate the sludge-beef tallow oil mixture in order to produce a high protein content animal feed. ITT Rayonier selected the multiple effect evaporator (MEE) system in lieu of single effect drying alternatives based upon the favorable anticipated energy savings and plant management familiarity with MEE technology. Although the system has been in operation less than a year, the projected energy cost saving of \$754,000 indicates that the \$600,000 estimated additional investment for the MEE versus flash dryer will yield an after-tax payback of 1.2 years.

DESCRIPTION OF ENERGY-CONSUMING PROCESS

Activated sludge treatment is a widely used method of disposing of organic pollutants in effluent streams. In this form of biological treatment, large quantities of air are bubbled through wastewaters, stimulating rapid growth of bacteria and other microorganisms. These microorganisms consume soluble organic substances, converting them to insoluble matter. Once separated from the treated liquid, this matter and the microorganisms generated in the process--the activated sludge--in turn require disposal.

ITT Rayonier, Inc.'s 500 ton-per-day (TPD) sulfite-dissolving pulp mill at Port Angeles, Washington, began operating a secondary treatment facility for activated sludge in 1979. For about 18 months, the activated sludge was mixed with the mill's primary treatment sludge. The mixed sludge was dewatered to about 20 percent solids concentration on belt presses and trucked to an interim landfill site.

DESCRIPTION OF ENERGY-SAVING ACTION

Because of the difficulty in dewatering the mixed sludge to the higher solids concentrations required for economical transport and landfill, plant management decided to investigate thermal dehydration of its activated sludge. The investigation centered around the use of thermal drying systems to dehydrate the sludge and produce a material suitable for use as protein-rich animal feed, fertilizer, or boiler fuel.

The activated sludge generated at the Port Angeles, sulfite mill has a 2.5 to 3.0 percent solids concentration. Plant management's objective was to dry the 20 TPD (dry solids basis) produced to at least 95 percent solids concentration. To retain the possibility of selling the dried product as animal feed, the system could not introduce inorganic chemicals or other toxic substances. Finally, the system had to be environmentally benign and compatible with the mill's total wastewater treatment facility. To achieve these objectives, a system that combined mechanical dewatering and thermal drying via MEE was selected by the Port Angeles plant management.

Using organic polymer conditioning material as a dewatering aid, the 2.5 to 3.0 percent solids sludge is first partially dewatered to 13 to 14 percent solids by a belt press. In the MEE process selected by plant management (developed by Carver-Greenfield), the thickened sludge is then mixed with beef tallow carrier oil and the resulting slurry is fed to a triple-effect, backward-feed MEE system (see Figure 1). The sludge is metered into the first stage (or third effect) and is concentrated as it proceeds to the third, or drying, stage (which is also known as the first effect because it is where boiler steam is condensed to supply the heat of vaporization). The vapor from the third stage is passed back to the shell side of the middle stage where it is condensed to concentrate the feed from the first stage. Vapor from the middle stage is condensed in the first stage, and vapor from the first-stage evaporator is condensed in a water-cooled heat exchanger.

FIGURE 1. SCHEMATIC OF MEE SLUDGE DRYING SYSTEM

Theoretically, in a three effect evaporator 1 lb of boiler steam is required to evaporate 3 lb of water. This is equivalent to 330 Btu of thermal energy to evaporate 1 lb of water in the sludge feed. For this application, however, about 560 Btu were required to evaporate 1 lb of water. This amount is consistent with industry experience, yet it is considerably less than the 1,500-2,000 Btu required to evaporate 1 lb of water in a kiln or multihearth type of sludge dryer. A flash dryer in a similar application requires approximately 1,630 Btu/lb of water removed.

The feed system controls permit proper operation of the MEE system at an oil/solids ratio of 6:1 to 9:1. The feed flows upward through a central pipe to the top channel of each evaporator, and then flows downward inside the tubes by gravity, forming a thin liquid film on the tube wall. The carrier oil, which does not evaporate at the temperatures used, prevents clogging, scaling, and corrosion. "Special" grade tallow oil is obtained from a nearby beef rendering plant.

Vapor from succeeding vapor chambers flows countercurrent to the forward feed, condensing on the shell of each preceding evaporator and supplying the energy required for evaporation. Boiler steam is used in the third drying stage. Noncondensibles are vented manually from the first and second stages and are vented from the third stage to steam ejectors. The final water content is about 1.5 percent by weight.

The dry product, at a 6:1 to 9:1 oil/solids ratio, is transferred to a centrifuge, which removes most of the oil, reducing the oil/solids ratio to about 0.5:1. The partially de-oiled solids stream flows by conveyor to expeller presses, where additional oil is removed. The resulting dry, powdery product contains about 18 percent beef tallow oil. From the plant's 20 TPD of sludge solids, the system produces 25.2 TPD of product animal feed containing 80.5 percent sludge solids, 1.5 percent water, and 18 percent beef tallow oil.

Since the MEE system began steady operation in December 1980, the mill has produced an average of 23 TPD secondary sludge solids. The MEE system, with a design capacity of 50 TPD, has thus been operating at about 50 percent of capacity. Overall, the system has performed well as designed, with only minor operating problems caused by the lower-than-expected capacity factor.

ITT Rayonier guarantees its feed customers a minimum 45-percent protein content in the dried sludge product. This product is the equivalent of protein supplements, such as soybean meal, which is seasonally priced at about \$205 per ton. Although the market for the new product is developing rapidly, some unsold product was burned at the mill as high-quality hog fuel (9,500 Btu/lb) during the first year of operation.

ENERGY SAVINGS

The energy used by the MEE system compares favorably with flash drying, the most effective conventional approach. A flash dryer has been in operation since 1974, for example, at a large sulfite pulp mill to dry activated sludge for sale as fertilizer. In this commercial flash dryer, sludge is brought into contact with hot gases (600-1,200°F) in a cage mill (Figure 2). The material is pneumatically lifted by the hot gas to a cyclone for separation. In contrast, the maximum drying temperature in the multiple effect evaporator is 265°F. Comparable energy use per ton of dry sludge solids (dried from 13 to 14 percent to 98.5 percent solids concentration) is as follows:

	<u>MEE Drying</u>	<u>Flash Drying</u>
Fuel Oil (No. 6)	10.6 x 10 ⁶ Btu	30.9 x 10 ⁶ Btu
Electricity	235 kWh	665 kWh

Hog fuel and spent sulfite liquor are fired to raise the 150 psig steam needed for the MEE system. The commercially proven flash drying system burns fuel oil in an air heater. Shaft power in the MEE system is used by the centrifuge, expeller presses, pumps, fans, conveyors, and agitators. The major electricity requirements in the flash dryer system are for cage mill, cyclone separators, pumps, fans, conveyors, and vessel agitators. Compared to flash drying, the MEE system saves 20.3 million Btu and 430 kWh per ton solids. In its first year of operation, now almost completed, the Port Angeles plant will produce approximately 8,400 tons of animal feed, containing 6,800 tons of sludge solids.

The first year's energy savings (compared to flash drying) will be 138 billion Btu of fuel oil, and 2.92 million kWh electricity. At the current (August 1981) price of No. 6 fuel oil of \$5.25 per million Btu, and the current electricity cost of \$0.01 per kWh, this annual savings translates to about \$754,000. The MEE system component, which costs approximately \$3.0 million, is about 20 percent more expensive than a comparable flash dryer. Using this information a cost evaluation was performed to indicate the benefits associated with the higher cost MEE system. Table 1 summarizes the information used to obtain the following after-tax payback values:

o DCF Rate of Return, %	36
o ROI, %	128
o After-tax Payback, yrs	1.3

FIGURE 2 . SCHEMATIC OF FLASH DRYING SYSTEM

Table 1. Data Summary for Discounted Cash Flow Analysis

Differential Installed Cost (DIC), December, 1980 (\$)	600,000 (1)
Length of Depreciation Period (years)	10
Life of Project (years)	10
Fuel Savings for First Year (\$)	754,000 (2)
Escalation of Fuel Savings (%)	15
Taxes and Insurance (% of DIC)	2
Investment Tax Credit (%)	10
Equipment Cost Eligible for Tax Credit (%)	100
Corporate Tax Rate (%)	46
Maintenance (% of DIC)	6

Notes:

1. The flash dryer system was estimated to be 20 percent less costly than the MEE system, thus the differential installed cost is $0.20 \times 3,000,000 = \$600,000$.
2. Fuel saving based upon the following calculation which shows the net difference in operating costs between the flash dryer and MEE systems:

Fuel Oil Saving

$$(30.9 - 10.6) \times 10^6 \frac{\text{Btu}}{\text{ton}} \times \frac{6,800 \text{ ton}}{\text{yr}} = 138 \times 10^9 \frac{\text{Btu}}{\text{yr}}$$

Fuel Oil Cost Saving

$$138 \times 10^9 \text{ Btu/yr} \times \$5.25/10^6 \text{ Btu} = \$724,500/\text{yr}$$

Electricity Saving

$$(665-235) \frac{\text{kWh}}{\text{ton}} \times \frac{6,800 \text{ ton}}{\text{yr}} = 2.924 \times 10^6 \frac{\text{kWh}}{\text{yr}}$$

Electricity Cost Saving

$$2.924 \times 10^6 \text{ kWh/yr} \times \$0.01/\text{kWh} = \$29,240/\text{yr}$$

Net Operating Cost Saving

$$724,500 + 29,240 = \$753,740/\text{yr} \text{ (use } \$754,000/\text{yr)}$$

DECISION PROCESS

Like most mills in the sulfite, neutral sulfite semichemical, unbleached kraft, and groundwood pulping segments of the pulp and paper industry, ITT Rayonier's Port Angeles dissolving sulfite mill had the problem of disposing of residue from the plant's waste treatment system. After investigating several alternatives, ITT Rayonier decided to install a \$10 million system, the first of its kind in the industry, to dry activated sludge for sale as an animal feed supplement. Sale of the RAY-PRO® product enabled the company to recoup some of the operating costs for the secondary treatment system at the mill. Plant management was familiar with MEE Technology, which had been used in combination with steam turbine-driven vapor-recompression units to dry spent sulfite liquor at the mill since 1976.

Based upon the operating experience to date and the favorable return for the MEE system versus the flash dryer alternative, the MEE system has proven to be a cost effective, reliable means for disposing of large amounts of activated sludge generated by the Port Angeles dissolving sulfite pulp mill.

CASE HISTORY NO. 7

PRE-DRYING OF HOG FUEL

CASE HISTORY NO. 7

PRE-DRYING OF HOG FUEL

Industry: Pulp and Paper

Company: Arkansas Kraft Corporation
Mill Division
P. O. Box 711
Morrilton, Arkansas 72110
(501) 354-4521

Contact: Edwin M. Read, Jr.
Vice President, Mill Manager

SUMMARY

Arkansas Kraft Corporation produces 1,000 tons/day of kraft linerboard. Early in 1978 the Morrilton Mill installed a system to pre-dry its hog fuel. This system, which uses a Rader-Thompson rotary dryer fired by waste heat from the hog boilers' flue gases, increased the capacity and efficiency of each hog boiler from 63,700 to 84,000 lb/hr and 68.5 to 76.5 percent. The pre-drying system thus allowed the increased use of hog fuel (biomass) and a subsequent decreased use of natural gas in their power boiler. Based upon an estimated fuel cost savings of \$738,000/yr, the pre-drying system yielded an after-tax payback of about 1.5 years.

DESCRIPTION OF ENERGY CONSUMING PROCESS

In the pulp and paper industry, a large amount of waste product from debarking and other mill operations is produced. An economical method for disposing of the waste is to burn it in a hog fuel boiler. These boilers generate process steam for mill use. Arkansas Kraft has two such boilers which burn waste (hog fuel) and generate steam at 600 psi and 700°F. The total average steam rate from the hog fuel boilers before modification was 127,400 lbs/hr based upon a hog fuel feed rate of 46,000 lbs/hr and a moisture content of 45 percent.

In order for gasification and combustion to take place, the hog fuel moisture content must be reduced to 10 percent. To do this, 16,100 lbs/hr of water must be evaporated. This requires approximately 18×10^6 Btu/hr or 8.4 percent of the hog fuel's available energy. In addition, because of the high moisture content of the fuel, the hog boiler's ability to respond to swings in steam demand was limited. As a result, the natural gas fired power boiler was used to assist in providing the required steam demand during swing load periods.

Figure 1 shows the process in use at the mill. Hog fuel is conveyed to a hog that grinds up the waste. The hog then discharges this hogged fuel to a disc screen that removes gross oversized material which is then recycled back to the hogger. The remainder of the hogged fuel is conveyed pneumatically to bottom metering bins. The energy saving pre-dryer was later installed ahead of this step. Hogged fuel is then metered to a nearly horizontal grate in the boiler. This grate has pinholes through it that allow combustion air to draft through the hog fuel. Combustion air is supplied such that it is 30 percent in excess of the stoichiometric amount of air necessary to insure complete combustion of the fuel under conditions of perfect mixing. The flue gas is exhausted at 480°F and steam is generated at 600 psi and 700°F.

DESCRIPTION OF ENERGY SAVING ACTION

As shown in Figure 1, the flue gas is exhausted at 480°F. The energy saving action is to recover the waste heat in the flue gas and use the heat to reduce the moisture level of hog fuel entering the boiler. This action reduces the amount of energy needed to dry the hog fuel in the boiler before combustion can occur. The mill installed a Rader-Thompson rotary pre-dryer ahead of the metering bins. The dryer uses the hog boiler flue gas as the heat source; the system arrangement is shown in Figure 2. Flue gas is exhausted from the dryer at 210°F. Note that not all of the boiler flue gas is needed by the dryer. Pre-drying the hog fuel allows more grate surface area to be used for combustion rather than for drying, thus boiler capacity is increased.

Hog fuel at 54,400 lbs/hr and 45 percent moisture enters the rotary dryer and flows cocurrently in a spiralling manner with the flue gas which enters at 480°F. The dryer is designed so that larger particles of hog fuel are retained longer. This insures a uniform moisture content for hog fuel entering the boiler. The flue gas heat is transferred to the hog fuel as it passes through the dryer. Water evaporates from the hog fuel to achieve a fuel flow rate of 46,000 lbs/hr with a moisture content of 35 percent at the dryer outlet. The flue gas is exhausted at 210°F along with the evaporated water. Figure 3 shows the material flows for the dryer based on current operation.

As shown in Figure 3, the rotary dryer uses 270,000 lbs/hr of flue gas from the two hog fuel boilers. This accounts for half of the available flue gas from the boilers with the remainder being exhausted at 480°F. The 270,000 lbs/hr of flue gas contains approximately 22 million Btu of which over 40 percent (8.8 million Btu) is used to evaporate water from the incoming hog fuel.

Figure 1. Simplified Block Diagram of Boiler Process.

Figure 2. Simplified Block Diagram of Boiler Process with Hog Fuel Pre-Dryer.

Figure 3. Material Flow Diagram for Hog Fuel Pre-Dryer.

The decrease in moisture level of hog fuel entering the boilers has made it possible to increase steam generation by over 20,000 lbs/hr per boiler. This is due to two factors. First, less energy is wasted to evaporate water from the hog fuel fed to the boiler, since hog fuel is more efficiently dried by the dryer than by the boiler. Second, more grate surface area is available for combustion and thus more hog fuel on a dry basis is burned.

ENERGY SAVINGS

By pre-drying 54,400 lbs/hr of 45 percent moisture fuel to 46,000 lbs/hr at 35 percent moisture, the hog boilers increased their steam output from 63,700 to 84,000 lbs/hr each. The total increased steam production of 40,600 lbs/hr allowed the natural gas fired power boiler to reduce its fuel consumption by 58.8×10^6 Btu/hr (assuming an 80 percent boiler efficiency). For natural gas costing \$1.90 / 10^6 Btu, the first year's estimated net fuel cost savings was \$738,000. Table 1 summarizes this cost saving as well as the other assumptions used to obtain the following approximate after-tax payback values:

o DCF rate of return, %	75
o ROI, %	105
o After-tax payback, yrs	1.5

DECISION PROCESS

Arkansas Kraft's decision to purchase and install a Rader-Thompson rotary dryer system to pre-dry hog fuel was based upon several factors. The company was interested in increasing the hog fuel boiler capacity and in reducing plant natural gas consumption because of continuing escalating fuel costs. One method to accomplish these objectives was brought to Arkansas Kraft's attention by Rader-Thompson. By purchasing and installing their hog fuel pre-drying system, the hog fuel boilers could be increased in capacity and the natural gas consumption simultaneously reduced. The projected capacity improvement of the pre-drying system was borne out by the fact that the hog fuel boilers were able to increase their capacity from a total steam production of 127,400 lbs/hr to 168,000 lbs/hr. This increased production allowed the natural gas fired boilers to be reduced in load and thus an estimated net fuel savings of \$738,000 for the first year was realized. The resulting after-tax payback of approximately 1.5 years fell within the company's criteria for capital investment.

Table 1. Assumptions for Discounted Cash Flow Analysis (1)

Installed Equipment Cost, June 1878 (\$)	700,000
Length of Depreciation Period (years)	10
Life of Project (years)	10
Fuel Saving for First Year (\$)	738,000 (2)
Escalation of Fuel Saving (%)	15
Taxes and Insurance (% of Equipment Costs)	2
Investment Tax Credit (%)	10
Equipment Cost Eligible for Tax Credit (%)	100
Corporate Tax Rate (%)	46
Maintenance (% of Equipment Costs)	6

Notes:

1. For confidentiality purposes, some of the values used (e.g., installed equipment cost and fuel costs) are approximations that do not necessarily reflect the exact conditions at this plant at the time of the equipment installation.
2. Fuel savings based upon the following methodology and assumptions:

Reduced Natural Gas Use

$$58.3 \times 10^6 \frac{\text{Btu}}{\text{hr}} \times \$ \frac{1.90}{10^6 \text{ Btu}} \times \frac{8,500 \text{ hr}}{\text{yr}} = \$949,600/\text{yr}$$

Auxiliary Power (to Dryer) Penalty

$$300 \text{ hp} \times 0.75 \frac{\text{kW}}{\text{hp}} \times 0.75 \frac{\text{load}}{\text{factor}} \times \frac{1}{0.95} \times \frac{8,500 \text{ hr}}{\text{yr}} \times \$ \frac{0.022}{\text{kWh}} = \$ 33,200/\text{yr}$$

Purchased Bark Penalty

$$(54,400-46,000) \frac{\text{lb}}{\text{hr}} \times \frac{8,500 \text{ hr}}{\text{yr}} \times \$ \frac{5}{\text{ton}} \times \frac{\text{ton}}{2,000 \text{ lb}} = \$178,500/\text{yr}$$

Fuel Saving

$$949,600 - 33,200 - 178,500 = \$737,900/\text{yr} \text{ (use } \$738,000/\text{yr)}$$

CASE HISTORY NO. 8

LIME KILN COMPUTER CONTROL

CASE HISTORY NO. 8

LIME KILN COMPUTER CONTROL

Industry: Pulp and Paper

Company: Louisiana-Pacific Corporation
P.O. Box 158
Samoa, California 95564
(707) 443-7511

Contact: Fred R. Martin
Technical Superintendent

SUMMARY

The Louisiana-Pacific Mill at Samoa, California produces 600 tons per day of bleached kraft pulp. In this mill the largest continuous user of natural gas is the lime kiln which was installed in 1966. The increase in the cost of natural gas provided an incentive for plant management to investigate technologies to reduce lime kiln energy use. One technology, a computer control system manufactured by Boeing of Seattle, Washington, was installed in September, 1980, at a cost of \$225,000. Since the installation, the system has reduced energy use by eight percent and yielded a potential annual fuel cost saving of \$176,300 with an after-tax payback of 1.7 years.

DESCRIPTION OF ENERGY CONSUMING PROCESS

At the Samoa Mill kraft pulp is manufactured by first breaking down the wood chips in a continuous digester in the presence of heat and chemicals. The chemicals, sodium hydroxide and sodium sulfide, form a white liquor that aids in the delignification and removal of other organics from the wood chips. After digestion, the pulp and spent liquor are separated and sent on for further processing. The lime kiln is an integral part of the processing operations to recover the valuable chemicals from the spent liquor. Figure 1 shows a simplified diagram of the chemical processing operations performed on the spent liquors which leave the digester. For this case history the area of interest is the lime kiln portion of the chemical recovery operations.

Beginning at the slaker, calcium oxide from the lime kiln combines with water in the green liquor to form hydrated lime, calcium hydroxide -- Ca(OH)_2 . Makeup lime is also added to the slaker as required and the mixture is sent to the causticizer where the following reaction occurs:

Figure 1. Simplified Diagram of Chemical Recovery Area.

To recover the sodium hydroxide, sodium sulfide and calcium carbonate, the mixture is sent to a clarifier to separate the white liquor (NaOH and Na₂S) from the calcium carbonate. The white liquor is then sent to the digester to complete its recovery cycle. The calcium carbonate (lime mud), however, is sent to the mud washer prior to entering the lime kiln at a 50 percent solids content. In the lime kiln the chemical recovery operation is completed as calcium carbonate is reduced to lime (calcium oxide) in the following reaction:

The lime kiln, a large rotary dryer, requires heat energy in the amount of 10×10^6 Btu/ton CaO. This energy is used to evaporate water from the lime mud, to increase the sensible heat of the lime mud to the reaction point (CaCO₃ to CaO), and to drive the chemical reaction to completion.

Figure 2 depicts the lime kiln portion of the chemical recovery system. Heat for the lime kiln process is supplied by combustion of natural gas. The hot gases pass countercurrent to the flow of the calcium carbonate as it is dried and converted to calcium oxide in the kiln prior to addition to the slaker to form lime.

DESCRIPTION OF ENERGY SAVING ACTION

To save energy in the lime kiln, the Samoa Mill purchased and installed a Boeing computer control system in September, 1980 for \$225,000. Energy savings of approximately 8 percent were achieved by precise control of the lime kiln product (CaO) temperature. With the Boeing system, optical pyrometer measurements indicated a reduction in product temperature. To achieve a reduced temperature, several lime kiln operating parameters were measured in order to determine the proper firing rate. Table 1 lists these control system variables. By controlling the product at a reduced temperature, a number of advantages in addition to energy savings were obtained, namely:

- o Elimination of ring formation due to impurities (iron, chromium, magnesium, aluminum, silica, nickel)

Figure 2. Lime Recovery Operation

Table 1. Control System Variables

- o Fuel flow
- o Primary air flow
- o Secondary air flow
- o Mud flow
- o Product temperature
- o Exit gas temperature
- o Exit gas O₂ level
- o Induced draft
- o Slaker temperature
- o Green liquor temperature
- o Mud loss to scrubber

- o Improved product (CaO quality, e.g., reduced ball formation)
- o Improve settling characteristics of the raw white liquor and more uniform white liquor flow production
- o Reduced lime kiln component wear, e.g., refractory, lump crusher, drag and elevating conveyors, etc.

Before the system was installed at the Samoa Mill, Boeing personnel performed a process analysis of the kiln. The analysis provided a definition of the process and control requirements for the kiln and it identified what additional or replacement instrumentation was required. After the analysis was performed and the instrumentation installed, the lime kiln was tested to obtain baseline efficiency data and actual operating parameters for a simulation validation. The simulation, performed by computer, was used to define the optimum operating parameters for the Boeing lime kiln computer control system. Once these steps were accomplished, the system was installed and tested.

The installation of the computer control system took about seven days and actual on-line control was achieved 10 days after the start of installation. Since the installation, the equipment has performed reliably and has been highly accepted by the lime kiln operators. Operator training took one session with Boeing, however, plant personnel believe a follow-up training session after on-line experience would be beneficial.

ENERGY SAVINGS

The installation and successful operation of the Boeing rotary kiln control system has yielded an estimated eight percent efficiency improvement. Before the modification, energy use was estimated to be 10×10^6 Btu/ton CaO. After the modification energy use was initially estimated to be approximately 9.2×10^6 Btu/ton CaO. Because of operational problems with the mud wash filter, kiln energy use has been as high as 9.7×10^6 Btu/ton CaO (only a 3 percent savings) with the computer control system in operation. The computer control system was very helpful in pinpointing the necessity to procure and install new pre-coat filter equipment and thus regain the energy efficiency improvement provided by the Boeing system. Assuming a satisfactorily operating mud wash filter, the lime kiln would have an annual fuel saving of about 40.6×10^9 Btu/yr for a throughput of 145 tons CaO/day and 350 days/yr of operation. At a fuel cost of \$4.3/ 10^6 Btu, the annual fuel cost saving would thus be \$176,300. Table 2 summarizes this information as well as the data used to obtain the following potential after-tax equipment payback:

o DCF rate of return, %	57
o ROI, %	44
o After-tax payback, years	1.7

Table 2. Data Summary for Discounted Cash Flow Analysis

Installed Equipment Costs (\$)	225,000
Length of Depreciation Period (years)	10
Life of Project (years)	10
Fuel Saving for First Year (\$)	176,300 (1)
Escalation of Fuel Saving (%)	15
Taxes and Insurance (% of Equipment Costs)	2
Investment Tax Credit (%)	20
Equipment Cost Eligible for Tax Credit (%)	100
Corporate Tax Rate (%)	46
Maintenance (% of Equipment Costs)	6

Notes:

1. Fuel saving based upon the following calculations:

Fuel Consumed Before Modification

$$\frac{10 \times 10^6 \text{ Btu}}{\text{ton CaO}} \times \frac{145 \text{ ton CaO}}{\text{day}} \times 350 \frac{\text{day}}{\text{yr}} = 508 \times 10^9 \text{ Btu/yr}$$

Fuel Consumed After Modification

$$\frac{9.2 \times 10^6 \text{ Btu}}{\text{ton CaO}} \times \frac{145 \text{ ton CaO}}{\text{day}} \times 350 \frac{\text{day}}{\text{yr}} = 467 \times 10^9 \text{ Btu/yr}$$

Fuel Saving

$$(508 - 467) \times 10^9 \text{ Btu/yr} \times \$4.3/10^6 \text{ Btu} = \$176,300/\text{yr}$$

DECISION PROCESS

Louisiana-Pacific was contacted by Boeing to determine the company's interest in a modern, state-of-the-art computer control system for lime kiln operation. Through the subsequent discussions, Louisiana-Pacific decided to purchase the Boeing system in the hope of satisfying the following goals:

- o Average reduction of 10 percent in gas usage
- o Improved slaker control through improved kiln product (CaO) quality
- o More uniform white liquor flow production
- o Improved settling characteristics of the raw white liquor

The previously quoted eight percent energy reduction for the lime kiln is a conservative estimate. Due to some equipment problems in the mud washer, an accurate estimate cannot be provided, however, one recent 24 hour test without computer control indicated a 15 percent energy reduction when the computer was brought back on line. Based upon an eight percent savings, the equipment would yield a 1.7 year after-tax payback and would thus fall within the company's guidelines for capital investment.

Besides the energy savings, the Boeing system achieved the other goals noted above. Overall, Louisiana-Pacific management at the Samoa Mill is satisfied with its lime kiln computer control system investment.

CASE HISTORY NO. 9

HEAT WHEEL FOR PROCESS HEAT RECOVERY

CASE HISTORY NO. 9

HEAT WHEEL FOR PROCESS HEAT RECOVERY

Industry: Pulp and Paper

Company: Simkins Industries
259 E Street
New Haven, Connecticut 06508
(203) 787-7171

Contact: J. W. Feeley
Power Plant Engineer

SUMMARY

Simkins Industries in New Haven, Connecticut manufactures folding grade paperboard liner. It coats 32,400 tons/yr of paperboard liner with a latex and water based emulsion. In 1975 the plant retrofitted its coating oven with a heat wheel to recover heat from the oven exhaust. This equipment yielded a fuel cost saving of \$14,000. Based upon a total installed cost of \$9,850, the equipment had an after-tax payback of 1.3 years.

DESCRIPTION OF ENERGY-CONSUMING PROCESS

One of the products of the pulp and paper industry is coated paper. At the Simkins Industries New Haven plant, latex in an emulsion is used to coat folding grade paperboard liner. The solvent (in this case water) is removed from the coated product by passing it through a drying oven. Air, which has been heated by steam coils to 250-260°F, is passed over the product to remove the water from the coating. Approximately 38,000 acfm of air flow at this temperature is used in the drying operation. About 83 percent of this flow is recirculated back to the oven and 17 percent is exhausted to the atmosphere. As a result of this operation, 1.25×10^6 Btu/hr of heat are rejected to the atmosphere. Approximately 19 percent of this amount is due to the energy content of the water evaporated from the latex emulsion; the remaining 81 percent is the sensible heat content of the air. These values are based upon the following factors:

- o Latex coating of 4.5 lbs (wet) / 1,000 ft² paperboard
- o Latex coating has 52 percent total solids
- o Average coated paperboard production rate of 10,000 lbs/hr
- o Average paperboard weight of 100 lb/1,000 ft² assuming 0.024 inch average thickness

DESCRIPTION OF ENERGY-SAVING ACTION

In 1975, to save energy the New Haven plant installed a rotary heat wheel in the exhaust stream of the coating oven. The Wing Company provided the equipment, a Correx® WC 875 B heat wheel and a supply air filter was also purchased. Figure 1 provides a schematic of the system before and after addition of the heat wheel.

The heat wheel recovers only sensible heat from the exhaust air stream to preheat the drying oven makeup air. Heat from the exhaust stream warms the heat transfer media (aluminum in this case) of the rotating wheel. As the wheel rotates, the warmed section passes through the segmented portion of the equipment in which the cold makeup air is flowing. The cold air stream is then preheated as it passes over the heat wheel transfer media. In this particular case, about 80 percent of the sensible heat of the exhaust stream can be recovered by preheating the makeup air. The makeup air is heated from an average year round temperature of 50°F to 210°F. Simultaneously, the exhaust stream is cooled from 250°F to 90°F.

To date the equipment has operated very reliably. Maintenance consists of cleaning the heat transfer surface with compressed air and changing the supply air filter four times each year.

ENERGY SAVINGS

By installing the heat wheel, approximately 850,000 Btu/hr of waste heat was recovered from the exhaust stream. Recovering this amount thus saved about 1,130,000 Btu/hr of boiler fuel, assuming an overall boiler efficiency of 75 percent. For No. 6 fuel oil costing about \$12/bbl (\$1.91/10⁶ Btu) in 1975, the annual boiler fuel savings were about \$14,000 for 6,500 hours of operation. Table 1 summarizes this and other information used to obtain the following after-tax payback values:

o DCF rate of return, %	88
o ROI, %	138
o After-tax payback, yrs	1.3

DECISION PROCESS

Simkins Industries' decision to purchase and install the Wing Company heat recovery wheel was based upon two factors:

- o Plant engineer familiarity with heat wheel technology for air-to-air heat recovery
- o Anticipated equipment payback of less than 1 year (simple payback)

Drying Oven Without Heat Recovery

Drying Oven With Heat Recovery

Figure 1. Configurations of Conventional Coated Paper Drying Oven With and Without Heat Recovery.

Table 1. Data Summary for Discounted Cash Flow Analysis

Installed Equipment Cost, July 1975 (\$)	9,850
Length of Depreciation Period (years)	10
Life of Project (years)	10
Fuel Savings for First Year (\$)	14,000 (1)
Escalation of Fuel Savings (%)	15
Taxes and Insurance (% of Equipment Cost)	2
Maintenance (% of Equipment Cost)	6
Corporate Tax Rate (%)	46

Notes:

1. Fuel savings based upon the following calculation using the Wing Company performance data and the temperatures shown on Figure 1:

Make-up Air Flow

$$6,500 \text{ acfm} \times 0.75 = 4,875 \text{ scfm}$$

Energy Savings

$$4,875 \text{ scfm} \times \frac{1.085 \text{ Btu}}{\text{hr-scfm}^\circ\text{F}} \times (210-50)^\circ\text{F} = 846,300 \frac{\text{Btu}}{\text{hr}}$$

Boiler Fuel Savings

$$846,300 \frac{\text{Btu}}{\text{hr}} \times \frac{\$1.91}{10^6 \text{ Btu}} \times 6,500 \frac{\text{hr}}{\text{yr}} \times \frac{1}{0.75} = \$14,000/\text{yr}$$

The ease of installation, good operating experience, and very attractive payback show that the decision to invest in the equipment was well founded. This energy saving investment and others by Simkins Industries have allowed the New Haven plant to reduce energy consumption from about 17×10^6 Btu/ton product to $11-12 \times 10^6$ Btu/ton product; a net improvement of about 33 percent. Very high energy costs in New Haven relative to other areas in the United States have contributed to Simkins Industries awareness and motivation to invest in energy conservation technologies.

CASE HISTORY NO. 10

ORGANIC RANKINE BOTTOMING CYCLE
FOR TMP HEAT RECOVERY

ORGANIC RANKINE BOTTOMING CYCLE
FOR TMP HEAT RECOVERY

Industry: Pulp and Paper

Company: Mechanical Technology, Inc.
Plains Road
Ballston Spa, NY 12020
(518) 899-2976

Contact: Bob Rose
Energy Systems Division

SUMMARY

An organic Rankine bottoming cycle (ORBC) has been developed as part of a U.S. Department of Energy sponsored program for advanced cogeneration technologies. The ORBC system can be used to generate electricity through the recovery of waste heat from the thermomechanical pulping (TMP) process. The system was developed by Mechanical Technology Incorporated and a one megawatt prototype model has been reliably demonstrated for 1,000 hours at their development site.

For an integrated pulp and paper mill producing 750 tons of pulp per day, an MTI ORBC system would generate 1,000 kW of electricity and yield a net electrical cost saving of \$516,000/yr assuming an electricity cost of \$0.06/kWh and 8,600 hrs/yr of operation. Payback on the investment would be four years.

DESCRIPTION OF ENERGY CONSUMING PROCESS

Thermomechanical pulping (TMP) is a process which has been adopted by approximately 25 percent of the pulp and paper industry. Figure 1 shows the TMP portion of the overall pulp and paper process. The thermomechanical pulping takes place in the digester where combined heat, chemical and mechanical action are used to breakdown the wood chips. At the end of the digester cycle, the mixture is sent to a blow tank where it is flashed to atmospheric pressure. Some additional mechanical action occurs in the blow tank as the liquid containing the pulverized chips is separated from the flashed steam. From the blow tank, the liquor/ pulp mixture is sent on for further processing while the flashed steam is normally vented to atmosphere.

In the TMP process $3 - 3.5 \times 10^6$ Btu/ton of pulp and 50-100 kWh/ton of pulp are required thermally and electrically for the

Figure 1. Thermomechanical Pulping Without Heat Recovery

pulping operation. Assuming an average total energy use of 3.4×10^6 Btu/ton of pulp, approximately 40 percent (or 1.36×10^6 Btu/ton) is lost as steam vented to atmosphere. Therefore, for a plant producing 750 tons of pulp per day, the annual energy loss is 367×10^9 Btu for 360 days/yr of operation.

DESCRIPTION OF ENERGY SAVING ACTION

Pulp and paper mills can take advantage of the large amount of recoverable waste heat in the vent steam from the TMP process. One method to do this is to install an organic Rankine bottoming cycle to cogenerate electricity. The U. S. Department of Energy has sponsored a project with Mechanical Technology, Inc. to develop such a system. Figure 2 is a schematic of the TMP process with heat recovery via the ORBC system developed by MTI.

To cogenerate electricity, waste heat from the vent steam is recovered by condensing the steam in the ORBC boiler. In the boiler the latent heat of the steam converts the organic working fluid (in this case Freon® -- R113) from a liquid to gaseous state. The working fluid is then expanded through a specially designed, radial inflow turbine-generator set. Electricity produced in the generator is delivered to the mill's electrical distribution system. From the turbine the working fluid passes through a condenser to convert the gas back to a liquid state. The liquid is then pumped into the boiler where it once again is converted to gas.

Although R-113 has a relatively low toxicity and is inflammable, the entire fluid boundary is hermetically sealed to minimize the possibility of fluid leakage to the environment. This feature thus ensures highly safe system operation as well as minimal environmental impact due to the depletion of the upper atmosphere's ozone layer.

The MTI ORBC system has been extensively tested at the site of the developer under a DOE sponsored program. Sufficient prototype test information has been collected on a 1 megawatt prototype module to substantiate the reliable performance of the hermetically sealed, oil-free Freon® working fluid device.

The TMP process is a good candidate for application of this demonstrated advanced concept.

ENERGY SAVINGS

The installation and operation of a 1,000 kW ORBC system in a mill using the TMP process with a 750 ton of pulp per day capacity would yield an on-site energy saving of 8.6×10^6 kWh/yr. At \$0.06/kWh the net energy cost saving would be \$516,000/yr. Table 1 summarizes this information as well as the

Figure 2. Thermomechanical Pulping With Heat Recovery Via ORBC

Table 1. Bases for Discounted Cash Flow Analysis

Installed Equipment Costs (1981 \$)	2,000,000 (1)
Length of Depreciation Period (Years)	5 (2)
Life of Project (Years)	15
Fuel Saving for First Year (\$)	516,000 (3)
Escalation of Fuel Saving (%)	10
Taxes and Insurance (% of Equipment Costs)	2
Maintenance (% of Equipment Costs)	2
Investment Tax Credit (%)	20
Equipment Cost Eligible for Tax Credit (%)	100
Corporate Tax Rate (%)	46

Notes:

1. Based upon a system designed to produce 1,000 kW of power with an installed cost of \$2,000/kW.
2. Assumes accelerated depreciation using double declining balance.
3. Fuel saving based upon the following calculations which indicate a net power output of 1,000 kW:

Heat Recovered from Vent Steam

$$\frac{750 \text{ tons pulp}}{\text{day}} \times \frac{360 \text{ days}}{\text{year}} \times \frac{1.36 \times 10^6 \text{ Btu}}{\text{ton}} \times 0.80 = 294 \times 10^9 \frac{\text{Btu}}{\text{yr}}$$

where 0.80 = percent of total waste heat recoverable as latent heat at 212°F

Heat converted to Electricity

$$294 \times 10^9 \frac{\text{Btu}}{\text{yr}} \times 0.10 \times \frac{\text{kWh}}{3,413 \text{ Btu}} = 8.6 \times 10^6 \frac{\text{kWh}}{\text{yr}}$$

where 0.10 = ORBC system overall conversion efficiency at 212°F waste heat temperature

Table 1. Bases for Discounted Cash Flow Analysis
(Continued)

Fuel Savings

$$8.6 \times 10^6 \frac{\text{kWh}}{\text{yr}} \times \frac{\$0.06}{\text{kWh}} = \$516,000/\text{yr}$$

Net Power Output

$$8.6 \times 10^6 \frac{\text{kWh}}{\text{yr}} \times \frac{\text{yr}}{8,600 \text{ hr}} = 1,000 \text{ kW}$$

other assumptions used for the economic analysis which yielded the following results:

o DCF rate of return, %	25.4
o ROI, %	24.2
o After-tax payback, years	4

DECISION PROCESS

Although no MTI ORBC systems have been installed to date in an industrial plant, the pulp and paper industry is one possible application of the technology. Laboratory pilot tests show that the equipment can operate reliably. The decision to install the equipment would thus probably be made on the basis of economics, i.e., equipment payback potential. As the economic analysis shows, the ORBC system offers a moderately attractive DCF rate of return of 25.4 percent and an after-tax payback of four years.

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