Energy Conservation in Oil Refining

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ABSTRACT

An industrial energy manager can conserve energy in a number of ways. He can turn off energy loads, turn down energy intensity, install more energy efficient equipment, insulate tanks and pipe lines, recover and reuse energy, convert batch processes into continuous processes, or optimize the efficiency of converting fuel energy into a distributable medium (i.e., steam) if he knows where, why, and how much energy his plant is now using. A detailed energy audit of the plant conducted by a qualified energy consultant will identify conservation opportunities. If the energy manager can't find a qualified consultant that he can afford, there is something he can do. By establishing a set of simple ground rules to go along with his knowledge of plant operation plus an operator's spec book, he can calculate an energy audit from his desk. This paper tells how one energy manager did just this for a fats and oils plant.

The two words "energy conservation" have become "buzz" words in today's social and industrial life. Like "peace" and "motherhood," no one can be against "energy conservation." It is evident from the rapidly increasing cost of purchased fuel and electricity that *something* needs to be done to bring some sense of stability to our life style.

To trace a bit of recent energy history, the Arabs probably did a great favor for this nation by placing an embargo on oil exports to the United States in 1973. This certainly brought to our attention the fact that we *had* an energy problem, that we were *too* dependent on energy imports, that we could not control the price of energy, and that our usable energy reserves were declining rapidly. At that time we were importing about 25% of our petroleum energy requirements. Since that time, it is obvious that the federal government has been unable to cope with the energy problem. Energy prices continue to rise anywhere from 2% to 10% or more above inflation rate, our importation of petroleum has now grown to 50%, attempts by federal legislation to solve our energy problem have been ineffective and have resulted in more controls, higher prices, less supply, more bureaucracy, more dependence on imports and limited conservation. One congressman told me that there was one thing he was certain about and that was our energy problem would *not* be solved by the federal government, and if it is solved, it will be done by the technology and profit incentives of private industry.

The attempt at industrial conservation by the federal government as set forth in the "Energy Policy and Conservation Act" (EPCA) of December 27, 1975, resulted in the identification of the top ten energy using industrial groups. Our group, "Food and Kindred Products," was ranked number six. Based on the energy consuming size of fats and oils companies, it is mandatory that each company report energy consumption twice annually to the federal government and strive to meet a voluntary reduction in energy use of 14% by January 1, 1980. In setting this target, the federal government used research done by "Development Planning & Research Associates, Inc." of Manhattan, Kansas. Their research revealed that the "Shortening and Cooking Oils industry" used 2400 BTU of energy per pound of product produced.

Our Company was named as one of those that must report energy use and strive to meet the 14% reduction goal. Our management asked three questions:

1. Since 2400 BTU/lb. is the industry average, what is our average?
2. Can we meet the 14% reduction goal?
3. What and where are our opportunities to conserve?

To answer these questions, we needed a quick yet detailed audit of our energy usage of each plant. We couldn't afford a consultant and weren't sure we could find one even if we could afford him. So we did the energy audit ourselves by calculation, using one year's historical data plus our operating standards for processing flow rates, temperatures, pressures, etc. We answered question one immediately and found we use more than 2400 BTU/lb. product, so we had fertile ground for improvement.

The first thing we did was to look at the plant as a whole to determine the process flow logic from an energy standpoint as in Figure 1.

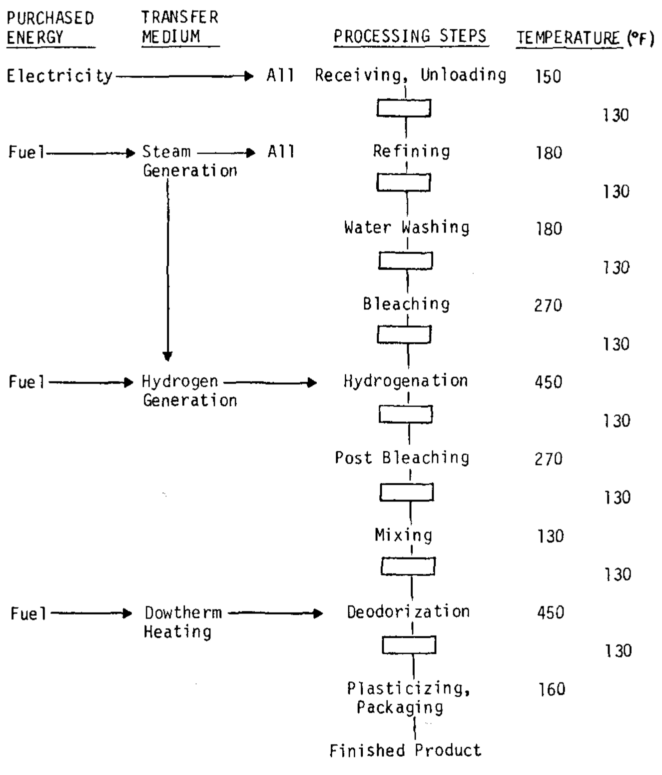

FIG. 1. Processing temperatures.

Edible oil processing consists of independent process steps that are not connected with each other by continuous flow. Between each processing step there are one or more storage or holding tanks. Generally, in each step oil is heated to a reaction temperature, held for reaction, then cooled to protect oil quality. Between processing steps, oil is allowed to cool to a minimum or ambient temperature, yet it is maintained in a fluid state to facilitate material handling by pumping.

Energy is used to provide heat, motive power, cooling and comfort. Heat is provided by burning a fuel to generate a medium which transfers that heat to a point of use. The mediums are steam, a heat transfer fluid like Dowtherm, and hydrogen gas (exothermic heat a by-product of the process step). Motive power, cooling, and comfort are provided by either steam or electricity. Thus, purchased energy is either fuel or electricity.

The total purchased energy for one year was used as the historical basis for our calculation. Total for the year included a complete weather cycle and showed the following percentages:

	Total %	Variable %	Non Variable %
Fuel for steam generation	68	22	46
Fuel for dowtherm heating	3	3	---
Fuel for hydrogen generation	18	18	---
Fuel for misc. (i.e., comfort)	3	---	3
Electricity	8	5	3
	100	48	52

In order to fit our calculated analysis, we needed to analyze our historical year to determine the split between energy variable with production while operating vs. energy that did not vary with production. This latter cannot be called fixed, since with a total plant shutdown all energy use can stop.

It was obvious by looking at steam production for each month of the year that weather had a dramatic affect on fuel purchases. A typical year showed steam production for January to be 1.5 times the July production. Therefore, we had to quantify the use of heat energy in relation to weather as measured in heating degree days or cooling degree days.

After reviewing the overall plant energy total for the year, including the fact that weather has a dramatic effect on energy usage and must be quantified, the next step was a detailed energy audit of each process step and interim storage or holding tank. The foundation for every Industrial Energy Conservation Program is a detailed energy audit by process, by plant. The degree of detail and accuracy must be determined by the time and data available. Whether or not a detailed study or calculated "desk audit" overview is conducted is not as important as is the fact that a balance is completed. Before the audit of each process was done, a set of assumptions was made to simplify the calculation since we did not base the audit on measured data. These assumptions were:

1. All material and energy quantities have a heat energy content that is quantifiable. It is similar to saying that all materials have a weight that is quantifiable.
2. Heat energy can be reused over and over within the first law of Thermodynamics.
3. Heat energy can be transferred to other materials but at less than 100% recovery within the second law of Thermodynamics.
4. Heat content expressed as BTU is the sum of: (a) the heat required to raise the temperature of a material from a base temperature to a desired temperature and is expressed by $Q = W\ Cp\Delta T$ (sensible heat) where Q is in BTU, W is pounds, Cp is BTU/lb.°F., ΔT is °F; (b) the heat required or liberated to change the material state (i.e., liquid to solid, liquid to gas, etc.) is expressed as BTU/lb. (latent heat).
5. The base temperature is 65 F. Heat content at this temperature is 0.
6. Convection loss calculations were based on $Q = UA\ \Delta T$ where Q is BTU/hr., U is BTU/hr. °F.sq.ft., A is Sq. ft. and ΔT is °F.
7. Steam is saturated at 150 psig pressure. When used for heating in a heating coil, only the latent heat provides heat.
8. The heat content values used for calculation are shown in Table I.

These heat content values, when used in calculations, are shown in Table II.

After calculating the theoretical heat needed, we allowed for efficiency and convection loss then converted the BTU to steam pounds and to total steam heat supplied by multiplying by 1,163 BTU/lb., which is the sum of steam's latent plus sensible heat, corrected to 65 base, for 150 psig steam.

There are 5 logic steps to be followed in making an energy audit:

1. Draw a flow diagram of the process.
2. Determine the operating conditions, i.e., flow rate, temperature, pressure, etc.
3. Establish the boundary within which the audit will be measured, calculated or estimated and energy input balanced to equal energy output.
4. Complete a material balance showing a material quantity for each flow arrow. This should include all mass (i.e., solids, liquids, gasses, air, etc.). The balance can be hourly, monthly, or any time frame.
5. Convert the material balance to an energy balance by determining the energy content of each item of mass.

After completing the calculated energy audit for each process step, the data can be listed on the flow diagram and on a balanced account ledger to insure that all energy is accounted for.

The flow diagram in Figure 2 shows an example of this for the refining process step for a refinery production level of 20,000 M pounds. Following the flow diagram, the material and heat balance data are shown again in a balanced account ledger, Table III.

The analysis for heat used to keep oils liquid in interim storage or holding tanks was done by following this logic:

TABLE I

Heat Contents

Material	Latent heat	Specific heat BTU/lb.-F
Natural gas, MCF	1.0 MM BTU/MCF	.25
Fuel oil, gal.	.148 MM BTU/gal.	.6
Electricity, KWH	.003413 MM BTY/KWH	---
Steam, M lbs. 150 psig sat.	857 BTU/lb.	1.0
Edible oils, lbs.	---	---
SBO, PNO, CN	0	.6
CSO	7 BTU/lb. (40-60 F.)	.6
Palm	55 BTU/lb. (70-90 F.)	.6
PKO	90 BTU/lb. (70-90 F.)	.6
Meat fat	40 BTU/lb. (60-110 F.)	.6
Hydrogen, as ingredient	1.7 BTU/lb. -Δ IV of oil	---
Solid mtl., filter earth, catalyst, etc.	---	.5
Liquid mtl., lye, acid, etc.	---	1.0

TABLE II

Heat Content Calculation Example

Basis: 150 M LB. tank car lard
received at 40 F.,
heated by 150 PSIG SAT. steam
to unloading temperature, 140 F.
Convection loss based on time is 10%

Heat content as received:

$Q = W\ Cp\ \Delta T$
$= (150{,}000)\ (.6)\ (40°\text{-}65°) = \text{-}2{,}250{,}000$ BTU

Heat needed to unload:

Q = sensible heat + latent heat
$Q = (150{,}000)\ (.6)\ (140°\text{-}40°) + (150{,}000)\ (40)$
$Q = 9{,}000{,}000 + 6{,}000{,}000 = 15{,}000{,}000$ BTU

Convection loss: (15,000,000) (10%) = 1,500,000 BTU
Steam needed: 16,500,000 ÷ 857 = 19,253 LBS.
Total steam heat: (19,253) (1,163) = 22,391,240 BTU
Heat lost in condensate and flash steam:
22,391,240 - 16,500,000 = 5,891,240 BTU
Heat supplied per pound of product:
22,391,240 ÷ 150,000 = 149 BTU/LB.

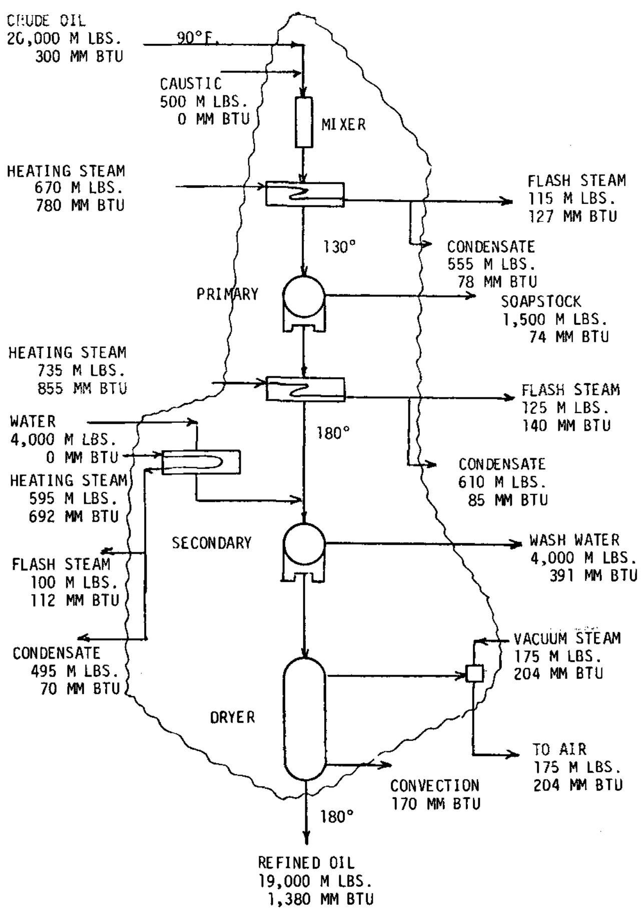

FIG. 2. Refining.

1. Using inventory standards, we determined the average oil pounds for each class (i.e., crude, refined, bleached, hydrogentated, etc.).
2. We calculated the cumulative volume capacity for oil tanks used by each inventory class.
3. The ratio of oil pounds to tank capacity by class was used as the % each tank was filled on the average.
4. This % then represented that portion of each tanks exposed surface area for heat transfer calculation in the formula, $Q = UA \Delta T$.
5. U for an uninsulated tank is 2 BTU/hr. Sq.ft.°F. or 4 in a 10 mile average wind.
6. The Δ T was the difference between the oils' holding temperature and 65 F.

In this presentation, we will concentrate on heat energy since it represents 92% of purchased energy. The 8% that is electricity was calculated in the energy audit based on the rated HP and hours of operation of each motor, all converted to BTU. Finally, an energy summary for each plant was made from the process and oil storage audits to compare with historical usage. The difference was then allocated based on calculation, measurements, if available, or estimates. In summary, then, our energy usage pattern was as shown in Table IV. These data are shown as % of total rather than as actual BTU since our plant's BTU per pound of energy use is influenced more by geographic location and our insulation against the effects of weather than by production level. The industry average is 2400 BTU per pound output.

From the energy audit balance data, we analyzed the final disposition of energy as it leaves the plant as in Fig. 3. This analysis was important, as it identified energy waste that might be salvaged.

Conceptually, all our oil and other raw materials enter the plant at ambient temperature and leave the plant at ambient temperature with some exceptions as finished product. This is not true in a detailed sense, but can be used to summarize the final disposition of energy as shown in Table V.

One other analysis made with the energy audit data was the effect of weather on energy use. For the historical year analyzed, we plotted the steam energy used (after excluding process energy, which varies directly with production regardless of weather) vs. net heating degree days minus cooling degree days for each month. The result was a straight line with 90% fit of all 12 months. The slope of the line (MM BTU per net heating degree day) will help us predict future energy use as weather varies. The intercept of the line at 0 heating degree days is the MM BTU steam energy base load under current operating conditions. This is a reference from which conservation effort with steam can be measured.

After completing the calculated energy audit, we analyzed our results so we could answer questions two and three which our management had asked.

The data showed us that our conservation efforts involved heat, and heat meant steam generation and use. Also,

TABLE III

Refining Balance[a]

Material balance	Input M Lbs.		Output M Lbs.
Crude oil	20,000	Refined oil	19,000
Caustic	500	Soapstock	1,500
Water	4,000	Wash water	4,000
Heating steam	2,000	Flash steam	340
Vacuum steam	175	Condensate	1,660
		Steam to air	175
	26,675		26,675
Heat balance			
	Input MM BTU		Output MM BTU
Crude oil	300	Refined oil	1,380
Heating steam	2,327	Soapstock	74
Vacuum	204	Wash water	391
		Flash steam	379
		Condensate	233
		Steam to air	204
		Convection loss	170
	2,831		2,831

[a]Production basis: 20,000 M lbs. crude oil.

TABLE IV

Annual Energy Use

	Steam total	Total BTU %
Purchased electricity – 8%		
As used:	- - -	8.0
Purchased fuels – 92%		
Steam generation – 68%	- - -	
H_2 generation – 18%	- - -	
Dowtherm heating – 3%	- - -	
Misc. (conform, etc.) – 3%	- - -	
As Used:		
Conversion loss	- - -	28.1
Exothermic hydrogenation heat	- - -	1.6
Dowtherm heat	- - -	2.1
Misc. natural gas heat	- - -	2.2
Steam use		
Distribution Loss	5.5	
Building Heat	2.7	
Plant Sanitation	4.4	
Fuel Oil Handling	4.6	
Boiler Feed Water Heat	8.1	
Vacuum Jets	6.0	
Liquid Oil Storage	10.3	
Processing	16.4	
		58.0
Total plant purhcased energy		100.0
Steam processing detail %	Process total	
Receiving, unloading	1.8	
Refining	1.8	
Water washing	1.3	
Bleaching	1.5	
Hydrogenation	2.9	
Post bleanching	2.9	
Deodorizing	4.2	
	16.4	

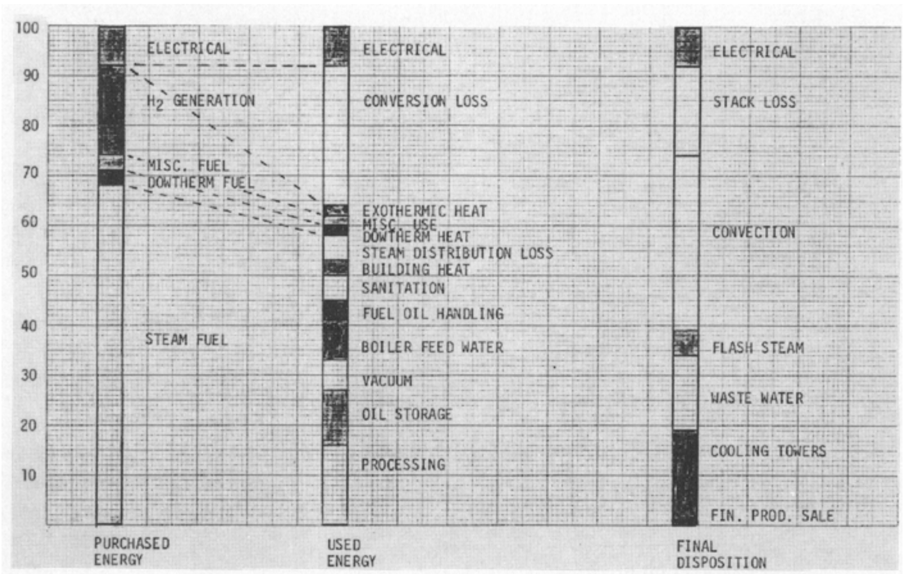

FIG. 3. Energy profile.

since 18% of purchased fuel was used to make hydrogen from which the only recoverable heat was the 1.6% from exothermic hydrogenation, we answered question three by pursuing conservation opportunities in five areas.

1. Optimize steam boiler efficiency.
2. Insulate tanks and equipment.
3. Establish a maintenance program to repair steam leaks, traps and faulty insulation.
4. Replace or retrofit the Hydrogen Generating Plant.
5. Modify processing so as to salvage heat for reuse with heat exchangers and economizers.

Our program has started, but it has not been easy. Energy conservation requires money, both capital and expense, and it requires a change of habit for operating people. We have made a lot of progress in some of the five conservation areas and limited progress in the other areas. Briefly, these are some of our results. The diagram in Figure 4 shows the energy balance for an assumed steam production of 50 M lbs. per hr for a 720 hr month, based on our operating conditions at the time of the energy audit. Boiler efficiency based on the heat content of steam produced (corrected to 65 F.) divided by the heating value of the fuel burned was 85.2%. We made these changes:

1. Change bfw treatment program and installed continuous blow down controls to reduce blow down.
2. Installed stack economizers to salvage waste heat.
3. Reduced excess combustion air by closer tracking and control.

TABLE V

Final Disposition of Energy

	Total BTU %
Electricity	8.0
Stack flue gas	17.9
Convection loss	35.6
Flash steam	4.3
Waste water	15.0
Cooling towers	18.6
Finished product sales	.6
Total plant purchased energy	100.0

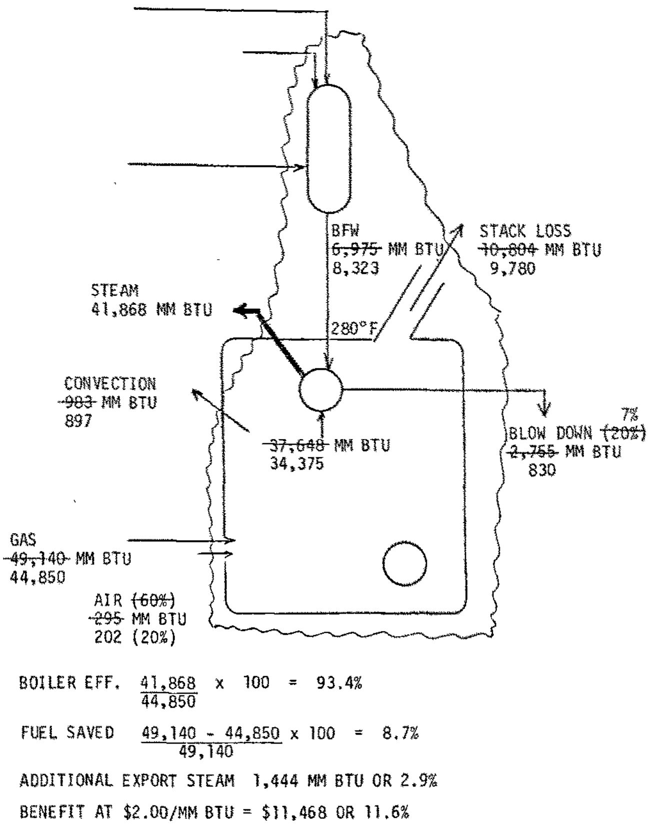

FIG. 4. Steam generating – before lined numbers and after.

4. Cleaned interior scale from boiler drums and tubes.

After improvement, the diagram in Figure 4 shows the new energy balance data under the crossed out previous data. Boiler efficiency was increased to 93.4%, fuel use was reduced 8.7%, and additional steam became available for use other than bfw heating. For a 50 M pound per hr steam production, the savings is $11,468 per month in purchased fuel.

We have started a program of insulating all oil storage tanks where oils must be held at above ambient tempera-

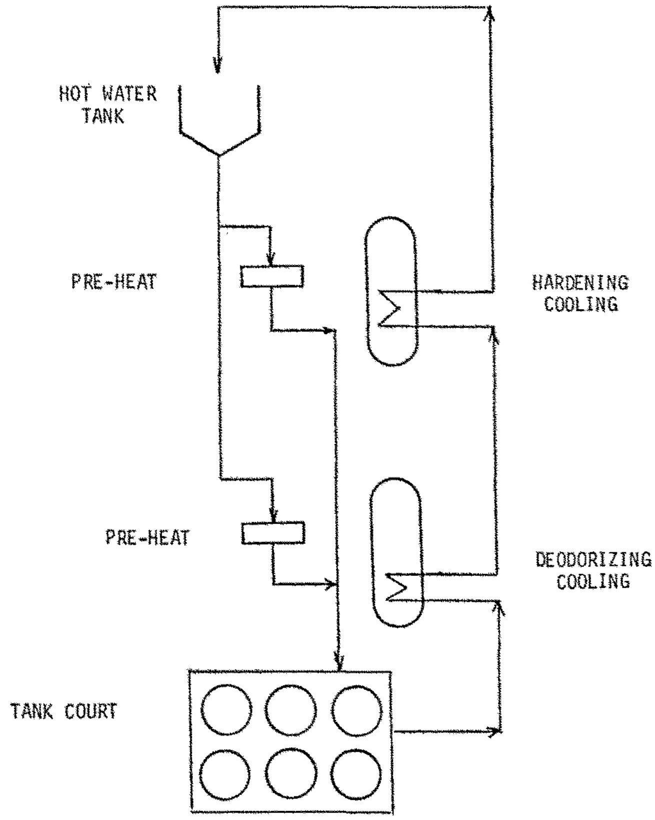

FIG. 5. Conservation system.

ture. The results when all tanks are insulated will reduce most of the 10% plant energy now used for keeping oils liquid. We are setting up a program for routine inspection and maintenance of specific energy use equipment. The objective is to keep all steam leaks repaired, all traps operating and generally to upgrade steam insulation performance. We are currently evaluating the energy benefit of either retrofitting our existing hydrogen plant or replacing it with a new, more efficient plant. Finally, we have designed and installed a conservation system (Fig. 5) to recover and reuse process energy with circulating hot water. Currently we are designing an expansion to this system.

Now, after quantifying all of our effort to date plus future potential, we are ready to answer question two asked by our management: can we meet the 14% reduction goal? The answer is yes. With a good maintenance program plus capital expenditures to replace energy inefficient equipment or processes, we have defined projects whose potential energy reduction is 35% to 40% of historical plant usage. The next step is to convert these defined projects into reality so that we can realize this 35% to 40% conservation potential.