New Approach to Optimizing Fired Heaters

Ashutosh Garg, Vice President, Furnace Improvements Services, Sugar Land, TX

Fired heaters are the largest consumers of energy in refineries and petrochemical plants. Most heaters in the industry are not operating at their peak efficiency. There could be several reasons for that. One of the common reasons is the fluctuation in the heater operating conditions and continuous need for optimization of the heater operating parameters. It is not possible to optimize the heater operation with fluctuating loads using current equipment.

FIS has developed a two-prong approach to take care of this problem. The "Heater Performance Index" software is built into the DCS and monitors the key performance indicators round the clock. It is based on modeling of the heater and provides direction to the operators to optimize the heater. In addition, FIS has developed hardware based control schemes which can optimize the heater automatically. Optimizing the heater operation will prolong heater life and reduce NOx emissions.

A recent heater optimization survey, carried out on a heater in Germany, indicated that it is possible to optimize a heater by making simple adjustments. The results of energy savings were in the order of 2-3%. With this knowledge we have developed a combination of software and hardware based controls that can control the heater and optimize the performance at all times. For a 100,000-barrel-per-day (BPD) refinery, even 2-3% improvement in thermal efficiency translates into energy savings of almost 2.5 Million Dollars per year. These schemes will pay out in less than a year!

INTRODUCTION

Petroleum Refining is the most energy intensive industry in the USA and accounts for 7.5% of the total energy consumption in the country. Energy purchases from outside sources cost about 3.8 Billion Dollars (1998) per year. Large percentage of energy is produced inside the refinery. If we include that we are estimating a total energy cost of 20 Billion Dollars at 6 $/MMBtu, energy consumed in the refining industry is around 7.1 Quadrillion Btu/year. Petroleum refining relies heavily on refining by-products as energy sources. About 6% of the petroleum is used as fuel. The situation is very similar in the Petrochemical and Fertilizer Industry. The production of Ethylene, a basic raw material for plastics, requires 22 MMBtu/ton of Ethylene. The energy required for the production of Ammonia, the basic raw material for urea and other fertilizers, is around 28.5 MMBtu/ton of Ammonia.

Fired heaters are major consumers of energy in the Refining and Petrochemical Industries. Almost 40 to 70% of the total energy consumption in a refinery or petrochemical plants is in fired heaters. While most of the heaters are designed for a thermal efficiency of 70-90%, the actual operating efficiencies are much lower. This is due to the fact that these heaters are not constantly operating at the design conditions. The heaters load keeps on changing due to several factors such as feed flow rate, feed temperature, variation in fuel composition, etc. Even changes in the ambient temperature can affect the performance of the heater. As a result, the design parameters in which the Fired Heater operates become inadequate to optimize the heater performance.

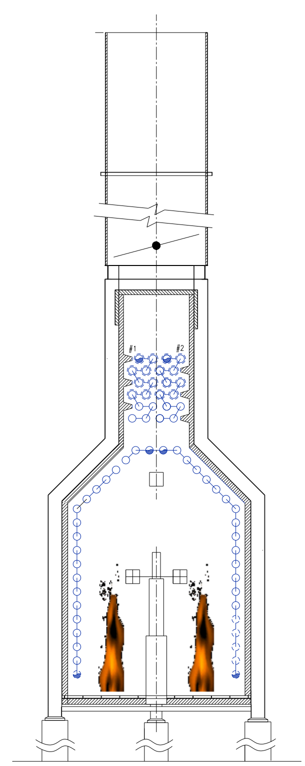


Figure 1. Typical Cabin fired heater

FIRED HEATERS

A typical fired heater consists of three major components: Radiant section, Convection section and Stack. Figure 1 shows an inside view of a typical Cabin fired heater. In a fired heater, the heat liberated by the combustion of fuels is transferred to fluids contained in coils.

The combustion is an exothermic reaction resulting from rapid combination of fuel with Oxygen. Fuel and air must be mixed thoroughly for complete combustion. In theory, it is possible to burn fuel completely with just the stoichiometric amount of combustion air. In actual operating conditions, it is not possible to have perfect mixing of fuel and air. If theoretical amount of combustion air is provided then some fuel would not burn completely. Therefore, it becomes necessary to supply excess air to complete combustion of the fuel. Excess air is expressed as a percentage of the theoretical quantity of air required for perfect combustion. This excess air shows up as excess Oxygen in the flue gases. Minimizing the excess air will improve the efficiency of the heater and reduce the NOx emissions. However, sufficient air must be provided to obtain the correct and desirable flame shape and complete combustion.

Burners start and maintain combustion in the firebox of the heater. They introduce fuel and air in the correct proportions, mix the fuel gas and air, provide a source of ignition, and stabilize the flame. Most of the burners in fired heaters operate under natural draft. All natural draft burners are sized for a specific draft loss across the burner throat. Providing higher draft than design will induce more air and providing lower draft will lead to insufficient air for combustion. There are also self inspirating premix burners. These are used in special heaters such as Steam Methane Reforming heaters, and Ethane and EDC Cracking heaters. Most of these are partially dependent on the draft available in the heater. Other type of burners are forced draft burners which get the air supply from a fan and are not dependent on the heater natural draft.

Draft has many meanings, but in our case it refers to the air or flue gas pressure that should always be slightly negative with respect to the atmospheric pressure. The hot flue gases inside the fired heater are lighter than the cold ambient air outside. This results in the creation of a slightly negative pressure inside the fired heater. Combustion air is drawn into the burners from the atmosphere and the hot gas flows out of the stack to the atmosphere due to the pressure differential. While passing through the convection section and stack, flue gases encounter friction resistance and these are known as draft losses.

Draft depends directly to the ambient temperature. Any variation in the ambient temperature affects the draft availability. For example, if we have a 30° F differential between the maximum and minimum temperature during the day, the draft available across the burner will change from 0.30 to 0.35 in WC, a change of almost 20%. This change in draft will lead to more combustion air supplied to the burners, making the operation inefficient. It is very important to maintain a constant draft in the heater at all times.

The heaters must be kept always under negative pressure. Negative pressure makes the heater inherently safe and prevents hot flue gases to escape from the fired heater. A positive pressure inside the heater will cause flue gas leakage and damage to the fired heater casing and structure. And more important, a positive pressure can be hazardous to the operating personnel.

A typical draft profile is show in Figure 2. The floor of the heater, where the burners are typically located, gains draft due to the radiant section's stack effect. Typical draft gains are of the order of 0.1 in WC per 10 ft of box height. A typical value of heater draft at the floor is of the order of 0.3-0.4 in WC for cabin heaters and 0.5-0.7 in WC for tall vertical cylindrical heaters. In the convection section, the flue gases encounter resistance due to the tubes but gain some draft due to the convection section height. In

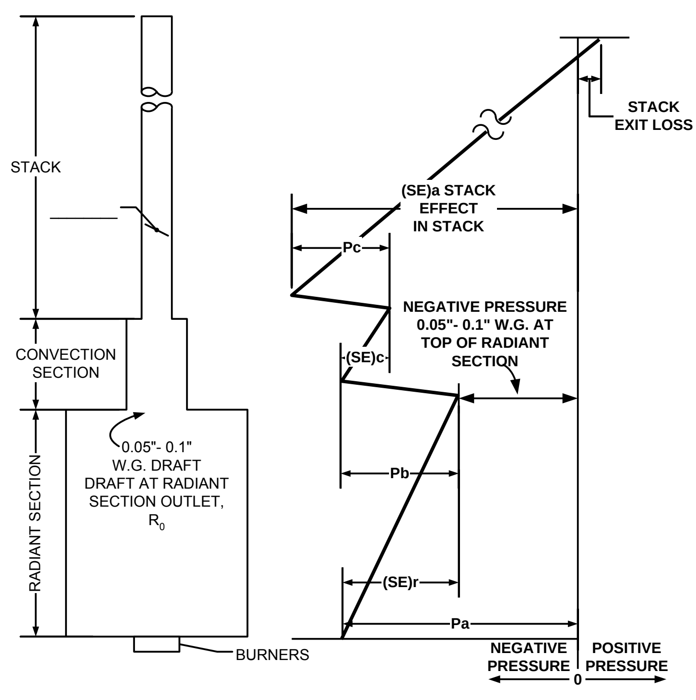


Figure 2. Draft profile

case the convection section becomes fouled the pressure drop across the convection section will go up and the heater arch draft can become positive.

The draft in the fired heater is controlled by means of a stack damper (natural draft systems). The arch of the heater or inlet to the convection section is the point with the highest pressure and thus has been used as a point of control. A typical value of 0.1 in WC should be maintained at the arch.

In the stack, the stack damper is provided to control the draft and there is a certain draft loss associated with the damper. If the stack damper is closed too far, the arch draft will become positive and similarly if it is opened too far, it will lead to a very high draft at the arch. The required stack height provides the draft required to maintain negative pressure at arch and take care of losses in the convection section and stack. The stack damper works as an upstream pressure controller. The burners are provided with air register to control the air supply to the burners. Closing the burner's air registers reduces the airflow but increases the heater draft. Closing the stack damper reduces the fired heater draft. In order to adjust excess air, the stack damper must be adjusted in conjunction with the burner's air registers.

In most of the heaters, existing dampers installed have a very poor quality and are not suitable for controlling draft. Most of these dampers are not designed for control and have only a limited number of blades. It is important to have multiple opposed blades damper for control. With a parallel blade damper, the control becomes very difficult. It becomes clear when you look at the control characteristic of the two types of dampers.
Controlling the excess Oxygen and available draft are key parameters to improve the efficiency of a fired heater.

OPTIMIZING FIRED HEATER

In a recent field optimization exercise at a refinery in Germany for 3 heaters, an important impact of field optimization was accomplished in the heaters.

One of those heaters was a horizontal tube cabin heater in a reboiler service. It was designed for a heat duty of 87.3 MMBtu/hr. The process feed was heated from 435° to 453° F. The heater had 15 burners installed at the floor and it was almost 50 ft long. The heater had two off takes on top of the convection section that are connected to the common duct leading to a 600 ft stack which serve for 14 other heaters.

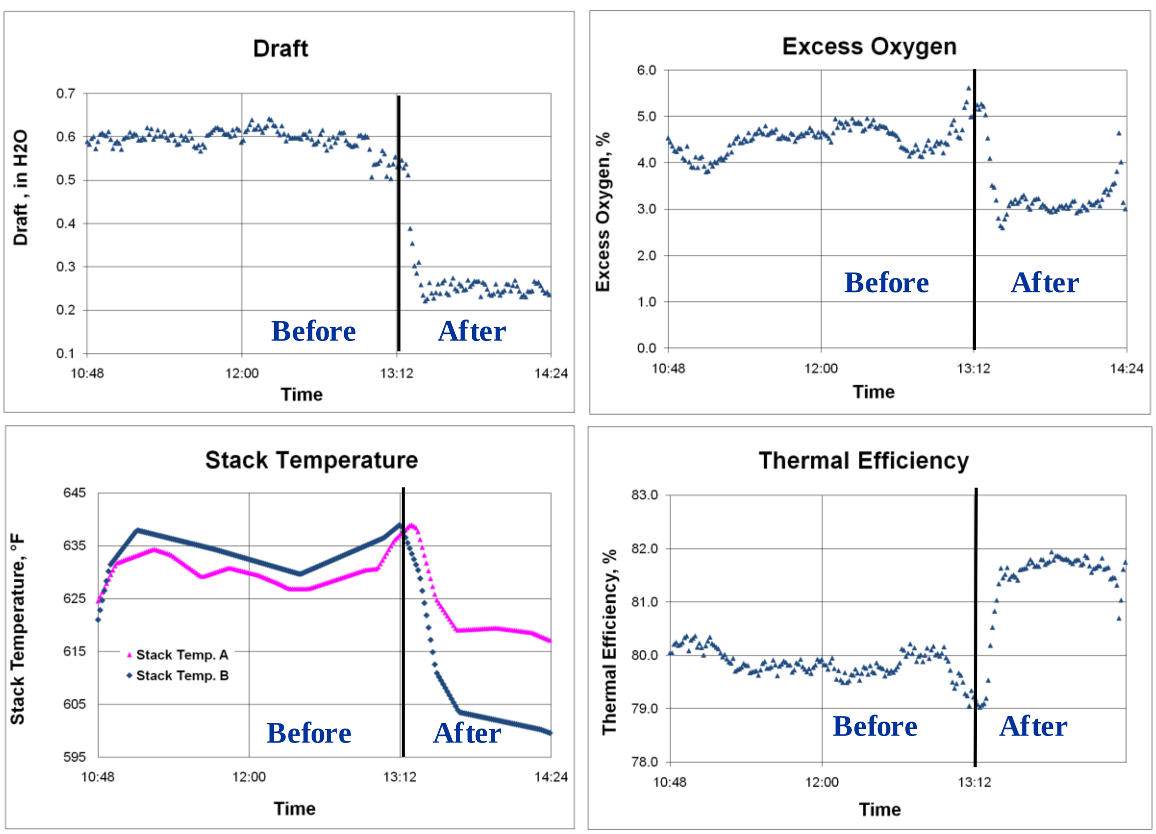


Figure 3. Heater performance, before and after adjustments

Figure 3 shows the performance of the heaters before and after making the adjustments in the stack damper and burner's air registers.

The results obtained are listed below:

- Draft decreased from (-) 0.6 in WC to about (-) 0.27 in WC.
- Operating excess Oxygen was around 4-5% before adjustments. It was reduced to 3%.
- Stack temperature was reduced from 635° to 600° F.
- The thermal efficiency of the heater increased by about 3%. Heater efficiency went up from 79% to 82%.
- NOx Emissions from the heater were reduced from 110 mg/Nm^3 to 50 mg/Nm^3.

Because the fired heater's conditions changes constantly, the stack damper and the burner's air registers have to be adjusted also constantly in order to maintain these improvements. These adjustments are not complicated when the fired heater has the adequate instruments and controls working correctly. However, most of the heaters have manual damper operation. These days, operators are having a lot of problems to control draft using the stack damper. It is almost impossible to do this job manually.

This problem could be solve by adding a pneumatic operator to the stack damper and control manually from the control room. This approach will require a panel mounted draft gauge pneumatic.

However, one of the problems in pneumatic operated dampers is the under sizing of the pneumatic operator. As a result, the damper movement is not smooth and takes place intermittently. This needs to be avoided as operators are scared to operate such dampers. These actuators should be sized at minimum operating air pressure. The dampers should be provided with a manual hand wheel to be used in case of emergency. The linkage should be stronger. A typical over sizing should be 300% of the calculated torque to take into account duct deposits, dead loads and thermal distortion.

A better approach is *The Automatic Control of Draft*. In this option draft is automatically controlled to the set value by adjusting the stack damper. In the past, this scheme has not worked successfully as it was not implemented correctly. In today's world with improved instrumentation and controls, this scheme can be implemented on DCS system or in a standalone PLC controller. The typical control scheme developed by my company is explain below.

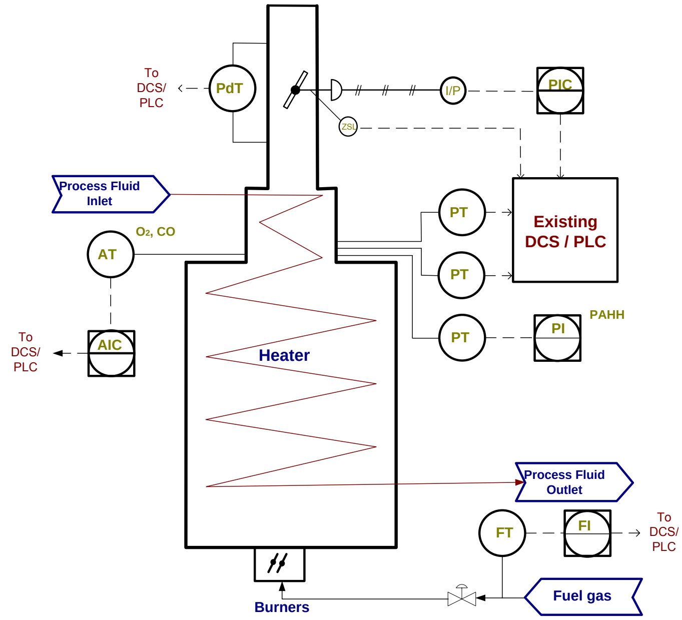


Figure 4. FIS automatic draft control

The scheme proposed is very reliable as it takes into account a number of parameters before making any adjustments.

- Heater Oxygen control
- Fuel firing rate
- ΔP across damper
- Damper position switch
- Arch draft

By monitoring these parameters, the adjustment to the heater draft is very safe and secure. Figure 4 illustrates the draft control system proposed by FIS.

Another approach to improve the efficiency of the heater is the "*Heater performance Index (HPI)"*. This is a software solution which will not only increase the efficiency of the heater; it will also ensure the best possible performance of your heater at all times and all conditions.

The HPI is a computer based analytical system that can be used for any kind of fired heater. It is an online tool many used to monitor the performance of the heater 24/7. The HPI software thoroughly analyzed the current performance of the heater by taking live data from the DCS and performing calculations. It is really easy to use and if the heater is found deficient in any area, action items are alarmed to correct the issue immediately generating a

Heater Performance Index

Description	Flow (BPM)	Inlet Pressure (PSIG)	Crossover Temp (°F)	Outlet Temp (°F)	TMT (°F)
Pass #1	709.5	278.92	585.1	686.78	960.7 / 969.4
Pass #2	676.52	295.97	589.75	678.62	965.1 / 994.5
Pass #3	670.8	275.85	592.02	680.15	895.8 / 927.1
Pass #4	729.08	285.95	597.14	678.49	907 / 1034.4
Pass #5	729.1	281.66	594.54	683.37	930.6 / 1041.67
Pass #6	695.13	283.84	590.9	670.14	887.6 / 845.62
Pass #7	737.39	298.2	594.39	682.95	959.9 / 863.41
Pass #8	653.35	275.73	583.27	679.04	964 / 1048.68

No. of burners in operation	24
Heater Performance Index	0.56
Thermal Efficiency	90.25
Fuel Saving Potential	3.08

Performance Monitors

Individual pass flow above minimum acceptable
Heat pickup in convection section is high – Afterburning Suspected
Radiant coil metal temperature is OK
Burners are OK
Oxygen in firebox OK
Draft in the firebox is OK
Number of burners in operation is OK
Air Flow reported appears erroneous. Check the meter calibration.

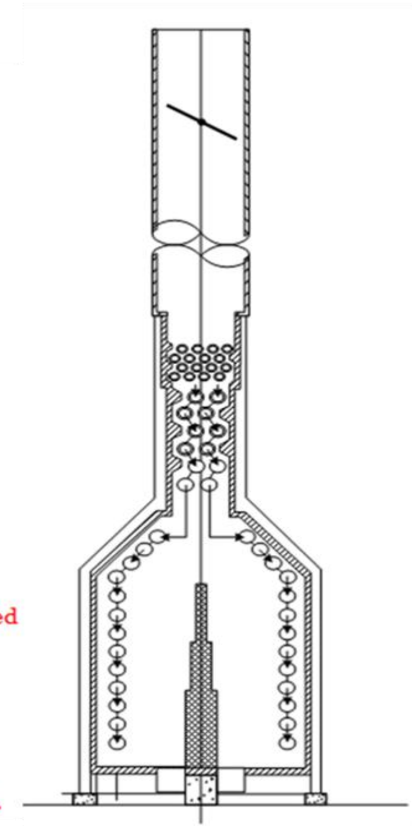


Figure 5. HPI monitor view

message to provided guidelines for the operators (Figure 5).

HPI will analyze the following parameters:
• Tube Metal Temperatures
• Coking inside Tubes
• Burner plugging & Fuel Gas Pressure at Burners
• Draft and Excess Oxygen
• Flow Distribution
• Stack Temperature and Efficiency
• Convection Section Performance
• Fuel Saving Potential

HPI is custom built for each heater based on analysis of heater operating data and modeling. HPI helps increase the run length of heaters by taking corrective action. Any significant deviations of the key process parameters from the desired values are highlighted and can be corrected.

CONCLUSIONS

Improving the efficiency of a fired heater can be done without major modifications. Controlling the draft and excess Oxygen in the fired heater will reduce the fuel consumption and NOx emissions.

I highly recommend the installation of "*The Automatic Control of Draft"* and the use of "*Heater performance Index (HPI)".* Both, hardware and software based controls, will improve the efficiency of your heater, increase the run length and optimize their performance. The payback time for these minor modifications is estimated to be less than 6 months.

ABOUTH THE AUTHOR

Ashutosh Garg has more than 36 years of hands on practical experience in design, engineering and troubleshooting of Fired Heaters. He has also being giving Fired Heaters Training for more than 13 years. He graduated from I.I.T. Kanpur, India in 1974. He worked with KTI India, Engineers India and, KTI Corp in their heater group for almost 20 years. Since 1996, he is leading more than 50 engineers and designers at Furnace Improvements. He is a registered professional engineer and member of AIChE and ASME. He is also a member of API subcommittee on Heat Transfer Equipment. He has published several papers on Fired Heaters in magazines such as Chemical Engineering, Hydrocarbon Processing, International Petroleum Refining and others.

Practical Solar Thermal Chilled Water

K.A. "Bud" Leavell Sales Engineer Yazaki Energy Systems Inc. Plano, Texas

ABSTRACT

With the pressing need for the United States to reduce our dependence upon fossil fuels, it has become a national priority to develop technologies that allow practical use of renewable energy sources.

One such energy source is sunlight. It has the potential to impact America's use of non-renewable energy beyond its own design capacity by applying it to the optimization of an existing building's system. Solar-thermal chilling systems are not new. However, few of them can be described as a practical success. The primary reason for these disappointments is a misunderstanding of solar energy dynamics by air conditioning designers; combined with a similar misunderstanding by solar engineers of how thermally driven chillers react to the loads and energy sources applied to them. With this in mind, a modeling tool has been developed which provides the flexibility to apply a strategy which can be termed, "Optimization by Design".

THE CURRENT STATE OF SOLAR THERMAL CHILLING SYSTEMS IN THE US.

As of January 2010, there are about 22 solar thermal chilling systems installed in North America. Of these, only a handful can be said to be providing a useful function. The majority are in place for research, or as a showcase, while never realizing system potential. Yet the interest in the possibilities of this technology is growing rapidly. The simple prospect of having the sun do for free what we have traditionally paid hard cash for is very compelling. Add to that, the changing political climate, driving State and Federal Governments to offer cash and tax incentives and now the demand for engineers to evaluate the potential of this technology in various applications is tremendous. If the technology can be made practical, especially from a financial point of view, the impact can be significant.

So what is wrong with those few systems installed in North America? If we are going to make these systems practical, it is imperative that we understand what motivated the installation, how it was designed and implemented and why certain design practices were followed, especially on those less successful systems. What was discovered from an examination of many of these systems was a disconnect between the two different disciplines involved in this technology. While air conditioning designers were competent and comfortable with hydronic cooling, plumbing, building loads and chilled water in general, they seem to have a misunderstanding of solar energy dynamics. When combined with a similar misunderstanding by solar engineers of how thermally driven chillers react to the loads and energy sources applied to them, you have the recipe for a very expensive system incapable of performing satisfactorily. Among the issues observed have been grossly underpowered systems, inadequate and incorrect control strategies, and a lack of critical safety devices.

Another obvious shortcoming was the application of too small an amount of common sense, and an inaccurate understanding of the technology. Solar Thermal is one area of engineering which is rife with misinformation, yet there is a wealth of accurate information available on the internet for free. It comes from reputable sources including the US Government and third party product evaluation laboratories, not to mention some very good texts. Today there is no reason for a system to be designed in the United States based on other than empirical data.

As an example, the most common problem observed in these systems is their lack of adequate solar energy. The explanation for this turned out to be very simple, it is caused by the disconnect between air conditioning disciplines and solar thermal disciplines. Traditionally, the solar thermal guys have used integrated daily solar energy values, which are themselves derived from averages of averages. They also calculate the loads they intend to service in the same way. And for simple loads like domestic hot water, this seems to be adequate. On the other hand, air conditioning loads are very difficult to average over a day, much less over a longer period of time. So how do you adequately match the load with the energy source? Following these methods, you are bound to find yourself under powered. Looking at it from the other side, the air conditioning engineer designs for extremes, also termed "design conditions". When designing a chilled water system to meet the 1% design condition, which is the only logical way to insure that the load is met satisfactorily, you may still lack the data needed to determine how much solar energy is available during those extremes. Once again, the system ends up grossly underpowered. So far, only one of the systems evaluated seems to be over-powered, and only one system appears to be adequately powered that is still operating. And it is a derated system.

One other issue which has contributed to this shortfall of energy is the application of the absorption process to solar thermal energy. Even if we adequately determine the load, and accurately estimate the energy available over the course of an average of average days, we are likely to find the chiller short of power. Simply because an absorption chiller's Coefficient of Performance is affected by both the temperature of the heat medium, (the energy source) and the temperature of the cooling water (the condenser loop). If we size based on the daily average load and the daily average solar energy, we will find that the energy available around noon is greater than the energy demand of the chiller. This results in the heat medium fluid temperature in the buffer tank increasing. This is what we want. Store the energy for use later. The only trouble is, the increased temperature in the tank, increases the amount of work the chiller can perform, while at the same time reducing the COP of the chiller. Later in the afternoon as the solar energy is decreasing and the building load is increasing, the engineer discovers too late that he has less energy stored than he thought. The result is an inadequately powered chiller when you need it the most.

So how do we remedy these shortcomings? Utilizing a recently developed modeling template in a step by step process, the engineer can adequately size the energy source and buffer storage, position the collector array for best performance and evaluate the predicted output, including the financial benefits of the application.

STEP 1. EXPLICITY DEFINE THE EXPECTATION.

We need to start with a clear definition of what we expect the sun to do for us. There are a lot of opportunities for increasing the energy efficiency of a building HVAC system. Solar provides a lot of possibilities limited only by the engineer's imagination and the economics of the individual application. In looking for the place where we can have the most effect, the low hanging fruit would be those applications where we can get more savings out of the investment, than the capacity of the invested system. If we can find a way to get greater than 40% reduction in electric use, by correctly applying solar energy to 25% of the load, then we will have achieved an exponential savings. This is possible in at least two scenarios where the physics of an existing process is optimized by strategically applying the energy from the sun.

Since many commercial buildings have existing chilled water systems, and since virtually all chillers have a COP (Coefficient of Performance) which improves as the load on the system decreases, then we have an opportunity to use solar energy in a peak shaving configuration to gain just such savings. Figure 1 is a graph of the power curve of a popular water cooled screw chiller. A close examination shows that if we can keep this screw chiller running between 25% and 75% of full capacity then the electric demand per ton of chilled water is at its most advantageous point.

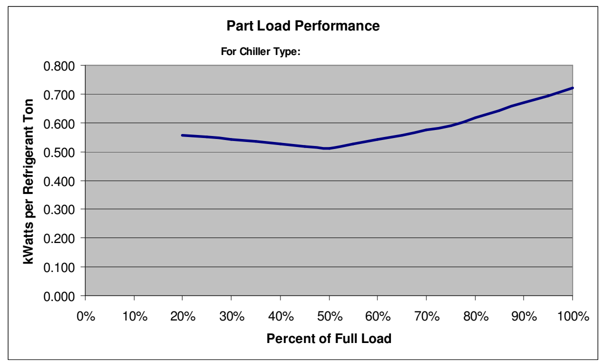


Figure 1

Figure 2 illustrates the financial effect of part load operation on this same chiller. Notice that at 100% capacity, the COP is 4.88. So for every 1 kW of electric energy applied, the chiller does 4.88kW of work. This is actually quite good. But reduce the load to 75% of capacity and that COP increases by another 21%. So the expectation for this example application will be to keep this existing screw chiller from exceeding 75% of full capacity while the sun is shining. This will provide an absolute reduction in power required to air condition the building during the peak period of about 25%. Plus, we will realize an additional savings for the remaining portion of the load through the increased COP of the chiller. It should not be unexpected to realize an electric consumption reduction of over 40% during these peak periods.

The method we will use is a sidestream configuration where the solar driven absorption chiller is pre-cooling a portion of the return chilled water. By reducing the temperature of the chilled water returning to the electric chiller, it will then unload as the solar system is reducing the work it is expected to do. See figure 3.

	100% Cap	75% Cap	
COP	4.88	5.91	21%
Input KW elec	105.1		
Output kW cooling	513.2		
KW electric / Ton	0.720228	0.595	
Cost per KW	$0.1266		
Cost per Ton Hour	$0.0912	$0.0753	-$0.0159

Figure 2

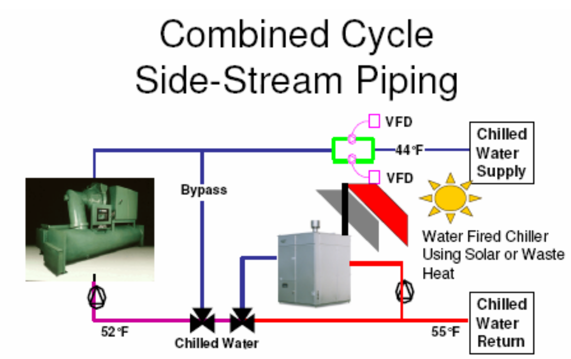


Figure 3.

Anytime the load is smaller than 25% of the electric chillers full capacity, and the sun is shining, we can completely stop the electric chiller. The VFD (Variable Frequency Drive), in the chilled water loop must have a lower limit of the flow rate for the absorption chiller and a maximum rate of 100% of the load capacity.

Another advantage to this type of configuration is in the capital cost savings. Since the building already has an airside system with chilled water, we can ignore that portion of the system when calculating the costs. And there is no need to supply a back-up heat source for when the sun is bashful or sleeping, since the building is already equipped with a chilled water system sized for 100% capacity.

STEP2. HOW MUCH SUN DO WE HAVE?

There are a number of factors affecting the intensity and duration of solar radiation available to power our system. Among these factors are latitude, air pollution (especially ozone and particulates), atmospheric moisture content, cloud cover, frequency and duration of precipitation. Other factors which must be considered are the ambient dry bulb and wet bulb temperatures. The intensity of the solar radiation and the dry bulb temperature are required to estimate the heat production of the collector(s). The wet bulb temperature is required not only for sizing the cooling tower, but also for estimating the temperature of the water leaving the tower as this affects both the chilled water output and the volume of heat input to the chiller.

It is far better to size a solar array for a chilled water system by using hourly solar and meteorological data than attempting to use daily integrated values. There are several weaknesses with the daily data. The first is knowing how many hours per day the integrated data covers. Even if you know how many hours it covers, that doesn't guarantee that your collector array will be able to collect heat for the entire period. It probably cannot - due to the angle of the sunlight to the collector aperture. So, how can you then estimate the average hourly solar intensity since the total daily amount available is in question. Secondly, it is impossible to get a single dry bulb temperature and solar intensity that adequately represents the average value during the entire day. You will inevitably get one or both values such that you are either overestimating or underestimating the output of the collector. The observed tendency is that the output of the collector array is overestimated resulting in many of the existing North American solar chillers being grossly underpowered.

If on the other hand, you use hourly data, the anticipated load on the chiller during a given time period may be compared to the expected heat output from the collectors during that same period. This will allow for a more precise method of sizing the collector array and buffer storage tank.

Calculating collector output is one area that is rife with misinformation. There is much oversimplification in the marketing materials of some equipment manufacturers that lead the engineer to make performance calculations based on solar and meteorological conditions which do not exist in the real world. This of course is completely unnecessary as data describing real world conditions in the United States is readily available.

The source for this hourly data in the United States and its territories is the National Solar Radiation Database. If you are outside of the US or its territories and your government does not have this data available, you will need to model it from the daily average data available from NASA. Don't forget that you need solar irradiance, plus dry bulb and wet bulb. Often when using data from somewhere other than the National Solar Radiation Database you will only get the data in 3 hour averages. You will need to interpolate this data in order to get a reasonable approximation of the actual hourly conditions. And if you are modeling your own data, you must differentiate between “Direct” or Beam” radiation, and diffuse. Normally, this daily data is described as Global Normal, or Global Means. This is a combination of Beam and Diffuse and you will have to separate them. The data from the NSRDB is already broken out as Global Means and Diffuse. Beam radiation is then calculated by subtracting diffuse from global.

The National Renewable Energy Labs has been collecting solar and meteorological data since 1961. It covers approximately 1440 locations within the US and its territories. A portion of those locations are actually measured data. The remaining locations are modeled based on the measured data. We are interested in both the Hourly Statistical Summaries which show the hourly average insolation, and the Typical Meteorological Year data. This data may be accessed for free from:

http://rredc.nrel.gov/solar/old_data/nsrdb/

The Hourly Statistical Summaries will provide a monthly average of solar energy falling on a horizontal plane in Watts per square meter for the hour ending at the indicated time. So for January, the 1300 hours data will be the average of every day in January of the irradiance falling on the ground between 1200 hours and 1300 hours in Watt hours per square meter. This data is given for global horizontal, horizontal diffuse, and direct or beam radiation. This data is also available for each of 15 years. You should download all 15 years and then average them. The modeling template will do the averaging for you.

Typical Meteorological Year data (TMY3 files) provides multiple measurements on an hourly basis for both the sunlight and the meteorological data. It is based on a 30 year period of time, and chooses for each month, that month from the 30 year period of time that is statistically the most typical. You are likely to find that you have a different year chosen for each of the 12 months of the “Typical Meteorological Year”. Since there are differences from one year to the next, some smoothing is done on the transition days between these months. The modeling template will give you a choice of using either the 15 year average or the TMY3 data for the solar energy, and goes to the TMY3 data for all dry bulb and relative humidity values.

We will also want to download some daily integrated data from NASA. We will use this for the purpose of determining the most advantageous initial tilt angle for the collector array. To retrieve this data, visit:

http://eosweb.larc.nasa.gov/sse/

Tilt of the collector is defined as that angle from the ground to the collector on the side of the collector away from the equator, (figure 4).

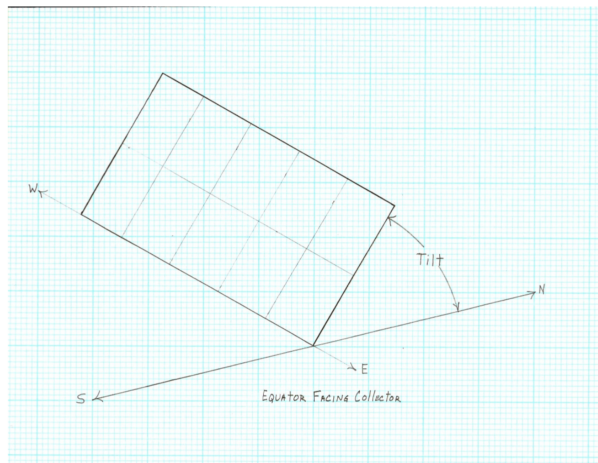


Figure 4.

Tilt angle can have a profound effect on the amount of energy delivered to the aperture surface of the collector. The data which we will be using is that sunlight which is falling on the horizontal surface of the ground. Tilting the collector to the point where it is normal to the sun (perpendicular to the sun’s rays) will increase the amount of sunlight to which the collector aperture area is exposed. Figure 5 illustrates the difference.

In the case that the collector is normal to the sun, we take the amount of sunlight falling on a horizontal surface, Ih and divide it by the cosine of the solar zenith angle θz. The collector will rarely be normal to the sun. So any angle of incidence that the sun has to the collector will have a similar but opposite effect. In that case, we will now calculate the actual sunlight by first multiplying the horizontal radiation by the cosine of the solar angle of incidence to the collector θ, and then dividing by the cosine of the solar zenith angle θz. All of this is done automatically in the modeling template.

$$I = Ih \times \cos\theta / \cos\theta z$$

Equation (1)

where:
I = insolation on the tilted collector
Ih = insolation on the horizontal surface
Θ = solar angle of incidence to the collector
Θz = solar zenith angle

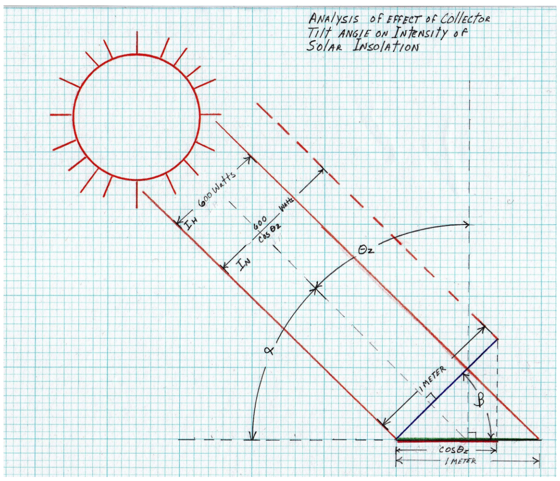


Figure 5.

Now examining a graph of the daily integrated data from NASA, figure 6 presented as the Insolation on a collector at 4 different tilt angles, we can determine the best starting tilt angle for our application.

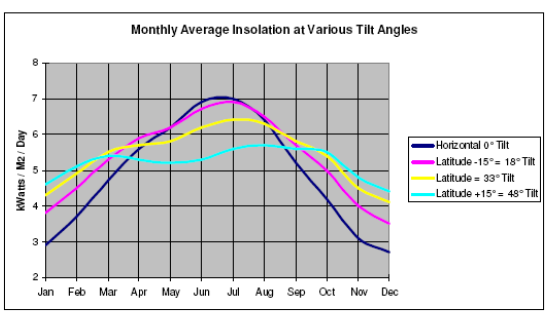


Figure 6.

We see that the line representing a tilt of 18° or Latitude - 15° provides us the best overall starting tilt angle for an application that is more interested in air conditioning during the months April through September than any other angle. If on the other hand, our application was for dehumidification and we needed to accomplish that during the winter months as well as the summer months, we might opt for Latitude + 15° instead. Overall, in North America, Latitude - 15° seems to work best for air conditioning. This is the only use we will make of daily integrated values of solar data. Everything else will be done with hourly data.

STEP 3. WHAT TYPE OF COLLECTOR?

Now we need to select the most appropriate collector for our application. The key here is remaining focused on the application. This modeling tool recognizes only 2 types of collectors. Those are the flat panel and evacuated tube collectors. Since this tool is designed around single effect low temperature water fired chillers, high heat medium temperatures are not required. What is required is a high volume of heat. For instance, a 30 Refrigerant Ton Chiller at rated conditions will require 512MBtuh input hot water to produce 30 Refrigerant Tons. It will in fact produce greater than 30 Refrigerant Tons if the heat input is increased. With this in mind, we need to find the most cost effective way to get heat into the chiller when it is required or can be utilized.

The primary differences between flat panel and evacuated tube collectors lies in their loss profile, ratio of aperture area to gross area, and incidence angle modifier. The choice of one type of collector over the other is dependent on multiple factors. Cost is always one of them. Perhaps available roof space, or the existence of large quantities of snow should be considered. The application's needs must be paramount. If the collector array choice brings more negatives than it does positives, then the system implemented could easily turn out useless.

There are two variables which primarily affect the efficiency of these collectors. The 1st and greatest effect is the temperature difference between the outdoor ambient and the average temperature of the heat medium fluid in the collector. The greater this ΔT is, the greater the thermal energy losses, and the lower the efficiency of the collector. Evacuated tubes have a significant advantage here, as they essentially have the heat collection medium sealed up in a thermos bottle. But, this can turn into a serious disadvantage in locations with a large amount of snow. Due to their inherently low losses, it is very easy for evacuated tubes to be rendered useless by snow cover. On the other hand, the losses of flat panel collectors can effectively keep the snow cleared away, providing solar contribution when evacuated tubes would be buried in the snow. Evacuated tubes are most often designed using heat pipe technology. This brings the advantage of lower losses through emission, but also forces them into a minimum tilt angle, which may prove a disadvantage in the tropics.

The second variable is the intensity of the sunlight. The brighter the sunlight, the more efficiently it can convert the sunlight into heat. This is more related to the heat absorption mechanism and neither type of collector necessarily has an advantage over the other on this one.

Flat panel collectors have a greater aperture area to gross area ratio than evacuated tube collectors. With a flat panel, a very large proportion of the area within the frame is absorption material. While with the evacuated tubes, only the tubes themselves represent the aperture area. There is a space between the tubes where the sunlight passes straight through. This means there is less sunlight striking the working surface of the array resulting in less sunlight being converted into heat for an equivalent gross collector area.

When the collectors are lab tested, the results are converted into a quadratic efficiency equation which represents the performance of the collectors relative to the two primary variables which affect them. One is the intensity of the sunlight and the other is the ΔT (temperature difference between the fluid in the collector and the outdoor ambient). This modeling tool utilizes these empirically derived efficiency equations to simulate the performance of the collectors. There are two agencies doing independent performance testing on these collectors. In the US it is the Solar Radiation Certification Corporation, (SRCC) and in Europe, Solar Keymark. This modeling tool will recognize the performance data from both of these agencies with one caveat. In North America, all performance data is based on the gross area of the collector, where in Europe, it is based on the aperture area. This modeling tool is set to display results in gross area. However, if you enter the Solar Keymark data into this system using the aperture area, then the system will still calculate the required number of collectors, but the display showing gross area should be interpreted as aperture area instead.

There is significant disagreement among many in the solar thermal industry as to the appropriateness of using gross collector area as the basis for collector efficiency. For one thing, it makes the efficiency of some collectors appear far lower than they would be if aperture area is chosen. But using gross area vs. aperture area has absolutely no impact on the number of collectors used, nor does it affect in any way the amount of roof space required. And after all, what we need to know when sizing the collector array is how many collectors are needed, how much roof area is required and how much spacing is needed between rows to prevent shading.

In the southern latitudes, flat panel collectors will require less roof space than evacuated tubes. In the northern latitudes, that can be just the opposite due to the greater ΔT. Flat panel collectors will provide more shading on the roof, but may in turn place a greater structural load on the building.

Finally, the Incidence Angle Modifier can have a profound effect on the amount of energy collected. When the collector is normal to the sun, virtually 100% of the direct solar radiation is captured by the panel. Although some is lost and some re-radiated, none is reflected back into space. However, as the sun's angle of incidence advances either side of normal, a portion of that solar radiation is reflected back into space by the glazing of the panel. A bi-axial tracking array would eliminate that effect. With any fixed array, we must take the angle of incidence into account. For a glazed flat panel, calculating the angle of incidence and its effect, is quite simple.

Not quite so simple with an evacuated tube collector. Here there are two separate Incidence Angles we must deal with. First is the longitudinal incidence angle. This is the way the sunlight strikes the tube lengthwise and is normally calculated from the sun's altitude angle. The second is the transverse angle of incidence. This is the way the sunlight appears to the tubes as the sun's azimuth changes relative to the collector. As the collector is normal to the sun, the spacing between the tubes is most pronounced. But, as the sun moves laterally, the spacing between the tubes as seen from the sun decreases. This has the effect of increasing the ratio of aperture area to gross area. Graphing the heat output from these two different collectors shows that a flat panel collector's output is bell shaped. While the evacuated tube collector's output is much flatter. The evacuated tube collector will have the advantage of greater output both earlier and later in the day. See figures 9 and 10 respectively for a graph of the collector heat output from a flat panel and an evacuated tube collector.

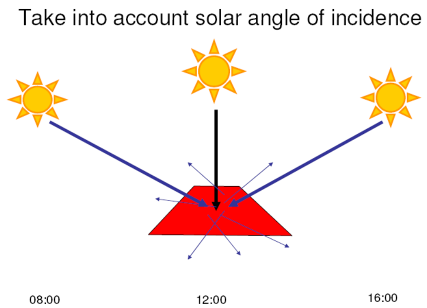


Figure 7. Solar Incidence Angle on a flat panel

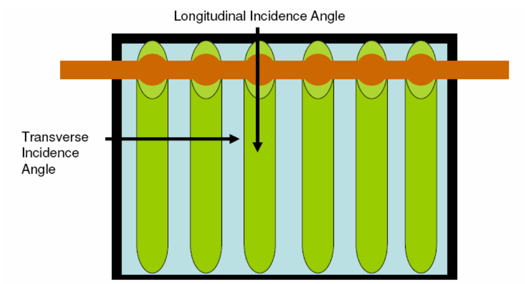


Figure 8. Incidence angles on an Evacuated. Tube

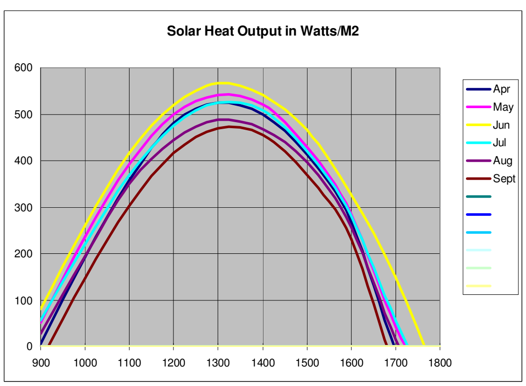


Figure 9.

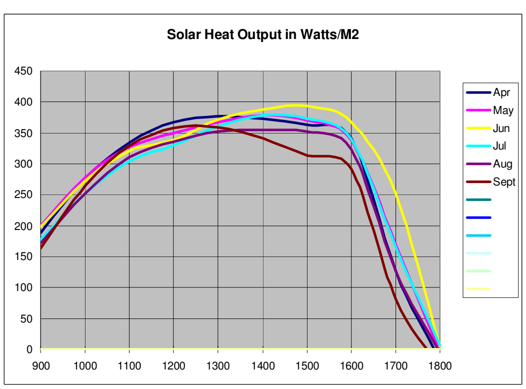


Figure 10.

In order to accurately size the collector array, we need to be able to calculate the output of the collectors at a given time of day. To accomplish this, we need to know the outdoor ambient temperature, the intensity of the sunlight and the position of the sun in the sky. This template does that for us for a select day each month. You should decide what day of any given month is the best representation of the month for your application and then enter those dates in the Solar Geometry tab. The default dates in this template represent the day which has extraterrestrial radiation closest to the average for the month as determined by Klein (1976).

This template does not take into account the apparent changes in solar position due to refraction through the atmosphere. Those are most pronounced much later in the day anyway and would have very little effect on our model.

Figure 11 shows where to expect the sun in the sky at this given location in March. The X axis depicts the solar azimuth angle, where 0° is due south (in the northern hemisphere), a negative azimuth is east of south and a positive azimuth is west of south. The Y axis represents the solar altitude angle. The altitude angle is equal to 90° minus the solar zenith angle. The solar zenith angle represents the angle of the sun relative to horizontal.

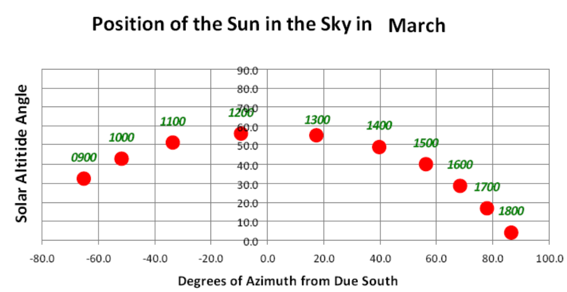


Figure 11.

No two collectors from different manufacturers are the same, and due to advances in collector technology, "Rules of Thumb" will no longer be adequate. Fortunately, there is plenty of empirical data describing the performance of the majority of those collectors currently marketed in the United States and Europe. There is provision in the template to enter efficiency equations for up to 48 different collectors. And there is provision in the template to compare the efficiencies and Incidence Angle Modifiers of these collectors to enable an intelligent selection of the most appropriate collector for your application. Figure 12 depicts the efficiency of a flat panel collector. The X axis show the ΔT (temperature difference between the fluid in the collector and the outdoor ambient), while the Y axis reflects the actual efficiency of the collector. If 100% of the sunlight is transferred to the fluid as heat, then the efficiency is

1.0. The variable η0 is defined as the zero loss efficiency, or how much sunlight is transferred to the fluid as heat with no losses from temperature differential, (0°ΔT). At zero loss efficiency, this collector converts about 77% of the sunlight striking the gross area of the collector into heat. Notice how the efficiency decreases as the ΔT increases.

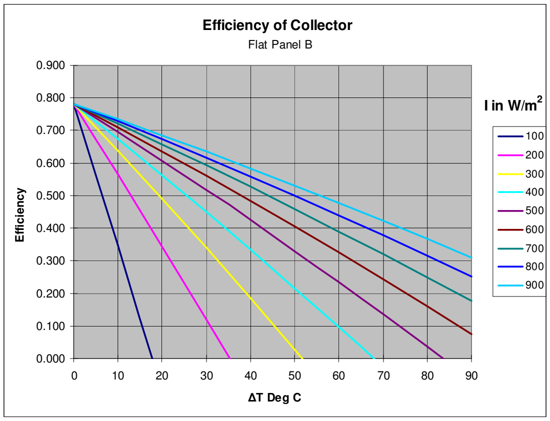


Figure 12.

As you can see, this graph displays a different slope for each of 9 different intensities of Insolation, (I). For an insolation intensity of 500 Watts/m^2 and a ΔT of 50°C, look where the purple line crosses the 50°C vertical grid line. Now looking across to the Y axis, you can see that this particular flat panel collector will convert about 33% of the 500 Watts into heat in the fluid. But at an Insolation level of 300Watts/m^2, this particular collector is virtually useless at a ΔT of 50°C.

Now refer to figure 13 to compare this collector with an evacuated tube collector. The first obvious observation is the apparently low zero loss efficiency. This collector only converts about 41% of the sunlight striking the gross area of the collector into heat. This difference is due to the much lower aperture area to gross area ratio. But notice that at a ΔT of 50°C, the collector still produces a good deal of energy at an Insolation intensity of 300 Watts/ m^2. It becomes obvious that this type of collector will provide more hours of contribution, while at the same time, requiring more gross area during the hours of peak Insolation.

We next want to compare the Incidence Angle Modifier (IAM) for these two types of collectors. Once we have the efficiency for our sizing conditions, we will compute the IAM, and multiply the efficiency by the IAM(s). As you can see from figure 14, the IAM for the flat panel begins to drop off at a fairly steady rate to the point where the panel losses are compounded above 60°. Figure 15 shows the IAMs for the evacuated tube collector. The longitudinal IAM is very similar to the IAM for the flat panel. But notice how the Transverse IAM seems to provide a gain in efficiency! This combination of low thermal losses with the Transverse IAM is what causes the flatter output graph seen in figure 10.

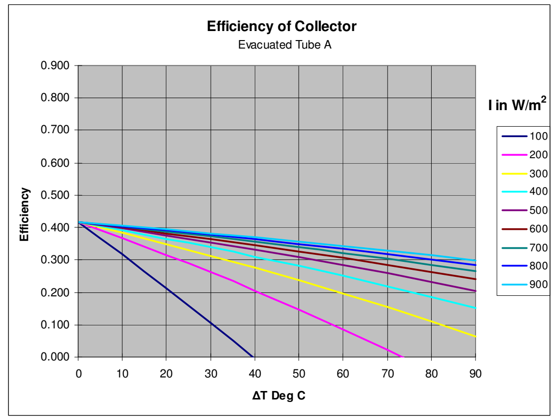


Figure 13.

Which collector strategy you choose should be driven by your application. The objective is to get the most solar contribution for your dollar invested. Since there are many factors which will contribute to this decision, you should use the template as a tool for "What If" calculations in order to make the best overall selection.

One final note on collectors; it is a myth that heat medium temperatures in excess of 200°F are required to drive an absorption chiller. There are single effect absorption chillers on the market which will effectively produce chilled water with heat medium temperatures as low as 158°F. And 175°F seems to be the best compromise between what the collectors can effectively produce and what the chiller can effectively put to work. So you should plan on sizing your collector array to meet the load demand with the solar energy available at that time at 175°F heat medium input. You will also discover from the template that the heat medium temperature often exceeds the 175°F design temperature as the heat input exceeds the chillers capacity. You should also engineer the ΔT of your collector array to match the ΔT of the chiller under your design conditions.

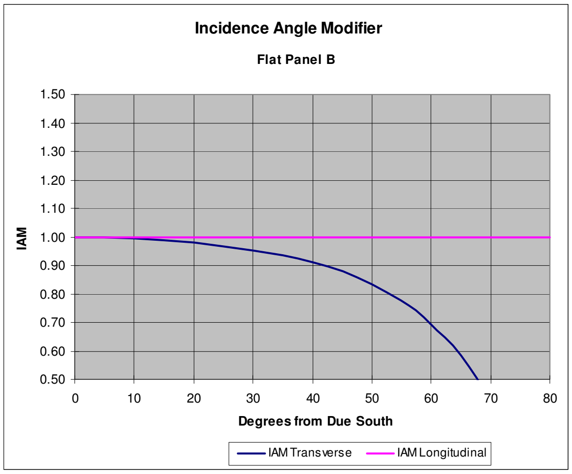


Figure 14.

Heat Output Ho for a flat panel collector:

$$Ho = (\eta 0 + a1\Delta T / I + a2(\Delta T)^2 / I) \times IAM$$

Equation (2)

Heat Output Ho for an evacuated tube collector:

$$Ho = (\eta 0 + a1\Delta T / I + a2(\Delta T)^2 / I) \times IAML \times IAMT$$

Equation (3)

where:
a1 and a2 are provided by the testing agency. They are usually, but not always negative values and must be entered into the template as signed values.
η0 is the zero loss efficiency supplied by the testing agency.
ΔT is the difference in temperature between the fluid entering the collector and the outdoor ambient,

**Make certain that you choose the proper constants. The SRCC displays the equations for both SI and IP units. The template uses the SI units for these calculations.*

IAML is the longitudinal Incidence Angle Modifier
IAMT is the transverse Incidence Angle Modifier

IAM and IAMT are normally represented as Kα and are a quadratic equation and IAML is a first order equation from SRCC. But with Solar Keymark, you normally get a table of values. You can either calculate based on these values, or use a spreadsheet to create the quadratic equation from the table and then use those values in the template.

$$K\alpha = 1 + b1(1/\cos\theta - 1) + b2(1/\cos\theta - 1)^2$$

Equation (4)

$$IAML = 1 + b3(1/\cos\theta - 1)$$

Equation (5)

Where:
b1, b2 and b3 are signed values supplied by the SRCC.
Θ is the angle of incidence.

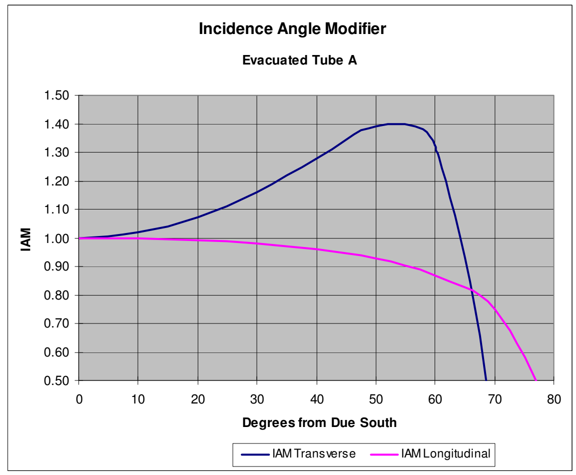


Figure 15.

STEP 4. CHOOSE OPTIMUM COLLECTOR AZIMUTH.

So which direction should we point the collector array? It is not necessarily true that the collector should be pointed directly south. Unless the array is a bi-axial tracking array, there will be a limited number of sunlight hours during which your collectors can effectively capture energy. So it is first necessary to decide whether we need morning sun, midday sun, or afternoon sun. For our example application, optimizing an existing chilled water plant by peak shaving, it is logical to target afternoon sun. Let's start by comparing the available sunlight with the peak temperatures. Figure 16 shows the Insolation available on an hour by hour basis, while figure 17 shows the typical outdoor ambient temperature on the same hour by hour basis.

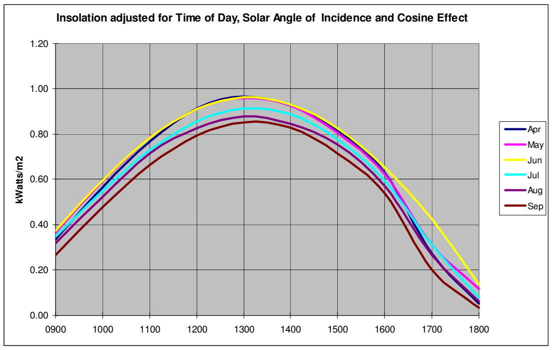


Figure 16.

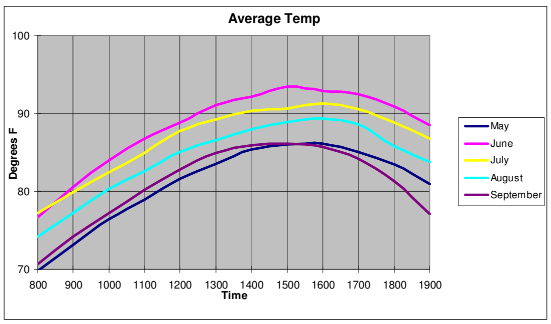


Figure 17.

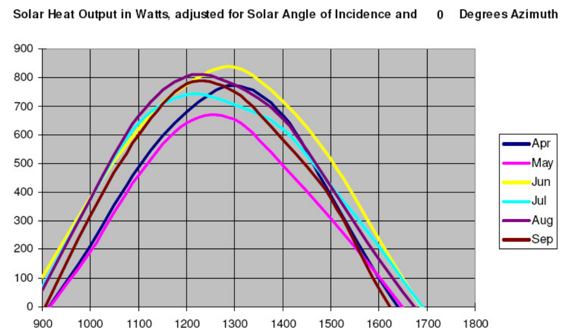


Figure 18.

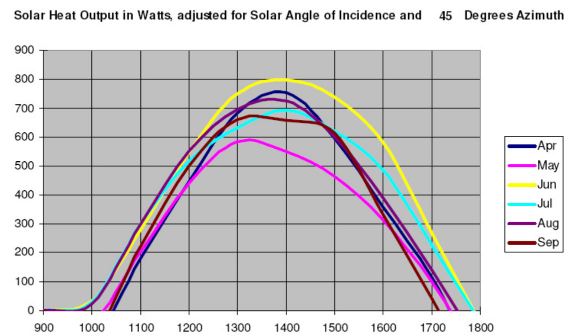


Figure 19.

As you can see, maximum solar energy appears around solar noon, at this location, just slightly past 12:00PM, while the warmest outdoor temperatures occur between 3:00 and 4:00PM. And the peak load on the building will probably lag the peak outdoor temperature by yet another hour. Since this is an air conditioning application, it is imperative that we provide adequate energy to drive the chiller at the time we need it the most. It appears that the best over all fit for sizing an air conditioning collector array is to meet the design requirements at 3:00PM. This will provide just enough over sizing during the mid day period to have adequate energy stored in the buffer tank for later in the afternoon.

Figure 18 shows the solar energy output from a flat panel array positioned due south. While figure 19 shows the output from the same array facing 45° west of south. If you are able to position the array this far west, you can see a 50% increase in energy available at 3:00pm versus pointing it due south. The tradeoff is in the reduced solar contribution in the morning. Since our application is focused on afternoon peak shaving, we get more value from afternoon sun than from morning sun.

Most of the flat panel collectors will meet this demand with a 45° west of south azimuth, while most of the evacuated tube collectors will provide the best afternoon sun with a 0° to 15° west of south orientation.

STEP 5. SIZE COLLECTOR ARRAY.

It is true that most any glazed flat panel or evacuated tube collector will meet the needs of our application, provided we use enough of them. It is also true that most any collector we want to use will cause us difficulties if we have too many of them. So it is important that we size the collector array in the most appropriate manner and have a strategy for managing the heat.

The solar modeling template will calculate the optimum size of the collector array, (number of selected collectors), for a number of different defined conditions. Once the solar data for your location is entered and selected, and the desired collectors are entered and selected, you can begin to set up your application. Start by choosing the best overall beginning tilt angle. Since we are planning to "Peak Shave" an existing chilled water plant, we will start out with a tilt angle of latitude minus 15°. We will set the array azimuth to 45° west of south for our flat panel or 15° west of south for our chosen evacuated tube. Next we need to set the cooling tower approach. The approach is defined in this template as the difference between the wet bulb temperature and the temperature of the cooling water leaving the tower. The ideal cooling water temperature is 80°F, but that may not be practical to achieve. Use the template to determine what you can live with.

We will next choose the size of chiller, either 10, 20, or 30 Refrigerant Tons and the target capacity of the chiller. And we need to decide the best method and season for sizing. If we choose automatic sizing, the template will average the heat output from the selected collector at the selected time of day over the selected months. For our example application, we will choose automatic sizing at 1500 hours during the months of May through September. The template will then take the amount of heat required for the target capacity, and divide it by the amount of heat output from the selected collector to calculate the number of collectors. The number of collectors required and the needed gross collector area are then displayed. We also have the option of limiting the number of collectors. In that case, the template will calculate the number of collectors required to achieve the stated capacity, with a maximum of the number you set for a limit.

In order to size the collector array to meet the demand, we must establish how much energy is required to drive the chiller, our losses in the heat distribution mechanism, how much solar energy is available on average at the time of our design load, and the physical characteristics of our collectors.

To start, calculate the solar energy available as an output from your collector in terms of Watts/M^2 at the design time for each month during your design season. Then average that output. Divide the energy required for design conditions by this average output to calculate the total gross collector area required to meet design conditions. Then divide the total gross area required by the gross area of the collector.

$$C\# = Hr / (\overline{Ho} \times CAg)$$

Equation (6)

where:
C# = the number of collectors required
Hr = heat required for design conditions in Btuh or (Watts) and don't forget your losses.
$\overline{Ho}$ = average heat output at design time in Btu/ft^2 or (Watts/m^2) during design season.
CAg = Collector gross area in ft^2 (m^2)

The template uses SI units for all of these calculations as the solar and meteorological data is supplied in SI units. The template then converts and displays primarily in IP units. All of the chiller based calculations are then done in IP units.

STEP 6. CALCULATE A HEAT BALANCE.

What comes next is sizing the cooling tower for design conditions. It is imperative that 100% of the heat input to the chiller is rejected. With an absorption chiller, there are 2 sources of heat input. There is of course the load, but since it is a thermally driven chiller there is the power source as well. The heat balance is calculated as:

$$Qc = Qg + Qe$$

Equation (7)

Where:
Qc = heat rejected to the cooling tower
Qg = Heat input to the generator
Qe = Cooling capacity

Since we are talking about a single effect chiller, the COP at rated conditions will be 0.7. That means for every 1,000Btu of chilled water, we must input 1,429Btu of heat to drive the process. Thus we must reject 2,429Btu of heat to the cooling tower. Failure to adequately reject the heat input to the chiller will cause the chiller to perform below expectations and possibly affect its life expectancy. The flow rates for the cooling tower tend to be much higher than for an electric chiller, and are generally fixed. You should plan on having a constant flow rate through the condenser loop regardless of the load, and allow the chiller to control the flow on and off. You will also want to have a strategy in place to maintain a minimum cooling water temperature. Absorbers are rated at one temperature, but often produce higher capacities at a lower temperature. There is typically a temperature below which you will no longer gain capacity but will in fact negatively impact the COP of the chiller. Allowing the chiller to control the fan on the cooling tower will provide some measure of control, but to reach the ideal 80°F cooling water temperature, you will probably want to add a thermostatically controlled mixing valve.

The capacity of the chiller will also change with the temperature of the heat medium. In order to take advantage of this potential extra capacity, the heat balance should be calculated based on the greatest anticipated capacity and heat input. These of course will vary with the changes in solar and meteorological conditions. The template will make those calculations for you.

STEP 7. SIZE THE BUFFER TANK.

You will need some mass of heat medium fluid to smooth out the fluctuations in heat medium temperature and to insure adequate energy to start the chiller at morning start-up. There have been "rules of thumb" used in the past of 1.5 to 2.0 gallons of buffer storage tank for every ft^2 of collector area. These rules are probably not valid any more due to the increases in the efficiency of today's collectors. Instead, you should take advantage of the template's ability to estimate the temperature of the storage medium under differing conditions. It is critically important that you not allow the heat medium temperature to exceed 203°F entering the chiller. This will cause the chiller to shut down, requiring a hard reset to protect from crystallization of the solution. Since the solar and meteorological data are typical, or averages of averages rather than peak conditions, it is very important that you anticipate receiving far more sun from time to time than you can handle. It is probably not a good idea to under-power the chiller to prevent over heating. That may make sense for domestic hot water, but will make for a very unsatisfactory experience with air conditioning.

It is a very good use of this excess heat to supplement domestic hot water, or some other application. You do need to insure there is a place to send 100% of the excess heat whenever it arrives, or else you must have a heat dump! The larger the buffer tank, the less likely you are to dump heat, but do not over size the buffer tank. You will pay a price in both the lost contribution in the early part of the day and in reduced capacity of the chiller due to a reduced temperature of the heat medium. Not to mention the expense of the larger tank. The modeling template will show that the best all around tank size will be somewhere between 8 to 20 minutes of heat medium flow rate.

Do not attempt to oversize the buffer tank with the idea of working for any significant period of time after the sun goes away. In order to support off sun operations, you will need to store excess energy in an adequate volume to operate the chiller. To do that will require that you collect significantly more heat than the chiller can use during periods of sunshine. This will require even more collector area. Significantly more collector area and that expense alone is likely to render the project impractical. If you have a summer day with about 7 hours of collectible sunshine, and you want to run the system for 7 hours after the sun goes down, you will essentially require twice the collector area, plus a little extra to account for the extra losses. Remember that the peak building load occurs later in the day, and tends to continue into the night. So your chiller load does not necessarily drop off immediately when the sun goes down. It will drop off gradually just like it built up.

STEP 8. DEFINE YOUR CONTROL STRATEGY.

Among the items with which we must be concerned, is determining when there is adequate heat to run the chiller, when the cooling water is to be on or off, how to control the temperature of the heat medium fluid and the cooling water, and how to minimize losses when the system is shut down for the night.

To begin with, it is necessary to define a temperature of the heat medium fluid below which you will stop the system. Then, once the system is stopped, you need to thermally isolate the buffer tank from the chiller and most importantly from the collector array. Experience has shown that unless the buffer is isolated, you will lose 60% or more of the heat in the tank over night, even with the pumps off. Thermal siphoning will literally suck the heat right out of your tank.

Then, come morning, you will find that the mass of fluid in the collectors and distribution piping will be at ambient temperature. This mass will be significant and might even be greater than the mass in your buffer tank. It is extremely important that you not start pumping this fluid into the buffer tank until it is at a higher temperature than the fluid in the tank.

So with the distribution and collector array isolated from the tank, establish a process where you can determine if there is adequate sunlight to begin heating water. One way you might choose to do that would be with a solar PV collector at the same tilt angle and azimuth as the solar thermal array. Connect this PV to the control system and use it to measure the sunlight. Once an adequate amount of solar energy is striking the array as measured by the solar P.V. device, have the control system turn on the fluid pump and begin circulating the fluid through the pipes and array only. (Many of the solar thermal collector manufacturers already have this capability available as an option). Monitor the temperature in the tank and the distribution lines. Once the temperature of the fluid circulating through the array and pipes reaches 1 degree higher than the tank, open the valves to the buffer tank and begin charging it.

Once the temperature of the fluid in the tank reaches the predetermined chiller start temperature (this should be much higher than the chiller stop temperature), turn on the system and start the chiller. (The reason for the higher start temperature is that the chiller at first start will take a great deal more energy until it gets balanced and will return a ΔT on the heat medium much greater than the design ΔT , resulting in the chiller bouncing on and off). Further, the chiller must be able to control the flow of heat medium fluid into the chiller to prevent the absorbent from precipitating out of the solution as salt. You must not continue the flow of hot water into the chiller if it has no call for cooling. This is critical. So you should have the chiller control this flow. Simply tell the chiller when it is to operate and allow the chiller to control those flows.

Finally, as mentioned above, there should be some means of relieving excess heat from the collector array. The best way to do this is with some kind of thermostatically controlled heat dump, located between the collector array and the buffer storage. It is best to locate the heat dump here to protect the collector array as well as the chiller. The last thing you want to do is damage the collectors by stagnating them. They are the single most expensive component of the system. Figure 20 shows how the hot water side of the system interfaces to the chiller.

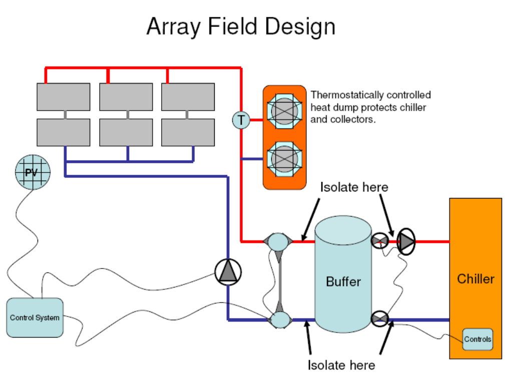


Figure 20.

For the chilled water side, figure 21 presents a representative diagram. If this system is to be the primary chilled water plant for the facility, an auxiliary boiler will be required. Should you place an auxiliary boiler into the system, it is imperative that you NOT attempt to operate the solar heat source and the boiler simultaneously! Use one or the other, but not both at the same time. This will at the very least result in the boiler bouncing on and off, but most likely will result in the boiler providing 100% of the heat to the chiller and eventual damage to the solar array due to stagnation. Depending on the type and design of your collector array, you will also very likely find a large volume of the heat from the boiler being lost through the collector array by emission.

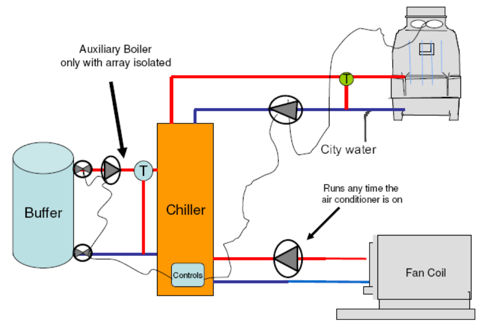


Figure 21.

STEP 9. EVALUATE ANTICIPATED (MODELED) SYSTEM PERFORMANCE.

The template will provide a graph of the anticipated output in Refrigerant Tons of chilled water on an hour by hour basis for the average day of each month. This data may now be used as the basis of test for your "what if" choices. Figure 22 shows a representative output from a 10 Ton chiller with flat panel collectors, pointed 45° west of south at an 18° Tilt and a 10°F cooling tower approach. This makes it easy to examine the impact of multiple "what if" scenarios. Among them are changes to the type of collector, orientation, cooling tower size, glycol solutions etc.

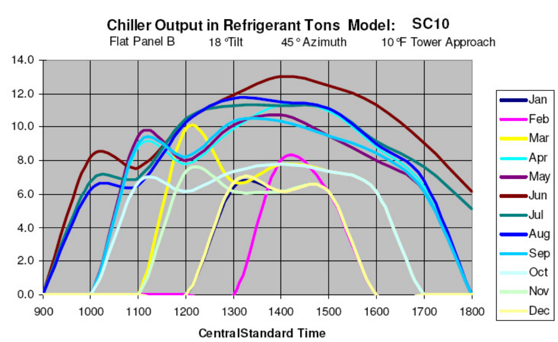


Figure 22.

Once we have settled on a basic design as expressed above, we should evaluate the systems impact on the existing installation to determine if it meets our specified design criteria. For instance, we determined at the beginning of the process that we were going to keep the existing chilled water plant running at or below 75% of full capacity. To do this, we will need to know what the existing chiller's performance curve looks like, as well as the building load hour by hour. The template provides the basic framework around which this may be built. It also includes a number of graphs which can be used to confirm that your defined goals for system COP, carbon footprint reduction, electric consumption and cost reduction were realized. It must be emphasized that this is a template, and not a completed tool for the simple reason that no two of these installations will be identical. Therefore, it should be expected that the template will be modified by the engineer to meet his anticipated application.

Figures 23 and 24 demonstrate from the template that our stated goals of maintaining the existing chiller at 75% or less of full load is met and that the system COP is improved by more than the 25% of the load we are taking with the solar system.

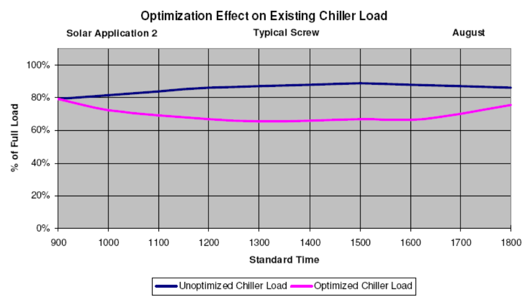


Figure 23.

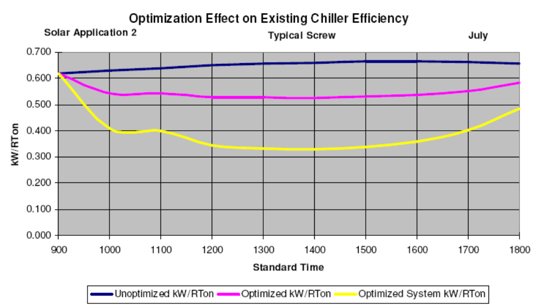


Figure 24.

STEP 10. SHADE AVOIDANCE.

This step is taken last as the final step in engineering the system, only because the template does nothing from a performance evaluation point based on shade prevention. Of course if the collector is shaded, it is not gathering energy from the sun. So the last item is to determine the minimum spacing required from an obstruction such as a parapet, adjacent building, trees etc., and of course the minimum spacing required between rows of collectors to keep them from shading one another. Figure 25 illustrates the process.

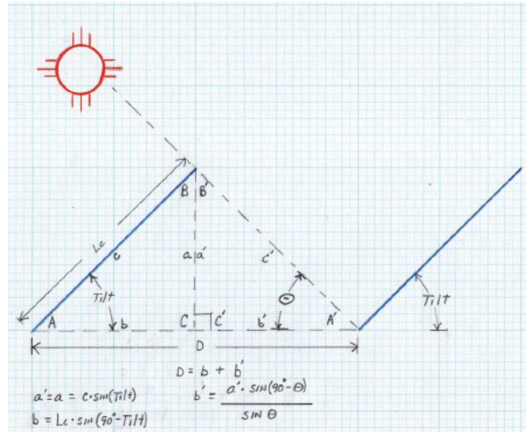


Figure 25.

Shade avoidance is the simple application of the Law of Sines as illustrated above. It is important to keep in mind that the azimuth of the sun changes as the day wears on and so the calculations must prevent shading of an eastern laying collector from a panel to the southwest of it. This worksheet takes into consideration the altitude and azimuth of the sun and the azimuth of the collector array at 2:00PM standard time for collectors pointed west of south, and at 10:00AM for collectors pointed east of south.

To calculate the spacing required, you will need to know the length of the collector, and the sun's azimuth and altitude angles on the day which you define as the shortest day of the year for your calculations. Normally, you would select December 21st as the shortest day of the year. But if you do not care about solar energy during the winter, you may prefer to keep the spacing minimized in order to maximize the shading on the roof. So perhaps April 15th is more appropriate for your application.

The spacing between the rows of collectors is as follows:

$$D = b + b' \quad \text{Equation (8)}$$

$$b = Lc\sin(90° - Tilt) \quad \text{Equation (8.1)}$$

$$b' = a'\sin(90° - \theta)/\sin\theta \quad \text{Equation (8.2)}$$

$$a' = Lc\sin(Tilt) \quad \text{Equation (8.3)}$$

Where:
D = distance between leading edge of the rows of collectors
Lc = length of collector
Tilt = the collector tilt angle from horizontal
Θ = solar altitude angle
a' = height of the collector as a function of tilt angle

You may want to perform this step much earlier in the process to insure that you have adequate space for your collector array. The calculations done for the amount of collector gross area do not take this minimum spacing into account and therefore do not reflect completely the amount of roof space (or other area) required to accomplish the desired mission. So don't forget this step.

Conclusion.

The application of common sense engineering principles, along with the use of this template, will provide the best chance of designing a solar thermal powered chilled water system with a financial payback and an end user satisfied with the installation. It is not necessary to design around very high heat medium temperatures, or to have complex design strategies. It is important to take a realistic approach to how much contribution can be made with the sun, and to minimize the initial investment as much as practical. However, it is best to minimize the recurring costs while at the same time maintaining simplicity as a key design component. Avoid the temptation to store heat for use when the sun is unavailable, and instead size the array to match the load at the time the load is greatest. This will insure a satisfactory installation that provides decades of trouble free operation.

References:

1. "Active Solar Heating Systems Design Manual", ASHRAE pub 1988

2. ASHRAE Handbook, Fundamentals 2001

3. ASHRAE Handbook, HVAC Applications 1999

4. ASHRAE STANDARD 93-77 "Methods of Testing to Determine the Thermal Performance of Solar Collectors", corrected printing, 1978

5. "Basics of Refrigerant Chillers", Vincent Schraida, P.E. featured article in "Engineered Systems" December 1, 2008

6. "DIRECTORY OF SRCC CERTIFIED SOLAR COLLECTOR RATINGS", Solar Rating Certification Corporation, January 21, 2009

7. National Solar Radiation Database 1991–2005 Update: "User's Manual", *Technical Report* NREL/TP-581-41364 April 2007

8. "Optimized Design of Hot Water Storage in Solar Thermal Cooling Facilities", R. Salgado, P. Rodriquez, M. Venegas, A. Lecuona, M.C. Rodriquez, ITEA Research Group, Universidad Carlos III de Madrid.

9. "Power From The Sun", by William B. Stine and Michael Geyer copyright © 2001 by William B. Stine and Michael Geyer, www.powerfromthesun.net

10. "Solar Energy", S.A. Klein, 1977 as quoted by Duffie Beckman.

11. "Solar Engineering of Thermal Processes", John A. Duffie, William A. Beckman, John Wiley & Sons Inc., 3rd Edition 2006

12. "Solar Heating and Cooling, Active and Passive Design", 2nd Edition, Jan F. Freider and Frank Kreith, 1982, Hemisphere Publishing Corp.

13. "Solar Heating and Cooling in Japan", T. Ishibashi, Yazaki Parts Co., LTD 1978

14. "Solar System Design Manual", Yazaki Corporation, 1980

15. "Surface Meteorology and Solar Energy SSE Release 6.0 Methodology", Version 2.3 November 6, 2008, NASA

16. "Users Manual for TMY3 Data Sets" S. Wilcox and W. Marion, National Renewable Energy Laboratory, *Technical Report* NREL/TP-581-43156 Revised May 2008

ENERGY EFFICIENCY IN COMPRESSED AIR SYSTEMS

ANIL HINGORANI
VP MARKETING EAST

ALEXANDER PAVLOV
PRODUCT MARKETING MANAGER

ATLAS COPCO AIRPOWER
OIL-FREE AIR DIVISION
ANTWERP BELGIUM

ABSTRACT

Energy use in compressed air systems accounts for typically 10% of the total industrial electricity consumption. It also accounts for close to 99% of the CO2 footprint of an air compressor and approximately 80% of the life cycle costs of a compressor, over its lifetime. Considering these facts, it is sometimes surprising to see the lack of attention to compressed air systems in industry. This paper attempts to create awareness as to how a great deal of energy can be saved through a conscious process of selection and use of compressed air systems, bringing substantial benefits in economics and the environment. It also attempts to highlight the relative importance of energy savings over the costs of investments made in energy saving features and processes.

APPLICATIONS OF COMPRESSED AIR

Compressed air finds applications in most industry. In broad terms, compressed air is used as:

- Energy air, where compressed air is used as a medium of transfer of energy. Typical applications in this category are motive applications, such as driving pneumatic tools and cylinders, operating instruments, pneumatic actuation and other such processes.

- Active air, where the compressed air takes an active part in the process and / or comes in contact with the medium being processed. Examples are fermentation of substrates in chemical and pharmaceutical processes, such as in the production of citric acid and antibiotics, aeration processes such as in waste water treatment and several other processes in the food and beverage industry, textile industry, semi conductor and electronics industry, power plants and several others

While the requirements of industry in terms of compressed air flow and pressure requirements, the quality of compressed air and the duty conditions may vary considerably, energy savings is equally and universally important.

SIGNIFICANCE OF ENERGY IN COMPRESSED AIR SYSTEMS

To get an insight in to why energy savings in compressed air systems is important, three major aspects deserve special attention:

- Studies indicate that energy in Compressed Air Systems (CAS) account for a substantial proportion of the total electricity consumption in industry. In this context, a study done in the European Union, gains significance (10% in EU).

Yearly energy consumption by compressed air systems*

Country	Compressed Air Systems consumption TWh	% of industrial electricity consumption
France	12	11
Germany	14	7
Italy	12	11
United Kingdom	10	10
Rest of the EU	32	11

* Blaustein, Edgar; Radgen, Peter (Ed.): Compressed Air Systems in the European Union. Energy, Emissions, Savings Potential and Policy Actions. Stuttgart 2001

Figure 1. Yearly Energy Consumption

- Energy in non optimized compressed air systems accounts for typically 80% of their life cycle costs over ten years.

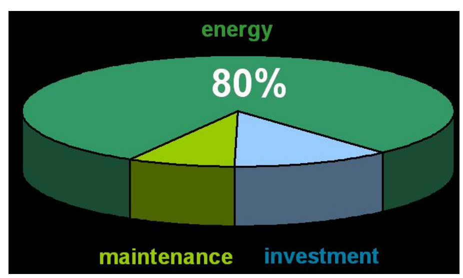


Figure 2. Life Cycle Cost of a Compressor

Given the significance of energy over the life cycle, the emphasis in deciding upon compressed air systems is clearly on energy savings, rather than on capital investments. Experience shows that careful selection and optimization can sometimes cut energy bills by as much as 50% or more.

- Energy consumption in the use of air compressors can account for more than 99% of their CO2 footprint, during their life cycle assessment.

Figure 3. CO2 Footprint of a Compressor

Cutting energy could then bring large benefits for our environment.

Having discussed the importance of energy savings, it is now important to see as to how energy in compressed air systems could be minimized. Here, very often, compressed air users tend to focus on one feature or one aspect, which is projected as a "silver bullet", to bring about energy savings. However, there are no shortcuts and to benefit from the entire energy savings potential of compressed air systems, one needs to look at every aspect and adopt an approach to:

1. Minimize the costs for generation of compressed air
2. Minimize the costs of distribution of compressed air
3. Minimize the costs in the usage of compressed air
4. Adopt integration with other utilities, when possible

Let us go step by step:

1. MINIMIZING COSTS OF GENERATION OF COMPRESSED AIR (ALSO CALLED SUPPLY SIDE OPTIMIZATION)

Optimizing the supply side must follow a logical sequence:

a. Air demand assessment to clearly understand the application
b. Selection of the appropriate core technology
c. Selection of the appropriate drive technology
d. Selection of the appropriate air treatment
e. Optimization of the entire compressor room
f. Employing energy recovery

While energy efficiency in the compressors themselves is also an aspect of the cost of compressed air generation, this is a subject on its own. Hence, the concentration here is on the choices that users can make and their large influence on energy efficiency, or otherwise.

a. Air Demand Assessment

Although this step is often ignored, supply side optimization must necessarily start with a clear understanding of the compressed air needs of the processes, as this is the most important step towards selection of the appropriate compressed air system. Air demand assessment includes four aspects – the requirements of flow and pressure, the pattern of the air demand and finally, the air quality required for the process.

Air demand assessment can be carried out by real measurements and a study of an existing plant or by studying similar plants employing similar air consumers and manufacturing similar products or by a careful study of the air demands of air consumers, in green field plants.
Flow, pressure, dew point measurement equipment, simulation programs and services are widely available, for the purpose.

Demand assessments, with regard to flow and the air demand pattern, could throw up a result as shown below:

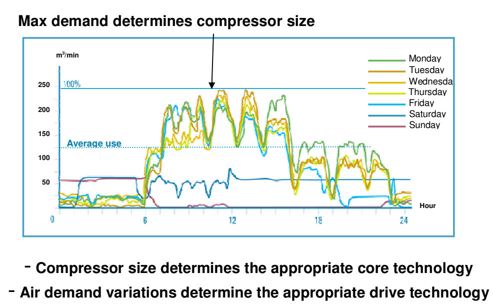


Figure 4. Selection of a Core and Drive

The graph indicates a typical three shift air demand pattern where the flow variations are measured over a 24 hour period and for one week. As is characteristic of these applications, the day shift shows peak demands, the second shift lower demands and the night shift, yet smaller air demands. All three shifts show significant variations in air demands from period to period.

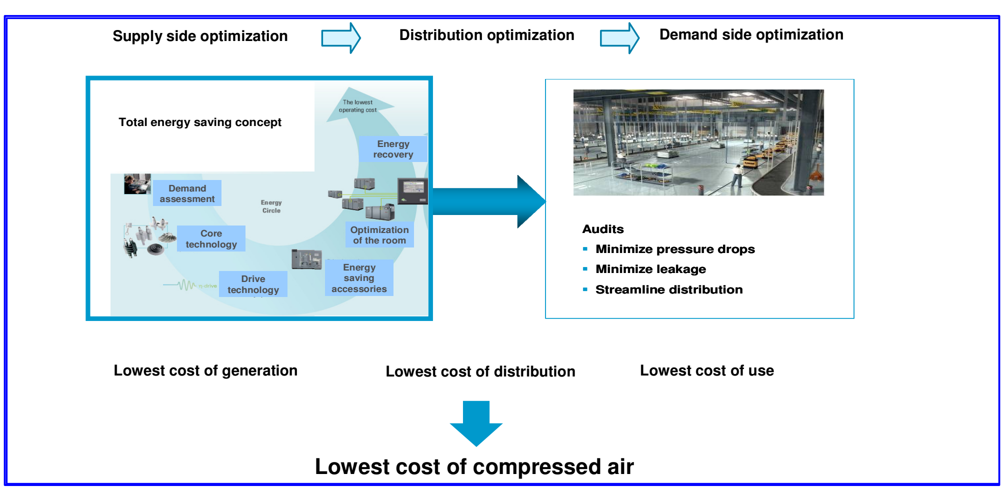


Figure 5. Ultimate Energy Efficiency Approach

b. Selection of the Core Technology

Simulation programs exist in order to determine the optimized selection of the number of compressors to cater to the above air demand patterns. When large demands exist at two or more substantially different pressures, separation of air nets must be considered and then the simulations done. Then depending on the size of the individual machines, the core technology could be selected, for the lowest energy consumption. An example is shown below.

The graph indicates that for a given flow, there is one core technology, which gives the lowest energy consumption. Where centrifugal or turbo compressors are suited to higher flows, there are other technologies which are more appropriate for smaller flows. This is however, not the sole criterion as there are other factors to consider, such as ambient temperatures and flow variations, as we will see later on. An appropriate selection of core technology could save a lot of energy for the users. Apart from this, selection of higher efficiency electric motors could provide another few percent of energy savings. These savings may be smaller in magnitude than the ones above, but constitute a 'quick win' with a small extra investment.

c. Selection of the Appropriate Drive Technologies

In cases where the air demand fluctuates, Variable Speed Drive (VSD) compressors can save a lot of energy by smoothly following the air demand, by speed variations. There are cases where over 40% energy is saved by employing variable speed drives. Studies demonstrate that about 88% of compressed air installations show substantial air demand fluctuations and consequently variable speed drives can offer significant savings in most cases. Variable speed compressors are presently available up to sizes of almost 1 MW, as a standard offering.

Now let us consider a concrete case where peak air demands are very substantial. Different technologies could be employed in this case, to meet the air demands (see Figure 7).

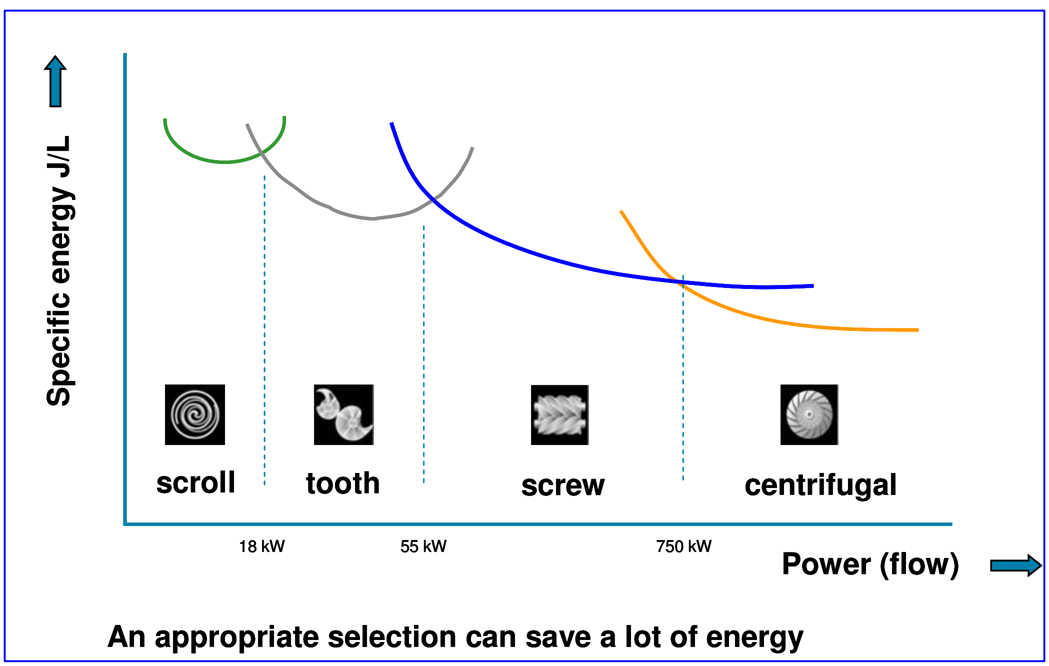


Figure 6. Appropriate Core Selection

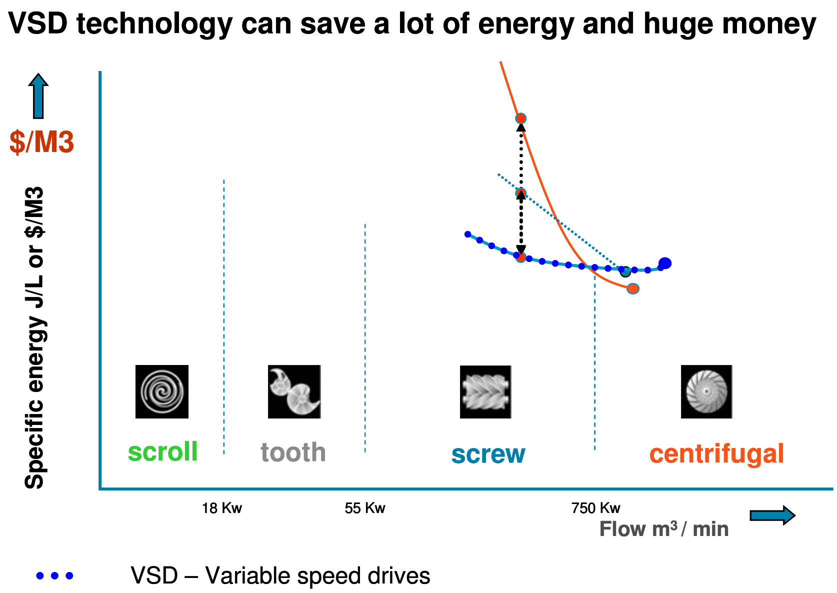


Figure 7. Example of Core Selection

In this picture, a combination of a centrifugal compressor (red curve) with a fixed speed screw (blue dotted line) and a variable speed screw (blue curve) is shown. Also shown are the characteristics of each of the machines when running at lower than their maximum capacities – part load operation. It is evident in this example that a centrifugal compressor which appears to be most efficient for the selection would consume the highest amount of energy at part loads. Next is the fixed speed screw compressor whose energy would also increase at part loads. On the other hand, the variable speed screw compressor which appears to be the most in-efficient at the full load shows almost flat energy characteristics at part loads, saving a lot of energy when the air demand reduces. In this particular example, a combination of a centrifugal compressor or a fixed speed screw and a variable speed screw may be the most optimum selection. Here, the centrifugal or the fixed speed screw should be kept running at full load, consuming minimum energy, whereas the Variable speed screw would take care of the part load operation, most efficiently.

It is however essential in such cases to use intelligent controllers to maintain the running of the different compressors at their most efficient point, often called the 'sweet spot'. Thousands of users are presently benefiting from a clever mix of core and drive technologies, in terms of substantial energy savings.

In conclusion, pre-conceived notions about the appropriate technologies or 'favorite technologies' for processes is an outdated concept as the selection purely depends upon air demand studies and simulations. The optimum choice can vary from case to case.

d. Selection of the Appropriate Air Treatment Equipment

An essential part of air demand assessments is the determination of the air quality required for the processes or the end product. This is often defined by the maximum level of contaminants. The latest edition of the International standard ISO 8573 – 1 ed.2, 2001, classifies the contaminants – solid particulates, water and oil, in different classes, based on these criteria (see Figure 9).

To achieve the desired air quality, filters can be employed for removing particulates and air dryers for water removal, while oil content in the air depends on the type of compressor used or the downstream treatment. Some useful tips for selection of air treatment equipment:

Particulates removal

Filters for particulate removal, must be adequately sized as smaller filters may lead to expensive pressure drops – a 1 bar pressure drop in a 7 bar net could result in an energy loss of 6-7%, which could wash away the initial cost saving, in a matter of days. Pressure drops increase with choking of the filters and a change of filters at appropriate intervals will prevent energy losses due to too high pressure drops. Most filters are equipped with pressure drop indications, to facilitate timely changes.

Water removal

The selection of air dryers depends on the degree of dryness (dew point) which is required for the process. Pressure dew point (PDP) is the temperature below which condensation would take place at the working pressure while atmospheric dew point (ADP) is the condensation temperature at atmospheric pressure. Various drying technologies are available for water removal from the compressed air. However, for simplicity, apply here, only two categories:

- Refrigeration dryers which achieve cool down the air and achieve PDP's +2 to 3°C and above.
- Desiccant dryers which employ adsorption to achieve sub zero PDP's of up to -70°C or even lower.

When contemplating the use of refrigeration dryers, the two important aspects are the direct energy consumption of the refrigeration circuit and the pressure drops through the air passages. The former is influenced by the design of the refrigeration circuit, the heat exchangers and the refrigerant used. An appropriate design and the use of energy friendly refrigerants (and environmentally friendly) could cut the direct energy consumption by 30-40%. Air pressure drops through the dryer should be minimized through adequate sizing of the pipes, steam lining passages and optimizing the heat exchangers. This would bring further energy savings.

When desiccant dryers are used, three aspects need attention, where energy efficiency is concerned – energy losses in heaters used for regeneration, air losses due to purging and pressure drops through the dryers as well as the pre and after filters, where needed. Heat of compression (HOC) dryers of the rotary drum type as well as twin tower types use hot air emerging from the compressor, to regenerate the desiccant, thereby saving a lot of energy, while also minimizing purge losses.

While on the subject, special mention is needed on purge type desiccant dryers (sometimes called heatless dryers). These dryers, which are often purchased on the pretext of 'simplicity', but blow off typically 20% of the compressed air to the atmosphere, to achieve regeneration. Not only is this a huge loss of energy but also necessitates oversizing the compressor to compensate for the air loss. Initial economy in capital costs is lost in high energy costs, in a matter of months.

Below is an indicative chart of energy consumption of various types of desiccant dryers, in terms of % compressor power. This is calculated for a PDP of -20oC.

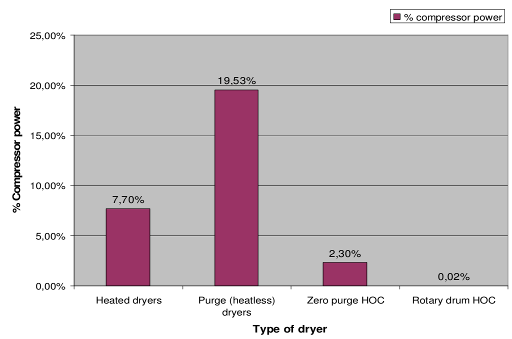


Figure 8. Energy Consumption by Dryers

Oil removal

When meeting the required purity of air for a process, it is by far preferable to choose compressors which directly deliver the required quality of air. This is because downstream filters to remove oil, introduce pressure drops and a consequent loss of energy. Initial pressure drops, mentioned for dry filters, quickly increase as the filter becomes wet and later becomes progressively clogged with dust and sludge.

Purity Class	Solid Particulate					Water		Oil
	Maximum number of particles per m³			Particle Size	Concentration	Vapour	Liquid	Total oil (aerosol, liquid and vapour)
	0.1 - 0.5 micron	0.5 - 1 micron	1 - 5 micron	micron	mg/m³	Pressure Dewpoint	g/m³	mg/m³
0	As specified by the equipment user or supplier					As specified by the equipment user or supplier		As specified by the equipment user or supplier
1	100	1	0	-	-	-70ºC	-	0.01
2	100,000	1,000	10	-	-	-40ºC	-	0.1
3	-	10,000	500	-	-	-20ºC	-	1
4	-	-	1,000	-	-	+3ºC	-	5
5	-	-	20,000	-	-	+7ºC	-	-
6	-	-	-	5	5	+10ºC	-	-
7	-	-	-	40	10	-	0.5	-
8	-	-	-	-	-	-	5	-
9	-	-	-	-	-	-	10	-

Example: A specification, Class 3 : 2 : 1 corresponds to the specific process requirements for Particulates : Water : Oil

Figure 9. Purity Classes

When maximum oil contamination levels correspond to Class 0 or Class 1, the use of oil-free compressors is necessary not only from the energy point of view but also because of the high risks of contamination of the processes and the end products. With energy economy, oil-free compressors pay back for themselves in a reasonably short period of time. Leave alone the higher costs of replacement of filters and oil and costs associated with possible productions stoppages and recalls of contaminated end products.

e. Optimization of the compressor room

As the next step in energy efficiency in the generation of compressed air, optimization of compressor rooms which employ multiple compressors can bring major benefits. Intelligent central controller constantly monitors air demands and select the most efficient combination of machines and compressor technologies to meet this demand in the most efficient way. Without central controller, it is necessary to maintain different pressure settings for different compressors in a so called pressure cascade. This wastes energy as the compressors develop a higher than required pressure. Central controller will bring the average pressure down, thus bringing further energy savings.

f. Employing energy recovery

Air compressors convert almost all their electrical energy to heat. This heat can be recovered in terms of usable hot air or hot water when these machines are equipped with energy recovery systems. Hot air has application limitations and can be primarily employed for space heating. Hot water energy recovery on the other hand, could have multiple applications. While hot water can be used for space heating or hot showers in factories, it can also be used for a continuous supply of process hot water to meet needs of process hot water or can be used as preheated boiler feed water where process steam is required. Well designed hot water energy recovery systems could recover 90% of the electrical energy as heat energy, by picking up heat from every element of the compressor, the loss of 10% being accounted primarily by radiation losses. In fact, efficient heat exchangers in compressors can condense atmospheric moisture, recovering a large amount of latent heat and more than compensating for the radiation losses, thus recovering 100% of the input electrical energy as heat energy in the hot water. It is possible with Atlas Copco Carbon Zero oil-free compressors.

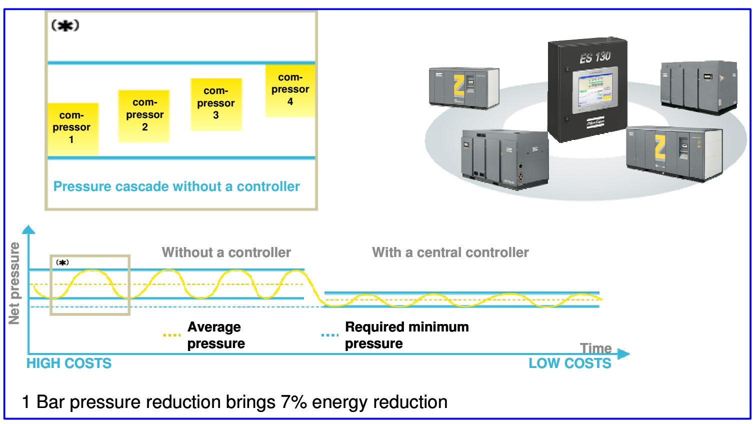


Figure 10. Central Control System

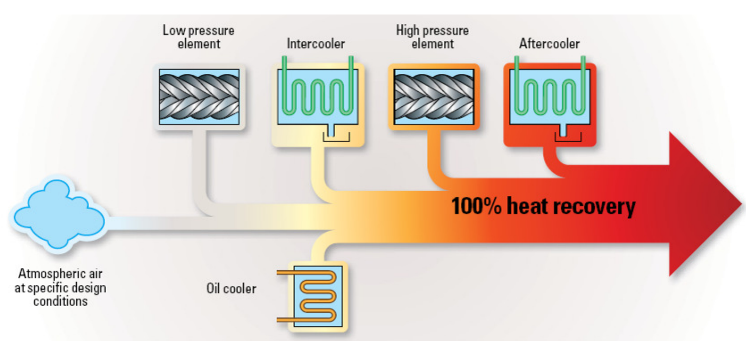


Figure 11. Energy Recovery in a Carbon Zero Oil-Free Compressor

When the hot water can be continuously used, the consequent savings in the boiler fuel could pay back for the entire compressor, within a year.

This concludes the chapter of bringing maximum energy efficiency in air generation. Following these steps, energy bills in compressed air generation could be cut by 50%, when comparing with non optimized systems. When energy recovery systems can be employed to full potential, almost 100% of the input energy can be recovered. So in conclusion, a lot is to be gained.

2. MINIMIZING THE COSTS OF DISTRIBUTION OF COMPRESSED AIR

Also important for energy savings is a well designed distribution network. Simple rules like placing the compressor room as close to the working area as possible, cuts pressure drops. Avoidance of too many pipe bends and a selection of valves with low pressure drops can save energy. Ring mains to distribute air to the points of use are preferable to feeding spurs as these cut pressure drops to 40% for the same pipe diameter. Properly sized air receivers also help in balancing instantaneous air demands and prevent too much cycling of compressors by providing storage. However, the merits of developing higher pressure in the compressors than is necessary for the processes can be strongly debated, although this is advocated by some.

Calculation and simulation programs for a proper design of piping systems and air receivers can be employed, for ease.

3. MINIMIZING THE COSTS OF USAGE OF COMPRESSED AIR

Within the factory, similar rules as for distribution would apply. Older factories must have their piping thoroughly checked for leakage in the pipelines. Tools such as ultrasonic leak detection equipment can help in locating leakages. Pipe sections requiring a change, must be replaced by highly corrosion resistant piping, available today. Leakages should be addressed as these could lead to substantial energy losses. A guide table is shown below.

Eq. Hole diameter	Air leakage at 7 Barg		Compressor Power req.	
[mm]	[l/s]	[cfm]	[kW]	[hp]
1,0	1,2	2,5	0,5	0,7
2,0	4,8	10,2	2,0	2,7
5,0	30,1	63,8	12,0	16,0
10,0	120,5	255,5	47,0	63,0

Figure 12. Leakage to Power Translation

One more aspect that needs consideration is the use of pressure reducing valves at the points of use. It is not uncommon to find high net pressures with pressure being substantially reduced at the use point. A review of required pressures should be undertaken to see if the pressure of the supply net can be reduced. With reduction in pressures the pressure developed by the compressors could be reduced, thus saving energy.

4. ADOPT INTEGRATION WITH OTHER UTILITIES, WHEN POSSIBLE

An example of integration is the use of compressor energy recovery systems, which yield hot water. Well designed energy recovery systems in oil-free compressors can recover 95-100% of the electrical input energy as heat, in the form of hot water at 90°C (see Figure 11).

Hot water can find applications in several areas within a factory, either directly or as pre-heated boiler feed water, to generate steam. Areas of application are:

- space heating
- showers within factories
- process hot water
- process steam

When requirements of hot water or steam are prolonged, a huge amount of energy and money can be saved when using energy recovery systems. When planning new installations, an analysis of all the heat users such as boilers can be undertaken so as to locate the equipment, close to each other. This will minimize temperature losses in transporting hot water from one location to another. A technique which is increasingly used for the analytical process is called a ‘pinch analysis’. The method calls for a listing of all the heated mediums and all the cooled mediums within a factory. The mediums can be made to transfer heat from one to the other, in order to reduce energy towards both heating and cooling. A good analysis and implementation can provide very good dividends.

SUMMARY

Following these steps, there may or may not be extra investments involved. Even when investments are involved, the benefits in energy savings would pay back for extra investments in a very short time span, giving huge net savings for the rest of the life cycle. Energy savings would benefit the environment and help users to meet CO2 reduction targets and earn credits, while boosting sustainability credentials for the companies involved.

Atlas Copco provides compressed air users a range of services towards measurements, analysis and simulations and implementation plans. Supplemented by a wide range of products, the company can help put together a comprehensive plan for minimizing energy usage in compressed air installations.

REFERENCES

[1] Blaustein, Edgar; Radgen, Peter: Compressed Air Systems in the European Union. Energy, Emissions, Savings Potential and Policy Actions, Stuttgart 2001

Emissions and Energy: An Integral Approach Using an Online Energy Management and Optimization Model

Diego Ruiz Carlos Ruiz Oscar Santollani Tyler Reitmeier
Soteica Ideas & Technology LLC
Houston, TX 77079

Abstract

With the expected legislation on the horizon in the U.S., the cost of CO2 emissions will have significant impact on industrial plant operations in the near future. Our purpose in this presentation is to show real industrial examples in which, with the existing equipment, continuous CO_2 emissions reductions were achieved while, at the same time, optimizing the energy systems using an online model.

We will show the importance of including the cost of CO_2 emissions and how they should properly be taken into account when managing energy systems. Furthermore, we will illustrate how an optimization model is used for evaluating case studies to suggest the most cost effective energy system modifications while taking into account CO2 emissions costs.

Several examples and results corresponding to the application of such systems to refineries will be discussed. In addition, the integration of CO_2 emission costs and constraints into the online energy system models and their optimization is also explained.

A Watchdog for Energy and Emissions System Management

Many industries are facing increasing pressures to reduce greenhouse gas emissions. The challenge is to optimize utility systems with the goal of maintaining or reducing their CO_2 emissions while keeping their competitive edge.

As the utility and energy systems are often the major source of SO_x, NO_x and CO_2 emissions, the control of these emissions and the management of the associated credits and quotas are essential considerations in the overall energy management of a site. In the case of refineries, chemical and petrochemical plants, which usually operate complex energy systems, CO_2 emissions introduce an additional factor to the complexity of the energy costs reduction challenge. Moreover, since energy is usually the highest operating cost after feedstock, energy reduction is more of a "bottom line" business decision than a challenge.

In addition, process plants use different type of fuels, often operate cogeneration units, have steam networks consisting of several pressure levels, have different types of energy consumers, and have emission limits that must be observed. Export or import of electricity into and out of deregulated markets, and the related effect on CO_2 and other emissions, also increases the optimization complexity.

In Fig.1 each blue dot represents the result of the optimization run which is executed automatically every 15 minutes with real time data. The graph shows the % in energy cost savings that is available to be captured at every run. It can be seen that the system was identifying approximately 5% potential and that around 14:30 on Sept. 29, 2007 the operational changes recommended by the optimizer were made and the savings captured.

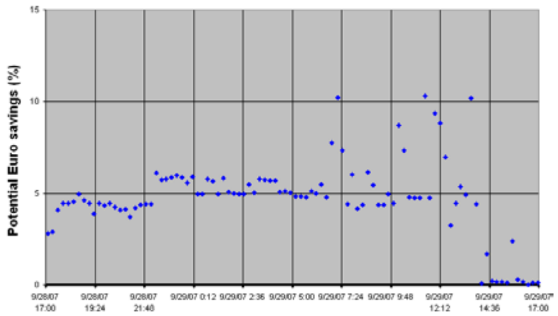


Figure 1. *Identified savings along a day*

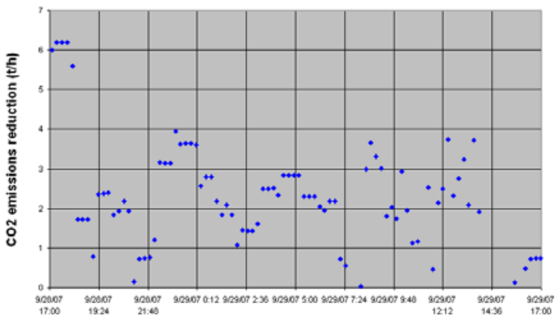


Figure 2. *Identified* CO_2 *emissions reduction along a day*

Figure 2 shows the corresponding potential reduction in CO_2 emissions found for the same example during the same period and from the same set of recommendations. For this particular example, an average of 2 t/h of CO_2 emissions reduction was achieved (more than 17 Kt/year), helping to obtain an energy cost reduction of 5%.

CO_2 Emissions Cost in the Online Model

The cost of CO_2 emissions is taken into account by the Visual MESA optimization model together with all the other existing supply contracts for fuels, steam, water and electricity. The CO_2 emissions modeling and economics must be configured according to each site's specific needs. Thanks to the availability of powerful and versatile calculation blocks within Visual MESA, it is possible to model the emissions factors for each fuel in addition to the costs and constraints associated to the CO_2 emissions, taking into account all the contractual and operational details of a given site.

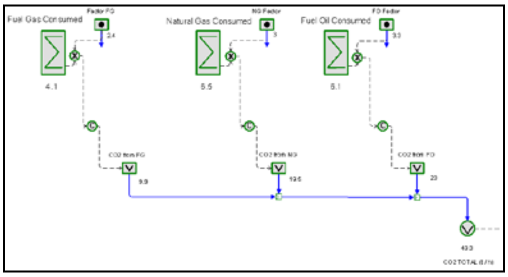


Figure 3. *Details of the* CO_2 *emissions model, differentiated by the type of Fuel*

For example, the CO_2 emission cost and total quota constraint can be added to the Optimization's economic Objective Function (OF) so that, when an optimizer minimizes the OF, CO_2 cost is taken into account together with all the other costs (fuels, electricity, demineralized water, etc.). In this way the optimum fuel feeds to boilers and gas turbines are recommended. Of course, the limits and/or quotas imposed to other emissions are taken into account at the same time.

In general, since the energy cost savings are mainly achieved by a reduction in fuels consumption, the optimization will typically imply a reduction in CO_2 emission, except in those scenarios where the optimizer finds the use of a cheaper fuel that generates more CO_2 instead of using a more expensive fuel that generates less CO_2. This could be the case when replacing Natural Gas with a heavy liquid fuel, for instance. This challenging tradeoff would be affected directly by both the CO_2 allowance price and the annual emission quota.

The following sections explain the importance of including the cost of CO_2 emissions and how it should be taken into account when managing and optimizing the energy systems. Furthermore, we show how an optimization tool like Visual MESA helps to perform case studies to evaluate energy system modifications taking into account the emissions. In addition, we will explain how CO_2 emissions are considered in the energy system model for everyday usage with real-time, online optimization.

CO_2 Emissions Accounting

In many countries, a given industrial complex has an assigned quota for total CO_2 emissions. They periodically report the total generated CO_2 related to fuels consumptions and operating processes. At the end of the year, if the quota is exceeded, a penalty for each ton of CO_2 emitted above the quota must be paid at a given market price. For instance, the price in Europe is referred to as the European Union Allowance (EUA), equivalent to one metric ton of CO_2 emissions (see http://pointcarbon.com).

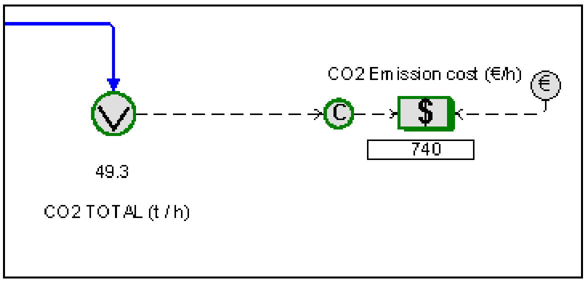
In some countries, there is an additional tax, sometimes much more expensive than the allowance price, as a penalty for having exceeded the quota.

Also, if emissions are below the quota, the tons of CO_2 not emitted can often be sold at the market price of the emissions allowance. It is unclear how the CO_2 market in the United States will develop over the next several years, but it will likely be similar to what has developed in Europe.

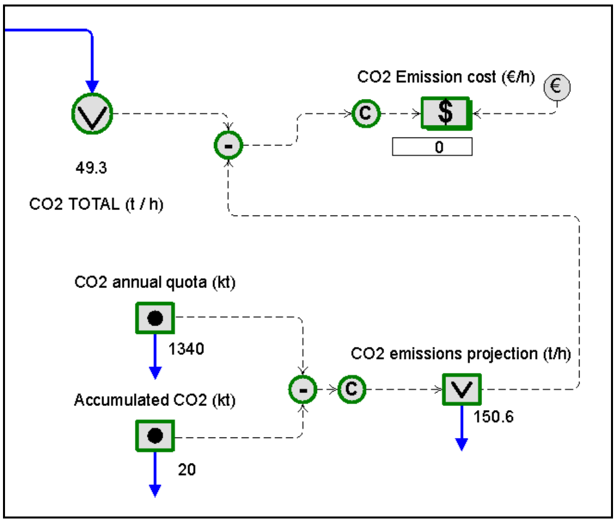
How CO_2 Emissions Impact Energy System Optimization

The cost of CO_2 emissions in the OF can be incorporated in several different ways depending on whether the quota has been exceeded or the accumulated emissions are below the quota, at a given point of time and over a given accounting period (generally one year):

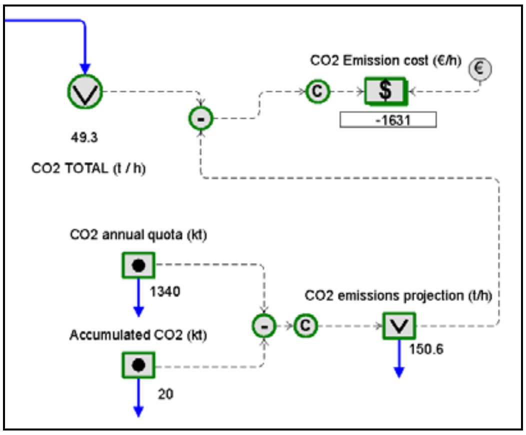
a) *For each ton of CO_2 emitted, a price equal to the emission allowance price is assigned (plus the applicable taxes).* This approach is not fully realistic from the accounting perspective, unless the plant has exceeded the CO_2 emissions quota. However, it assures that the optimization will be always focused on minimizing CO_2 emissions. This approach may influence the optimization results in those cases that a compromise between using a more expensive fuel with less CO_2 emissions and a cheaper fuel with more CO_2 emissions exists. It will, in fact, penalize the cheaper fuel.



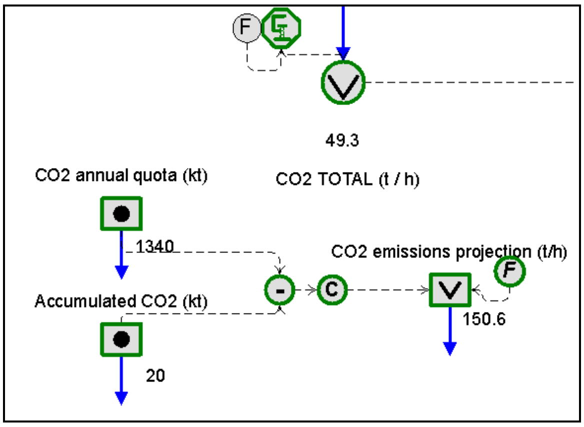
b) No cost is assigned to the emitted CO_2 until the quota is achieved. In this option, if there were compromise solutions between the use of a more expensive fuel with less CO_2emissions or a cheaper one with more emissions, the optimization would advise the second. Consequently, the quota will be achieved early in time. This approach should be only applied in those plants where, due to its particular operating conditions, the annual quota is unlikely to be achieved.



c) *The CO_2 emissions always have an associated cost; however, it will depend on the emissions projection for the rest of the period (typically one year).* If this projection of emissions estimates that at the end of the period the quota will not be reached, each ton of CO_2 below the quota will have a negative cost (-) equal to the price of sale of the emissions rights, which, for optimization purposes, will correspond to a credit. This assumes that the emissions credits not used can be sold). If the projection foresees that the quota will be reached, the price will be equal to the cost of emission credit purchase (plus the applicable taxes).



d) *In all cases a constraint can be imposed on the current CO_2 emissions.* Such a constraint should be to be equal to the projection of the future emissions calculated in such a way that the quota would be met at the end of the considered period (i.e., end of the year). This approach would help manage the fuels consumption so that the site is always below the emissions quota in order to take the maximum advantage of the quota by the end of the considered period.



If the quota eventually is exceeded before the end of the period, the additional CO_2 emissions cost will be included in the Objective Function to be minimized. Under this scenario the price of each ton of emitted CO_2 will be equal to the CO_2 emissions credits that would need to be purchased (plus the applicable taxes).

e) It is also possible to optimize a utility system with the OF being total emissions, as well, such that the model optimizes for lowest total emissions rather than for lowest cost. In such a case, the utility needs for the process would still be met, but cost and efficiency would not be considered in the optimization, leaving the only driver of the optimization to be total emissions reduction.

Industrial Examples

a) Day-to-day CO_2 Emissions Reduction

The first real industrial example corresponds to TOTAL Feyzin refinery (Ref 7). TOTAL is a leading refiner-marketer operating 11 refineries directly in Western Europe and one refinery in the U.S. at Port Arthur, TX. The reduction of greenhouse emissions and the enhancement of energy efficiency are among the current Company corporate challenges.

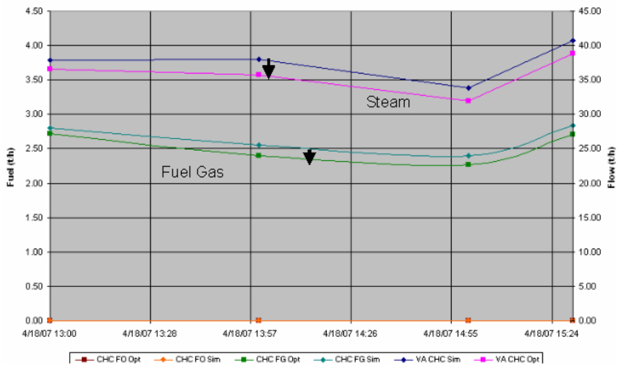
In this example, a set of manual operating recommendations given by the optimizer during a particular shift have been:

- Pump swaps (i.e., steam turbine and motors driving pumps that can be used interchangeably)
- Fuels to boilers, such as Fuel Gas (FG) and Fuel Oil (FO)

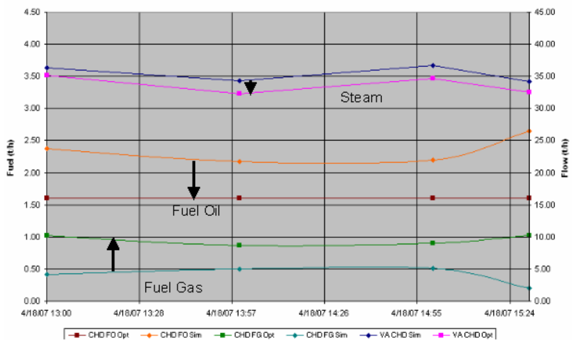
As a result of the manual actions, adjustments to the following have been made by the control system:

- Steam production from boilers
- Letdown and vent rates

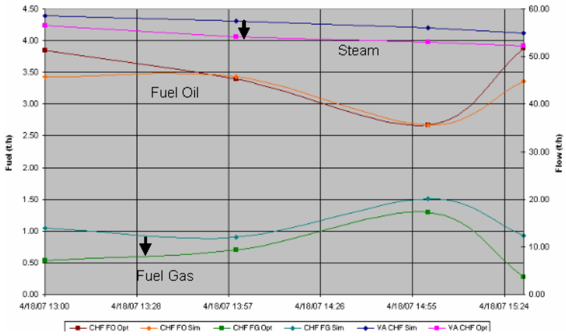
The following figures show the impact on steam production, fuel use and CO_2 emissions reduction.



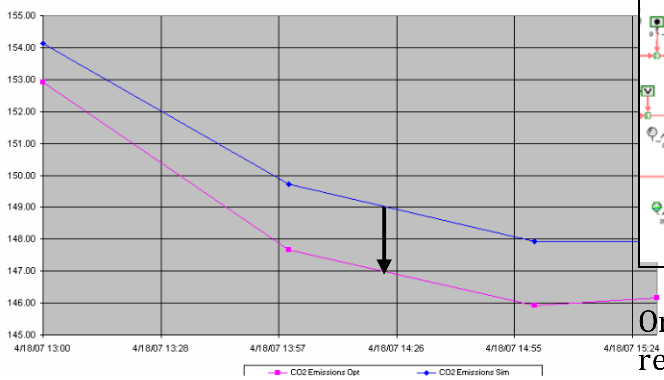
Boiler C (100% Fuel Gas): 2 t/h less steam



Boiler D (FO and FG): 2 t/h less steam) and FO to the minimum



Boiler F (FO and FG): more than 3 t/h less steam



CO_2 emissions: 2 t/h less

In summary:

- Almost 1 t/h less of FO consumed
- Approx 7 t/h less of high pressure steam produced
- Approx 2 t/h less of CO_2 emitted
- Approx 200 kW more of electricity imported

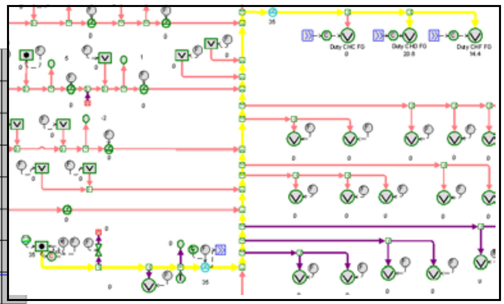
b) Fuel Choice

When considering the CO_2 emission cost, the following is an example of the recommendation for operators:

- Fuel to boilers

As a result of the manual change in the boiler fuel use (more FG and less FO in overall), the Fuel Gas header pressure control system made the necessary adjustments which resulted in the need to increase the incremental Natural Gas import.

The following figure shows the fuel gas network model representation highlighting the differences between current and optimized situation (delta view, duty flows).



On the left, fuel gas suppliers are represented, while on the right Fuel Gas consumers are displayed. The values indicate the corresponding changes, expressed in MW, after the application of the recommendations (zero value means no change).

As a result of replacing FO by FG (with the need to import more Natural Gas), CO_2 emissions are reduced by 4.7 t/h. This is important to consider when a trade-off between cheaper fuels that produce more CO_2 and more expensive fuels that produce less CO_2 exist. It would be an especially important consideration when the CO_2 emissions quota is expected to be exceeded by the end of the year.

c) Investment Evaluation

This third example corresponds to a Repsol YPF refinery (Ref 4). Repsol

YPF is the largest petroleum refiner in Spain and Argentina and also conducts operations in Peru and Brazil. This evaluation consists of the economic impact of adding a new Natural Gas line feed to the Gas Turbine. This investment would allow the replacement of its Gas Oil feed.

In terms of the Visual MESA modeling, the change can be made by simply changing the fuel to the gas turbine and running Visual MESA in "What-if?" mode. By running this "What-if?" study significant savings have been identified and CO_2 emissions reduction as well.

Conclusions

Real industrial examples have been presented in which, with the existing equipment, CO_2 emissions were reduced while optimizing the energy system using an online software tool.

Optimization is configured to give regular recommendations to operations personnel which are safe and directly actionable. CO_2 emissions cost has been taken into account, adapted to each site's particular operation needs.

Rigorous thermodynamic modeling and optimization that incorporates emissions modeling, as Visual MESA does, leads to significant and quantifiable cost and emission reductions.

REFERENCES

1. "Online Energy Management", D. Ruiz, C. Ruiz, D. Nelson, Hydrocarbon Engineering, September 2007, pages 60-68.
2. "Auditing and control of energy costs in a large refinery by using an on line tool", D. Ruiz, C. Ruiz, J. Mamprin, Depto. de Energías y Efluentes Petronor, (2005), ERTC Asset Maximisation Conference organized by Global Technology Forum, May 23-25, 2005, Budapest.
3. "Reducing refinery energy costs", Ruiz D., Ruiz C., Nelson D., Roseme G., Lázaro M. and Sartaguda M., (2006), Petroleum Technology Quarterly, Q1 2006, pages 103-105.
4. "Online energy management", S. Benedicto, B. Garrote, D. Ruiz, J. Mamprin and C. Ruiz, Petroleum Technology Quarterly Q1 2007, pages 131-138.
5. "The Use of an On-line model for Energy Site-Wide Costs Minimisation", García Casas, J.M., Kihn, M., Ruiz D. and Ruiz C., (2007), ERTC Asset Maximisation Conference organized by Global Technology Forum, May 21-23, 2007, Rome.
6. "Energy System Real Time Optimization", D. Uztürk, H. D. Franklin, J. M. Righi, A. T. Georgiou, NPRA Plant Automation and Decision Support Conference, Phoenix, USA, 2006.
7. "Site-wide Energy Costs Reduction at TOTAL Feyzin Refinery", Département Procédés - Energie, Logistique, Utilités, TOTAL - Raffinerie de Feyzin, D. Ruiz, J. Mamprin and C. Ruiz, (2007), ERTC 12th Annual Meeting organized by

Global Technology Forum, 19-
21 November, Barcelona.

Trends in Industrial Energy Efficiency Programs: Today's Leaders and Directions for the Future

Anna Chittum
Industry Associate

Daniel Trombley
Engineering Associate

R. Neal Elliott, Ph.D., P.E.
Associate Director of Research

American Council for an Energy-Efficient Economy
Washington, DC

ABSTRACT

As more states establish Energy Efficiency Resource Standards (EERS), goals for energy efficiency savings are increasing across the country. Increasingly, states are relying on their industrial energy efficiency programs to find and help implement those savings. Historically, industrial energy efficiency programs have not been completely effective at finding those savings, in large part because the programs have not been flexible enough to accommodate the heterogeneous needs and unique characteristics of the industrial sector.

This paper will discuss the state of industrial energy efficiency programs today. Relying on an ACEEE-administered survey of 35 industrial energy efficiency programs, we will determine current trends and challenges, address emerging needs, and identify best practices in the administration of today's industrial efficiency programs. The paper will serve as an update on industrial energy efficiency program activities and discuss the ways in which today's programs are trying to serve their industrial clients better.

INTRODUCTION

As increased goals for energy efficiency savings are mandated in regions of the U.S. and Canada, and as the likelihood of a national-level energy efficiency resource standard (EERS) in the U.S. increases, state lawmakers and utility regulators need to plan for achieving new energy savings. New commitments to efficiency can only be met with new commitments to efficiency programs, since, despite the cost-effectiveness of most energy efficiency projects, a number of market and educational barriers prevent many cost-effective energy efficiency investments from occurring.

The industrial sector in particular offers tremendous opportunity for energy savings, and a significant opportunity to instill the tenets of energy efficiency within facilities that, in turn, employ and influence millions of people. The industrial sector has thus been an attractive target sector for states looking to reach new levels of energy savings through efficiency. The sector itself, working constantly to increase shareholder value and reduce expenses, has found energy efficiency investments to be an attractive avenue to achieve those ends. Additionally, as climate change awareness and mitigation strategies increase, energy efficiency will likely be increasingly prioritized as a critical solution to reduce greenhouse gas emissions, and the potential financial risks associated with regulation.

But new efficiency goals and mandates, along with increased interest in the cost-saving potential of energy efficiency investments, present new opportunities and challenges to the administrators of industrial energy efficiency programs. It was within this context that the American Council for an Energy-Efficient Economy (ACEEE) decided to update its research into industrial energy efficiency programs throughout the U.S. and Canada. We conducted a survey of program managers, as well as additional primary and secondary research into industrial energy efficiency programs. The research focused on entities that are funded by "public benefit" or "system benefit" funds. This report refers to these programs as public benefit entities (PBE).

The full report, *Industrial Energy Efficiency Programs: Identifying Today's Leaders and Tomorrow's Needs*[1], discusses the barriers to industrial energy efficiency, what has worked in industrial-focused energy efficiency programs in the past, the types of programs that are serving the industrial sector today, trends in these programs, and some specific issues that will likely impact a growing number of industrial energy efficiency programs in the near future This paper summarizes the report, focusing on trends that were identified in the survey.

[1] The full report (#IE091) is available at our website, http://www.aceee.org/store

SURVEY AND RESEARCH METHOD

ACEEE conducted both primary and secondary research. The primary research collection was done via a survey that was conducted by telephone and e-mail between July 2008 and April 2009. The survey gathered detailed qualitative information on 30 industrial-focused programs.[2] The primary respondents to the survey were the individuals at each targeted energy efficiency program responsible for the day-to-day management of industrial PBE programs. Respondents' official titles included "Industrial Program Manager," "Industrial Sector Manager," and "Energy Efficiency Program Manager," among others. ACEEE also compiled secondary data via a review of individual program Web sites and publicly available information from the Consortium for Energy Efficiency (CEE), energy efficiency-focused conferences, and information from prior ACEEE research.

The survey covered both Canadian and American programs, and programs both new and well-established. Programs of varying sizes and scopes were surveyed as well. The requirement to be included in the survey was the existence of a distinct industrial focus, separate from, for example, a commercial buildings program. The survey was largely qualitative in nature, asking respondents to gauge their own program's successes and challenges and discuss their program's scope at length. Success was, of course, defined differently by each respondent. The subjective nature of the responses were illuminating, and helped to identify particular aspects of programs that could not be easily described in more objective, quantitative terms. A follow-up survey, collecting additional quantitative data, is suggested as a next step, and discussed later in this report.

Clear trends emerged that indicate industrial programs are quite dynamic, learning from and responding to their customers as they seek new savings across the industrial sector. As will be discussed, ACEEE feels substantial room for improvement remains among industrial energy efficiency programs, but most improvements already exist in some implementation of current industrial efficiency programs. Certain programs are aggressively leading the way and establishing best practices that can prove useful to newer programs or to programs looking to achieve an expanded reach or savings target.

[2] See the full report for citations of all survey respondents.

CURRENT BEST PRACTICES

Previous research shows the attributes of industrial energy efficiency programs that generally lead to successful penetration in the sector. These are:

- Build and maintain lasting relationships with customers,
- Recognize the need for longer timelines and flexible services,
- Have partnerships in place to learn of new and expanding businesses,
- Coordinate multiple program offerings,
- Recognize the importance of behavior,
- Help firms understand the non-energy benefits of efficiency investments, and
- Provide follow-through assistance.

The list above, discussed in detail in the full report, represents our current understanding of industrial efficiency programs from existing literature. These elements can be thought of as a "wish list," applicable to industrial programs that have the resources and flexibility to develop an ideal industrial program. Many elements of program design are beyond the control of an individual program manager. Requirements and regulations promulgated by federal, state, and regional entities will certainly shape and impact an efficiency program to some degree. Finally, these above elements can manifest themselves in a variety of ways in any given program.

EMERGING TRENDS IN INDUSTRIAL ENERGY EFFICIENCY PROGRAMS

While industrial programs have long used creative and innovative means to address their customers' needs, the survey and additional research shone light on some new trends. We define some of these as "trends" because of a noted increase in their use since previous studies. Others were considered "trends" by virtue of the fact that multiple programs were putting more resources or efforts into that particular approach. Many of these trends have been implemented in some form for several years, but have recently been more widely adopted, as industrial programs respond to rising efficiency goals and requirements set by regulators and legislatures.

Most of the respondents to the survey have been involved in the energy efficiency field for over five years, and were able to comment on the discrepancies between their programs today and industrial programs of the past. As a result they were in a position to highlight specific trends and shifts within their own programs, which, collectively, painted a broader picture of the trends in programs across the U.S. and Canada. The implications of these findings will be discussed in greater detail in the following section of this report.

Seven specific trends were identified in the survey. They are the emergence or growth of:

- Energy manager/management programs and employee behavior programs,
- Targeted industry sub sector-specific outreach and program deployment strategies,
- Natural gas efficiency programs,
- Coordination of industrial efficiency programs with regional energy efficiency efforts,
- Multi-stakeholder goals,
- Custom incentive programs, and
- Workforce challenges for programs.

We discuss each of these items in the sections that follow.

Energy Manager/Management and Employee Behavior Programs

For ACEEE's research purposes, energy manager and management programs are broadly viewed as those that support an actual individual or an internal organizational management structure responsible for paying attention to and advocating for the energy efficiency opportunities within a given firm or facility. Energy manager programs focus on identifying and empowering an individual to be the actual energy manager onsite, while an energy management program looks to integrate energy-saving actions into a firm's or facility's overall management structure. Many of these programs are based upon existing energy management or quality control standards. Examples of energy management standards and programs include the International Organization for Standardization's forthcoming *ISO-50001*[3] standard for energy management, the *Superior Energy Performance*[4] plant energy efficiency certification, the *Six Sigma* quality management strategy, and the federal *ENERGY STAR for Industry*[5] program.

Many of the PBE programs surveyed indicated that they recently added training of in-house energy managers to their list of technical assistance offerings, or were thinking about doing so in the near future. In an energy manager program, the selected energy manager may address energy-using behavior within a facility or firm, and can serve as a liaison to the energy efficiency program. Sometimes the energy manager will have energy management as his or her full time job, while in other cases a person will be tasked with encouraging energy management in addition to other tasks. Much of this is dependent upon the size and needs of a given firm. Some programs will help to financially support such a manager through a cost-share program, savings guarantee, or similar mechanism.

One such program was originally developed at BC Hydro and recently considered by the Ontario Power Authority. The program employs an energy manager, through a cost-sharing mechanism, for large energy users, paying no more than 80% of the cost of hiring an internal energy manager. The program is unique in that it allows multiple firms to share an energy manager. This aspect enables smaller facilities to enjoy the benefits of an energy manager without the need to fund an entirely new full-time employee. This particular program also allows a trade association or similar aggregating entities to apply for an energy manager and then share the manager with the associated or member firms. A similar program is running at Enbridge Gas Distribution.

Energy management can extend beyond just energy decisions made at a single facility. This type of energy management program approach integrates energy management priorities into existing corporate leadership priorities to stretch across facility or even state lines. Such an approach is especially effective in larger firms with multiple facilities and a common management platform, where no single person is responsible for advocating for company-wide energy efficiency.

The federal government's *ENERGY STAR for Industry*[6] program and the *Green Suppliers Network*[7] work to encourage internal energy managers to look

---

[3] See http://www.iso.org/iso/iso_catalogue/management_standards/specific_applications/specific-applications_energy.htm for more about the ISO 50001 standard.

[4] See http://www.superiorenergyperformance.net/ for more about the Superior Energy Performance program.

[5] See http://www.energystar.gov/index.cfm?c=industry.bus_industry for more about the ENERGY STAR for Industry program.

[6] See http://www.energystar.gov/index.cfm?c=networking.bus_networking_supply_chain for more on the ENERGY STAR program's Supply Chain Working Group.

[7] See https://www.greensuppliers.gov/gsn/home.gsn for more about the Green Suppliers Network.

beyond their own facilities to those of the rest of the firm, supplier companies, and even customer companies. These kinds of supply chain-wide efficiency efforts are in line with other types of non-energy partnerships entered into by industrial firms looking to maximize economies of scale in distribution and purchasing (8). This approach has been successfully used by DTE Energy for many years in conjunction with its automotive customers (4).

These energy manager/management programs go hand-in-hand with an increased emphasis on behavior-focused energy efficiency efforts. As noted earlier, a significant portion of potential savings in the industrial sector can be achieved merely by changing employee behavior, separate from making new equipment investments. In recognition of this fact, several of the surveyed programs are expanding and establishing distinct behavior-focused initiatives specific to the industrial sector. When large firms adopt energy management programs, or work to leverage existing corporate sustainability programs to extend to energy usage, they are very often working to implement smarter energy-using behavior across all its facilities and employees. These types of initiatives are often led or envisioned by executive-level leadership. Such high-level leadership is usually required in order to garner the requisite buy-in from all employees. These programs seek to create an awareness of the importance of energy efficiency among all employees, almost always first focusing on energy efficiency at home with the express intent that the change perspective will create an increased awareness in the workplace (3).

While such behavior efforts supported by PBE programs are fairly new, these programs have a long history within larger companies such as Dow Chemical and 3M. Many industrial firms have historically focused on energy-saving behaviors through operation and maintenance ("O&M") programs, but have done most of this work outside the scope of PBE programs. Firms have focused on O&M and other behavior-focused improvements for the financial savings, safety improvements, and production quality enhancements such efforts can yield. While few mature PBE-funded behavior-focused programs appear to exist in the industrial sector at this point, what the survey uncovered was a general consensus that more strongly addressing employee behavior among industrial firms would be necessary in order to achieve future savings goals by PBE programs.

Puget Sound Energy expanded their Resource Conservation Management program to their industrial sector customers, encouraging a suite of utility-saving (electricity, natural gas, water, sewer, etc.) behaviors. While this program is indeed a type of energy management program, the utility has specifically viewed it as a way in which to alter internal behaviors firm-wide.

For some PBE programs, energy management programs offer a tool they can use with customers who may currently be unwilling or unable to make large capital investments. At the Energy Trust of Oregon, the focus on energy management programs has, in part, been emphasized by the program's staff recently due to the fact that changes in operation and maintenance and other behavior-based activities can be done to a large extent with minimal capital investment. As companies find themselves unable to secure financing for large capital investments, O&M and behavior-focused programs in general could be viewed as increasingly useful tools in a PBE program's toolbox.

<u>Industry Sub-Sector-Specific Outreach and Program Deployment</u>

Increasingly, as industrial efficiency programs mature and develop a deeper understanding of their customer base, certain industries are identified as being well-suited for specialized, focused programs of their own. In some cases, industries are identified and targeted based on the fact that they represent a large percentage of system load. In other cases, industries are targeted because a utility or other energy program has a pre-existing relationship with an affiliated trade association or other entity, helping to foster a connection.

A program with an industry-specific focus, wherein industrial clients are grouped and targeted by industry sub-sector, usually holds a specific employee responsible for that particular industry. This individual can then focus on developing relationships, attending relevant industry meetings and events, and becoming familiar with target firms and markets. At CenterPoint (Minnesota), PG&E, Enbridge, and Wisconsin Focus on Energy, targeted "markets" are well-known by the efficiency programs that serve them, because experts in specific fields have been hired by these programs to be their go-to resource for firms looking to better understand and control their energy efficiency.

Some programs assign multiple industries to one staffer, or assign the largest industry to one staffer. In this way, firms know they have a real, recognizable person to call if they have a question or concern; they develop a working relationship with the individual, who in turn tracks the status of all of the projects the efficiency program is concurrently administering within a firm. This provides customers with continuity and the assurance that they will not need to reintroduce themselves and their firm each time they seek assistance from their local efficiency program.

A benefit of the industry-specific focus is that an individual tasked with a particular industry will become familiar with all of the investments each firm is making within the industry. When the program representative comes across a new challenge, it is easier to suggest a certain product or service if the case can be made that it has worked previously for a firm within the same industry. Firms are interested in their competitors' activities, and respond positively to information about successful projects at similar firms.

Most of the survey respondents with sector-specific programs noted that they combine their sector efforts with their generally older technology or end-use-focused energy savings efforts (e.g., motors, lighting, or compressed air). Many people refer to this approach as "cross-cutting," with programs at Xcel Energy, Efficiency Vermont, and Wisconsin Focus on Energy implementing this cross-cutting approach.

Natural Gas Efficiency Programs

As noted earlier in this report, natural gas represents a significant portion of the average industrial firm's energy consumption. While energy efficiency programs have traditionally targeted primarily electricity consumption, a growing number of utilities and state public benefits fund organizations are now also targeting natural gas. U.S. budgets dedicated to natural gas energy efficiency programs at utilities and public benefit fund organizations have been rising rapidly in the last few years, with much of that growth found in the commercial/industrial sectors (1, 15).

The rising spending on natural gas programs reflects new programs being started to address natural gas use, and new spending by existing programs to meet expanded program needs. National Grid has recently established and expanded new natural gas offerings, while other existing programs, such as PG&E, Vermont Gas, and CenterPoint (Minnesota), have recently ramped up their outreach efforts to meet new and higher savings targets. Many of the natural gas programs surveyed noted concern about impending rising savings targets, and were worried that their programs would not be able to meet the targets despite their best efforts.

Coordination with Regional Energy Efficiency Efforts

An increase in the industrial-focused efforts of regional efficiency organizations can be found across the country. These regional entities, often funded by multiple utilities and other efficiency stakeholders, are able to dig deep into market transformation opportunities that utilities or government entities are unable to address. These organizations leverage the knowledge and experiences of a variety of partners, bringing together a wide variety of stakeholders, which, in turn, enables wide-reaching programs to succeed. PBE programs work hand-in-hand with these kinds of regional efforts to best meet their customer's needs.

The efficiency goals and support program developed by the Northwest Food Processor's Association (NWFPA), in conjunction with the regionally-focused Northwest Energy Efficiency Alliance and other partners, offer a compelling case for the use of regional partnerships to tackle energy use activities across an entire sub-sector. NWFPA leveraged funding from the State Technologies Advancement Collaborative (STAC)[8] and resources from the U.S. Department of Energy's (DOE) *Save Energy Now* program to establish a customized program dedicated to the unique needs of the northwest region's food processing industry. The industry collectively committed to a 25% reduction in energy use over the course of the following ten years, and NWFPA developed a range of online tools, workshops, and other resources for the participating firms.

In some cases, the development of regional industrial energy efficiency leadership is so new that the programs are only just beginning to take flight. Both the Southeast Energy Efficiency Alliance (SEEA) and the Southwest Energy Efficiency Project (SWEEP) recently launched industrial efforts. SEEA developed an industrial leadership group to serve the region, holding a daylong gathering of individuals representing a multitude of interests. Participants included energy-intensive industrial firms, local utilities, the energy offices of the states in involved, and myriad DOE partners. These stakeholders agreed to the formation of a coalition to address industrial energy efficiency issues that they deemed worthy of

[8] See http://www.stacenergy.org/about/index.htm for more about the State Technologies Advancement Collaborative.

their joint attention. The coalition intends to operate as a consensus organization, enlisting a number of subcommittees to address both policy and technology issues.

Similarly, SWEEP and the Colorado Energy Office are launching an industrial energy efficiency initiative this year, in response to a request embedded within the *Colorado Climate Action Plan*. This voluntary effort would ask industrial companies to set energy intensity reduction goals and engage in "all cost-effective energy efficiency projects." The plan also includes resources for technical assistance and an effort to recognize the most notable participants. SWEEP intends to support similar efforts in the other states it serves as well (7, 12).

Multi-Stakeholder Goals

Because energy security, climate change issues, and general environmental concerns have begun to influence federal, regional, state, and local energy policies and programs, energy efficiency program managers have been tasked with a multitude of goals and objectives. Some are developed in-house as a means of encouraging the program to accomplish more, but many are developed externally by utility regulators or legislative bodies setting efficiency goals, environmental goals, energy security goals, and climate change-related goals in an attempt to mitigate the negative impacts of energy use and to reduce the need for additional sources of energy generation. Consequently, many program managers indicated in the survey that the goals they are now facing are more numerous and more difficult to achieve than in many years past, and are set by a wider array of entities.

In response to new goals in Minnesota, CenterPoint Energy has commenced a market assessment with other area utilities to help identify new ways to achieve customer savings and eliminate barriers to savings. In response to new savings goals and funding for industrial programs, NYSERDA has dedicated additional funds to securing a partner to help increase outreach to its industrial customers. Many of the survey respondents noted that they did not believe that their regulators fully understood the degree to which new savings goals were posing a challenge to their programs. Furthermore, several programs encouraging efficiency and sustainability are operating in the same service area and with similar savings objectives, presenting additional challenges to industrial program managers.

For example, in the Pacific Northwest region, multiple entities are working together to achieve energy savings and advance market transformation in the industrial sector. A variety of utilities help administer efficiency programs in conjunction with the Bonneville Power Administration, which works closely with NEEA. NEEA, in turn, is a partner of the Energy Trust of Oregon, which collaborates with the Oregon Department of Energy. The entire region is guided by power plans developed by the Northwest Power and Conservation Council, and is served by an industrial assessment center, which is sponsored by the US DOE and operated out of the energy program at the University of Washington. Meanwhile, at the state level, Washington, Idaho, and Oregon all have their own sustainability goals, as do a large number of their counties and cities. Some of these goals are codified as targets for energy efficiency, others for carbon emissions reductions, and still others as simply a collection of state incentives and services designed to reduce energy consumption. In addition to these goals, the Western Climate Initiative calls for voluntary greenhouse gas reduction efforts in both Washington and Oregon (9, 10, 14).

Similar amalgams of complementary and competing energy-related efforts can be found in nearly every corner of the country. It is no wonder, then, that at least half of the survey respondents noted the increased difficulty of operating within multiple programs with disparate goals. With several programs functioning in the same region, it can be difficult for program managers to effectively reach out to their industrial customers through the din of so many other marketing and outreach efforts.

Custom Programs

The past decade has seen an increase in customizable programs (16), which was also reflected as a continuing trend in the survey. Programs have become more responsive to very specific customer needs, and as programs mature and familiarize themselves with their customers, further opportunities for customized approaches can appear.

While narrowly-focused prescriptive programs remain integral components of many industrial energy savings efforts, a general trend towards increased flexibility can be seen in a variety of programs. These more flexible services take several forms and seem to exist primarily in well-established and mature programs that possess an intimate understanding of their customer base. Nearly every survey respondent with a program older than a few years indicated that some form of custom industrial incentive program was available to customers. A near universal consensus was that, while custom programs tend to be more expensive to administer, they are the best way to reach the industrial sector and help industrial customers meet their most complex needs. Though these programs cost more and require greater resources to administer, they can often achieve savings that prescriptive programs cannot. Conversely, prescriptive programs are ineffectual at achieving savings outside of their particular technology--based scope. Industrial customers with needs outside of this scope are thus not adequately served by prescriptive programs.

Workforce Challenges for Programs

Staffing continues to be a difficult challenge for a number of programs. About half of the survey respondents indicated that they had a very difficult time filling vacant program positions and finding individuals qualified to serve as program administrators. Several respondents noted that it was difficult to find individuals who could learn the technical aspect of the job as well as the customer service skills necessary to be successful. Further, at least five programs said that they had difficulty finding qualified people with appropriate engineering backgrounds, and that their needs to expand their programs could, in the future, be hampered by this challenge.

This challenge is also manifested in the resources that PBE programs are given in order to staff their outreach and technical assistance efforts. Several programs indicated that they have been encouraged by their regulators or their management to use external, contract employees when possible, because hiring in-house staff is viewed as more expensive. The implications of this will be further discussed in the next section of this report.

MAKING TOMORROW'S INDUSTRIAL PROGRAMS BETTER

A review of previous literature and the findings from our primary research indicates that industrial PBE efficiency programs are constantly improving and appear to be better meeting the needs of their industrial customers than in the past. The growth of industrial energy efficiency programs is heartening, as a tremendous amount of energy savings is available in the sector. In this section, we will discuss the findings from our research and give recommendations on how these findings might be interpreted by an industrial efficiency program. A special section is included, discussing important lessons for new and expanding programs, which are becoming more common in states across the U.S., though not in Canadian provinces.

Based on the responses to our survey, it appears that many of the new and emerging trends can be linked to an increased awareness and responsiveness to a program's client base. Much of the funding for the expanding programs and new program elements is a result of the increased funding for energy efficiency in general that has been prioritized by state-level leadership. To date, 19 U.S. states have instituted energy efficiency portfolio standards, which generally require that a certain portion of each of the local utility's sales be provided through efficiency investments instead of new generation (6). As we have seen a rise in these kinds of standards and other supportive efficiency policies, industrial efficiency programs have clearly been seen as critical to finding and achieving energy savings in the industrial sector, where significant savings opportunities exist.

Many of the trends identified in the previous section reflect a general movement toward greater program flexibility. This flexibility can be found embedded within individual program approaches to their customers as well as in the program leadership itself, as programs respond to the multiple goals associated with both energy use and climate change. To a large degree, such flexibility is a result of leadership among regulators.

The trend toward energy management and behavior-focused programs by PBE programs can in some ways be viewed as a response to the deeper energy savings that reside in people's actions, and the need to create flexible programs that can be seamlessly grafted onto existing internal operations of any given company. Programs that look to address how energy is used, managed, and understood by people in a firm will, by necessity, need to work within the confines and constructs of a firm's day-to-day operations. This is a more nuanced and flexible approach to achieving energy efficiency than, say, offering incentives for the deployment of a certain type of technology that may or may not be an appropriate fit for a company. A flexible and expert consultant who is highly responsive to specific customer needs visits, and just happens to be paid for by the local utility. This comes across more like a private sector service and less like a heavy-handed government-sponsored program that some firms loathe.

The beauty of program-supported energy managers and corporate management programs is that these in-house or outsourced managers can also play a larger role in firm-wide sustainability efforts, which have, in many cases, received increased funding at the corporate level (2). At Puget Sound Energy, the Resource Conservation Program helps to fund an in-house manager, but extends the coverage of the individual beyond energy, to water, sewer, and solid waste issues (11). The program not only helps finance an individual employee, but also provides resources such as accounting software, training, technical assistance, and assistance in developing company goals. This kind of forward-thinking, broad program appears to be structured to maximize corporate buy-in. It structures and markets itself as a suite of tools supporting the kinds of activities the companies really ought to already be thinking about.

The same degree of personalized attention can be said about the higher number of sub-sector-specific outreach efforts that can be found among the surveyed programs. A deeper understanding of a program's customer base allows a program to respond to needs that are very specific to a sub-sector or market. This also brings a new degree of flexibility to the program, as the individual program personnel responsible for working with a certain sub sector often identify new needs and work to shape possible solutions specific to that sub-sector.

Similarly, custom programs are inherently more flexible than prescriptive programs, and are more flexible in their response to customers' needs. While some of the newer programs have not yet developed custom programs, the more mature programs have been able to develop custom programs that they can take into the specific markets of their target areas.

We appear to be seeing this general trend toward more flexibility because growing savings goals require that industrial programs become more creative and find savings in areas that have proven hard to address with more simplistic, prescriptive program strategies. It is important to note that over half of the surveyed respondents indicated that their custom programs more effectively find and achieve energy savings than do their prescriptive programs. This observation should suggest to regulators that allowing their industrial energy efficiency program providers the freedom to be more responsive to their customers' needs, and providing them the resources to run more complex programs is critical to achieving all the possible savings in the industrial sector.

Related to these trends, several programs indicated that they were either implementing, or were hoping to soon implement, programs that allowed for longer timeframes between when a customer becomes eligible for a program and when the eligible project is actually completed. Southern California Edison is one program that features a codified three-year funding cycle in its industrial program. Other programs' allowances for longer timeframes may not be so clear, with projects longer than one year requiring a special contract agreement to allow for the incentive or technical assistance to be stretched further, while other programs do not allow such long projects at all. As noted earlier, industrial companies can be in a variety of positions within their own capital investment cycle, and may not be ready to make a major investment for several years down the road. They may also need a significant amount of time to approve the investment internally, which, added to the time a complicated capital investment takes just to plan, purchase, and install, can well exceed one year.

There were some new developments in the natural gas arena specifically. The recent increase in the number of natural gas energy efficiency programs and corresponding natural gas savings goals may have been in part a response to the natural gas supply concerns after Hurricanes Katrina and Rita in 2005. The federal government itself committed new resources post-hurricanes in its expanded *Save Energy Now* program, and customers reeling from the high prices worked to curb their use of the fuel (5). As greater energy efficiency savings targets have been developed on the state level, natural gas savings targets are playing an increasingly important role in reducing all energy consumption in any given state.[9]

The research identified a few challenges worth noting. Efficiency programs administered by multiple entities stretch across organizations, time, and geography. Some program managers noted that the savings their programs helped achieve cannot be credited to their programs for regulatory purposes, since they may not officially administer a particular program, but merely supply support services. Survey respondents also indicated that it was becoming more difficult to "claim" energy savings on behalf of their programs in the face of so many other programs.

One of the biggest unmet needs expressed by survey respondents and supported by other recent ACEEE research is the growing challenges that programs face in attracting and retaining workforce with industrial experience. About one-third of respondents noted workforce concerns as their biggest upcoming challenge, as individuals with

[9] For more detail on specific states, please refer to ACEEE's online database of Utility Sector Policies, available here: http://aceee.org/energy/state/policies/utpolicy.htm.

specialized training and experience relevant to their industrial program needs are harder and harder to find. There are two basic categories of skills required in industrial energy efficiency program staff: the ability to conduct the administration, marketing, and outreach of the program; and the ability to use efficiency expertise to address more complicated engineering and technical issues. Some of the larger industrial efficiency programs actually split these two types of skills into two separate positions, though smaller programs have to hire people that can do a little of both. When programs must combine those functions due to limited resources, program managers find it very difficult to find individuals who have both the appropriate engineering and customer-service skills.

This perceived lack of adequate workforce for the energy efficiency sector was echoed by participants at the *2008 ACEEE Summer Study on Energy Efficiency in Buildings*. The Electrical Industry Training Institute, which provides training services to North American utilities, has noted an increasing need for training in demand-side management (DSM) applications, and has responded by expanding its curriculum to better meet the staff training needs of its utility customers.

One of the concerns such a workforce challenge brings is that more programs seem to be looking to third parties to provide the services that their in-house staff cannot. While some programs, such as Wisconsin Focus on Energy, have long successfully used third-party providers to provide much of their services and outreach to the targeted industrial sector, others are feeling forced to use third-party service providers simply because they are cheaper in some cases than hiring in-house staff. Some program managers felt that this outsourcing is a somewhat disturbing development, because they feel that their industrial clients could be better served by hiring in-house staff. Further, as an industry, energy efficiency is growing, and some programs need to build their internal capabilities significantly to meet future savings challenges. Outsourcing that work could, in some instances, prevent the utility or public benefit fund organization from building the institutional knowledge that will be useful as the program grows and matures over time.

The challenge of finding and hiring appropriate workforce is exacerbated by the fact that many program managers are actually competing with their own industrial customers for talented engineers. What is clear is that there is more demand for such talent than there are talented people to fill these roles. Historically, the DOE's Industrial Assessment Center program has helped fill the pipeline of potential program staff, and other university-based educational centers that focus on industrial energy efficiency have helped significantly in producing adept engineers. But even those graduates are not enough to meet the need. A current proposed expansion of the IAC program, supported by ACEEE, would go a long way toward helping produce more talented individuals to staff PBE programs (13).

STARTING A NEW INDUSTRIAL PROGRAM

There are many areas of the country that are, for the first time, developing some type of PBE industrial energy efficiency programs. While the future managers and administrators of those programs were not targeted in this research, there was enough information gathered from the existing programs surveyed to put together a list of important considerations when starting a new industrial program. What follows is a list of critical lessons learned by existing programs that new and emerging programs may wish to consider. A detailed discussion can be found in the full report. These lessons are:

- Get to know your customer,
- Help your customer get to know *you*,
- The importance of persistence and trust,
- Start with assessments—and build internal capacity to do more,
- Identify internal champions, and
- Don't overlook small companies.

Existing industrial programs and existing literature provides extensive help to managers of new industrial energy efficiency programs. Each program will obviously need to be tailored to meet specific, local needs, but certain best practice elements exist that nearly all industrial efficiency programs can deploy. Best practices can be found in numerous places. Nearly all survey respondents indicated that they receive a host of information about best practices from publicly available resources such as DOE's *BestPractices*,[10] or the EPA's geographically-specific *Best Practices*.[11] Some surveyed programs, such as the Bonneville Power Administration, rely on external resources such as *E Source*, a service that provides syndicated information about pressing

[10] DOE's BestPractices program can be found here: http://www1.eere.energy.gov/ industry/bestpractices/.
[11] A number of EPA's Best Practices can be found using this page as a starting point: http://www.epa.gov/cleanenergy/energy-programs/index.html.

energy issues to subscribers or consultants. Most respondents also noted the importance of communication among programs, both at industry energy efficiency-focused conferences and in discussions fostered by groups like the CEE.

While these types of resources are useful, most program managers noted that they have a strong interest in gaining an even better understanding into what their peer organizations are doing. It is often difficult to identify "best practices" that are transferable to the unique needs of an individual region and its industrial mix. Being able to discuss in-depth and at length how other programs are finding success would be useful for program managers wishing to better understand whether a supposed "best practice" might work well within their program. By learning from other programs and discussing shared challenges and opportunities, new programs can use the existing knowledge base to build programs that will achieve the energy savings needed for the future.

CONCLUSIONS

The industrial sector will be critical to meeting our energy-saving and greenhouse gas reduction needs of the future. The industrial sector's energy use is significant, and the energy-saving opportunities are substantial. PBE programs have been a very important component of past industrial energy efficiency savings, and they will play an even more critical role in achieving the industrial savings of the future. Giving these programs the resources and flexibility necessary to reach and serve their industrial customers is the best way to lock in industrial energy efficiency investments that will yield energy savings for years to come.

The industrial sector is indeed a challenging sector in which to encourage energy efficiency. The manner in which energy efficiency investments are made is complex, and in some ways unique to each individual firm, and even each facility. Firms need to better understand their energy use, their energy opportunities, their energy challenges, and the benefits that energy efficiency can bring. A well-structured PBE programs can help them find answers to these issues.

Numerous examples of industrial energy efficiency programs exist that have "gotten it right" in the development and deployment of their programs. Successful programs today are ones that:

- use multiple approaches to reach their industrial customers,
- give industrial firms a high degree of latitude in determining their best path toward efficiency,
- provide a suite of tools that allows the firm flexibility in moving forward on that path,
- solicit feedback from their industrial customers, and
- provide substantial technical and business assistance as their customers consider important business decisions.

While many of the trends and approaches identified as successful in this paper could serve as valuable additions to an existing industrial program, they take on a high degree of importance for new programs that are establishing themselves in the immediate future. These new programs are expanding into markets not historically served by industrial energy efficiency programs, and will serve as important conduits for new information about the best ways to secure energy efficiency in the industrial sector. Helping these new programs learn from more established programs is a role that ACEEE and other organizations, like regional energy efficiency partnerships and alliances, could play.

In addition to new trends and primary data, the research conducted for this report illuminated the level of dedication and commitment that today's industrial program managers show toward their cause. Industrial programs are facing increasing efficiency deployment goals that, coupled with the current economic recession, are proving difficult to achieve in many areas. Despite this, program managers remain, on the whole, enthusiastic about prospects for new efficiency in their sectors and convinced that there is substantial potential for more savings. These programs need the resources and support to achieve those savings for the benefit of all.

REFERENCES

1. [CEE] Consortium for Energy Efficiency. 2008. Consortium for Energy Efficiency's 2008 Annual Industry Report. http://www.cee1.org/ee-pe/2008/us_combo.php. Accessed May 1, 2009. Boston, Mass.: Consortium for Energy Efficiency.

2. Deutsch, Claudia. 2007. "Companies Giving Green an Office." *The New York Times.* July 3, 2007.

3. Ehrhardt-Martinez, Karen, John A. "Skip" Laitner and Kenneth Keating. 2009. *Pursuing Energy-Efficient Behavior in a Regulatory Environment: Motivating Contexts for Policymakers, Program Administrators, and Program Implementers.* Prepared for California Institute for Energy and Environment and the California Public Utilities Commission.

4. Elliott, R. Neal, Miriam Pye, and Steven Nadel. 1996. *Partnerships: A Path for the Design of Utility/Industrial Energy Efficiency Programs.* Washington, D.C.: American Council for an Energy-Efficient Economy.

5. Elliott, R. Neal, Anna Monis Shipley, and Vanessa McKinney. 2008. *Trends in Industrial Investment Decision Making*. Washington, D.C.: American Council for an Energy-Efficient Economy.

6. Furrey, Laura 2009. *State Renewable Portfolio Standards and Energy Efficiency Resources Standards.* Presentation delivered to the Keystone Energy Efficiency Alliance. June 10. http://aceee.org/energy/national/Keystone_6.10.09.pdf.

7. Geller, Howard and Marshall Goldberg. 2009. *Energy Efficiency and Job Creation in Colorado*. Boulder, Colo.: Southwest Energy Efficiency Project. April.

8. [NAM] National Association of Manufacturers. 2005. *Efficiency and Innovation in U.S. Manufacturing Energy Use.* http://www.nam.org/~/media/Files/s_nam/docs/234500/ 234421.PDF.ashx.

9. [NEEA] Northwest Energy Efficiency Alliance. 2009. "About the Northwest Energy Efficiency Alliance." http://www.nwalliance.org/aboutus/index.aspx . Accessed October.

10. [NWPCC] Northwest Power and Conservation Council. 2009. Draft Sixth Northwest Power Plan. http://www.nwcouncil.org/energy/powerplan/6/default.htm. Portland, Oreg.: Northwest Power and Conservation Council.

11. [PSE] Puget Sound Energy. 2009. *Resource Conservation Manager*. Program brochure. http://www.pse.com/SiteCollectionDocuments/business/3642_RCMFinal.pdf. Accessed May 3.

12. [SWEEP] Southwest Energy Efficiency Project. 2009. "About SWEEP," SWEEP website. Accessed June 5. http://www.swenergy.org/about/index.html.

13. Trombley, Dan, R. Neal Elliott, and Anna Chittum. 2009. "Expanding the Industrial Assessment Center Program: Building an Industrial Efficiency Workforce." In *Proceedings of the 2009 ACEEE Summer Study on Energy Efficiency in Industry*. Washington, D.C.: American Council for an Energy-Efficient Economy.

14. [WCI] Western Climate Initiative. 2007 Governor's Agreement. http://www.westernclimateinitiative.org/component/remository/func-startdown/12/.

15. Witte, Patti, Dan York, and Katherine Friedrich. 2009. "Survey of natural Gas Efficiency Programs." Washington, D.C.: American Council for an Energy-Efficient Economy.

16. York, Dan and Martin Kushler. 2003. *America's Best: Profiles of America's Leading Energy Efficiency Programs*. Washington, D.C.: American Council for an Energy-Efficient Economy.

The Results (Lessons Learned) of more than 250 Energy Audits (Industrial Assessments) for Manufacturers by the Louisiana Industrial Assessment Center for the past Ten Years

Theodore Kozman, Director
Jim Lee, Deputy Director

Industrial Assessment Center
University of Louisiana Lafayette

Abstract

This paper and discussion presents the summary and results of energy audits or assessments conducted by the University of Louisiana Lafayette Industrial Assessment Center, which is sponsored by the US Department of Energy, for the first ten years of operation. To insure the confidentiality of our clients, the results are generalized and summarized by industry type and recommendation type. Where the assessment finding and recommendations have been implemented, the implementation rate is shown. For recommendations that have the most significant savings and a high implementation rate, we will show the summarized implementation cost and payback period.

The Industrial Assessment Center of the University of Louisiana Lafayette began operation in FY01 and conducted its first industrial energy assessment in December 2000. In this paper we present the results of this energy assessment and those of approximately 250 more through September 2009. By industrial type, these assessments were for: Oilfield Equipment Manufacturing (~20%), Food and Food Processing (~20%), Petrochemical Manufacturing and Refineries (~15%), Other (non-Oilfield) Equipment Manufacturing (~10%), Ship Building and Repair (~10%), Woodworking, Clothing and Wire Manufacturing (~5%), Paper, Cardboard, Boxes and Bag Manufacturing (~5%), Machining (<5%), Building and Building Materials (<5%), Printing (<5%), and Glass and Ceramics Manufacturing (<5%). The distribution of manufacturers for the State of Louisiana is weighted much higher in the Petrochemical Manufacturing and Refineries, however because of limitations on the amount of energy consumed (restrictions for the Industrial Assessment Centers), many of these are beyond the scope for Industrial Assessment Centers. For the few of these we have performed, we have included them in the results.

For most of the recommendations we make, we try to keep the installation cost (parts and labor) within a two-year payback period. However, we have occasionally looked at longer payback periods when suggestions were made by the clients.

As stated in the abstract this paper is the result of conducting more than 250 industrial plat assessments by the Louisiana Industrial Assessment Center. All of these assessments were performed during the period of December 2000 through August 2009. The makeup of the plants is typical for south Louisiana although some of these plants were in Texas, Mississippi and Arkansas. The plants dominated by the Oilfield Equipment Manufacturing and Food and Food processing.

Because some of the oilfield companies are large plants (refineries and chemical manufacturers) some of these assessments took place over several days.

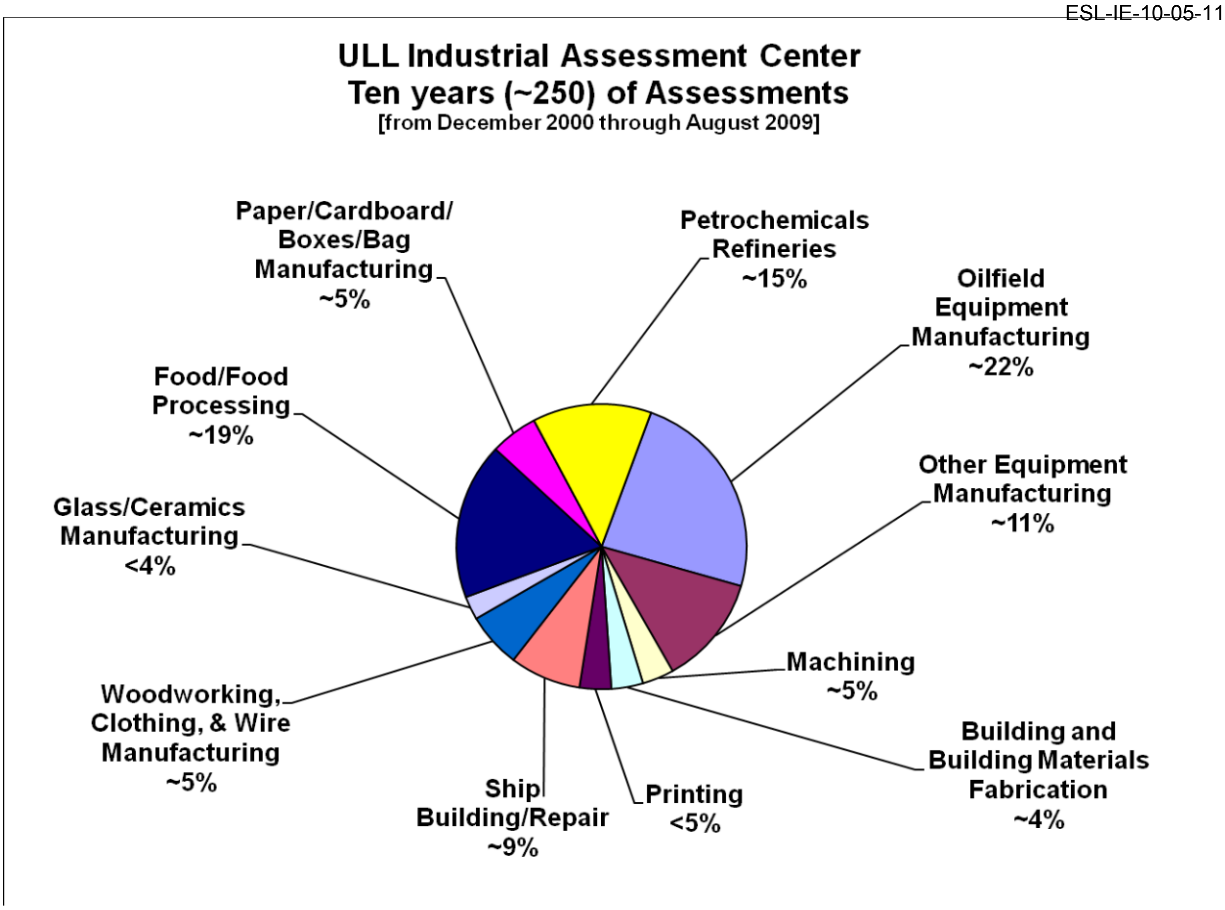
During the course of these ten years of assessments, we have made recommendations totaling more than $173M per year and more than 1650 individual recommendations. During a period of nine years we have averaged about $35M per year in realized implemented savings. Of the implemented savings, 26 percent of the dollar amount has been implemented and about 41 percent of the total number of recommendations has been implemented. Based upon dollars saved, thirty-six percent of our recommendations have been in the area of combustion and steam production, and steam production, 18 are in productivity. While these are the largest by dollars per year saved, the largest number of plants requiring repairing air leaks and/or reducing air pressure. These are upwards of 90% of the plants surveyed.

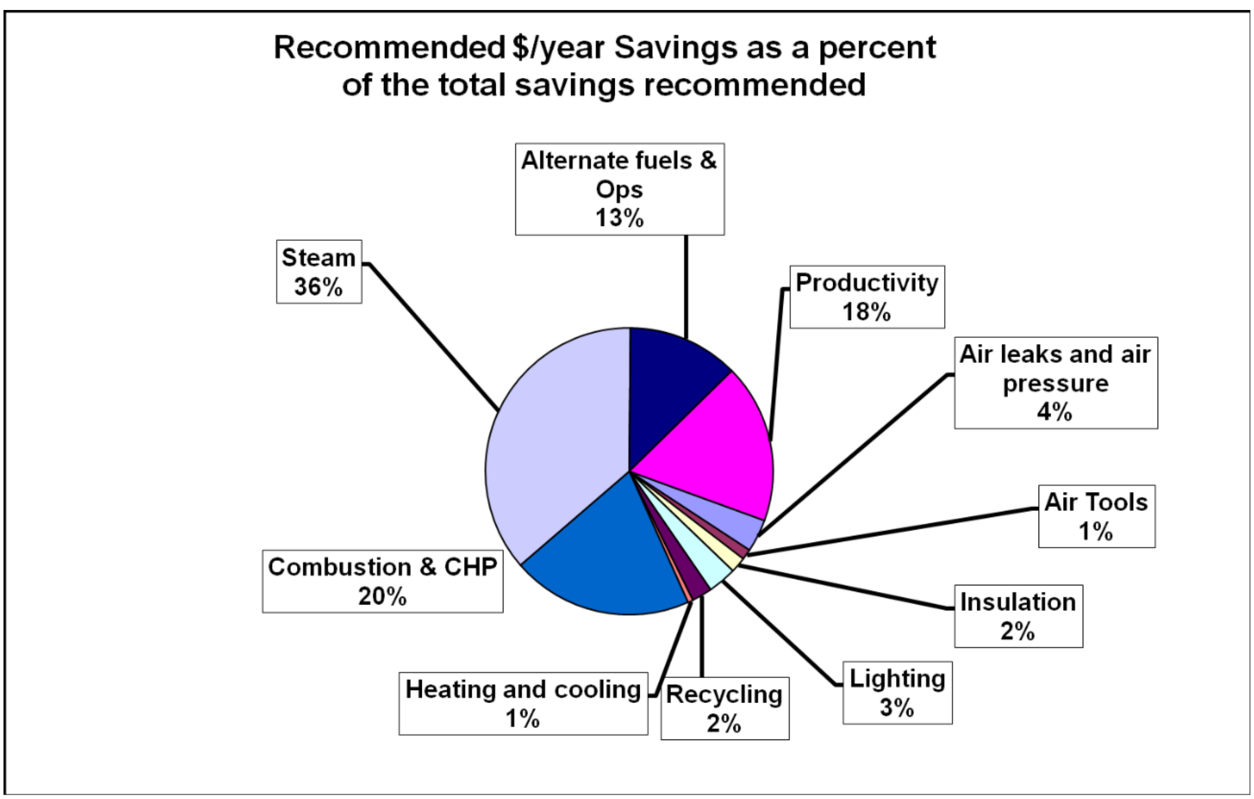
The company type with the greatest percentage of implemented results ship building/repair. This is closely followed by other equipment manufacturing and oilfield manufacturing.

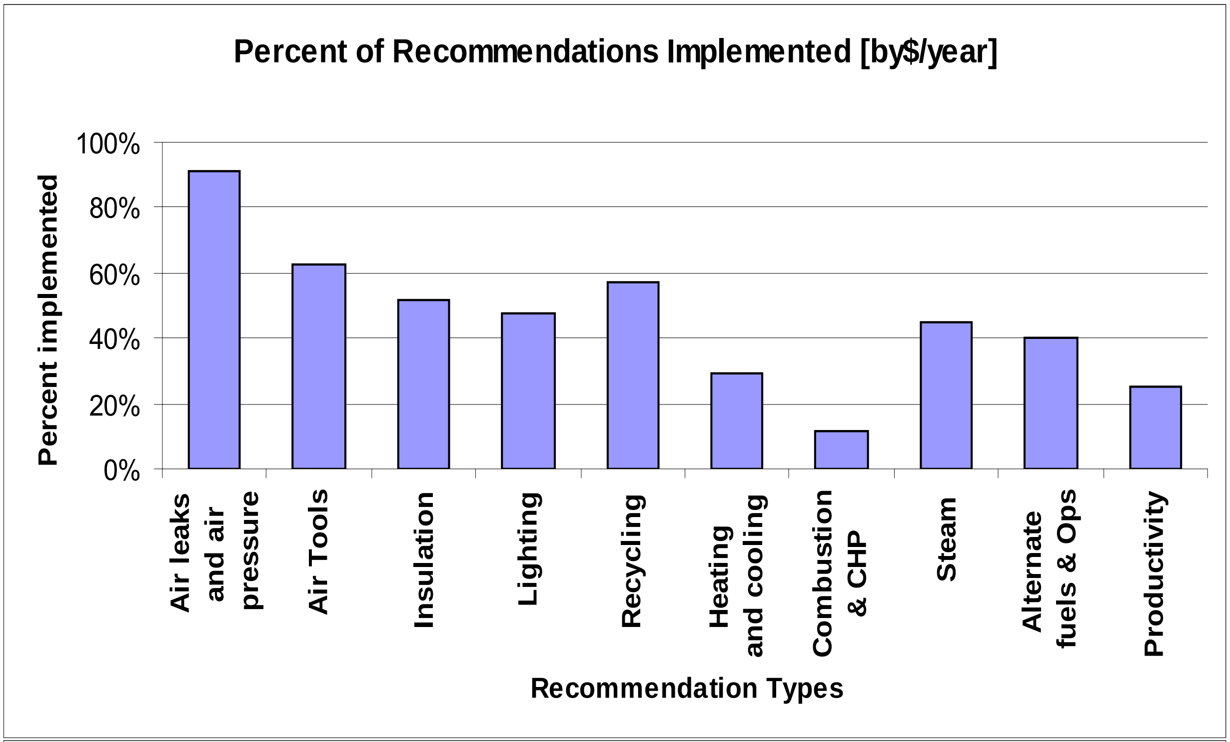
The implemented results with the greatest savings were steam systems, followed closely by alternate fuels and operations and productivity. The reason that steam systems had the percentage as a function of the total is because of the relative high cost of natural gas during the review period. This cost peaked at more than $15.00/MMBtu in the winter of 2006. At that time a significant portion of the country was under-going difficulties with the price of natural gas.

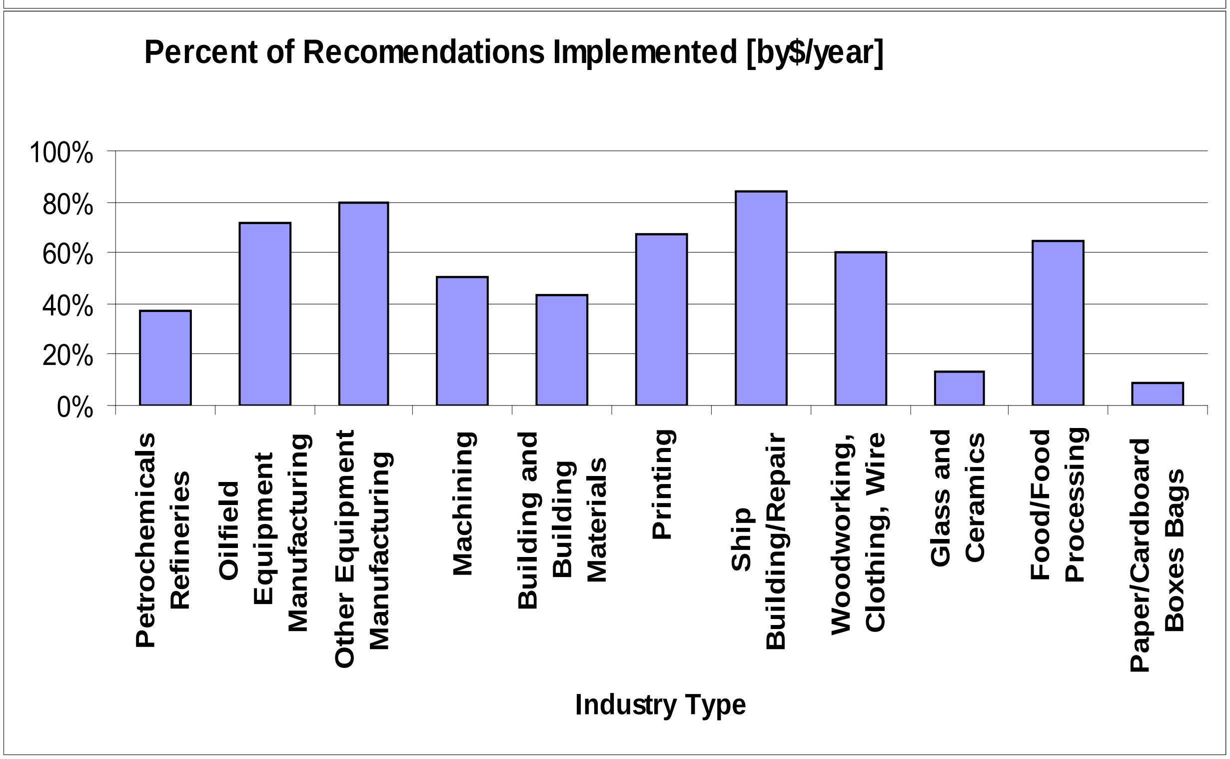
Conclusions

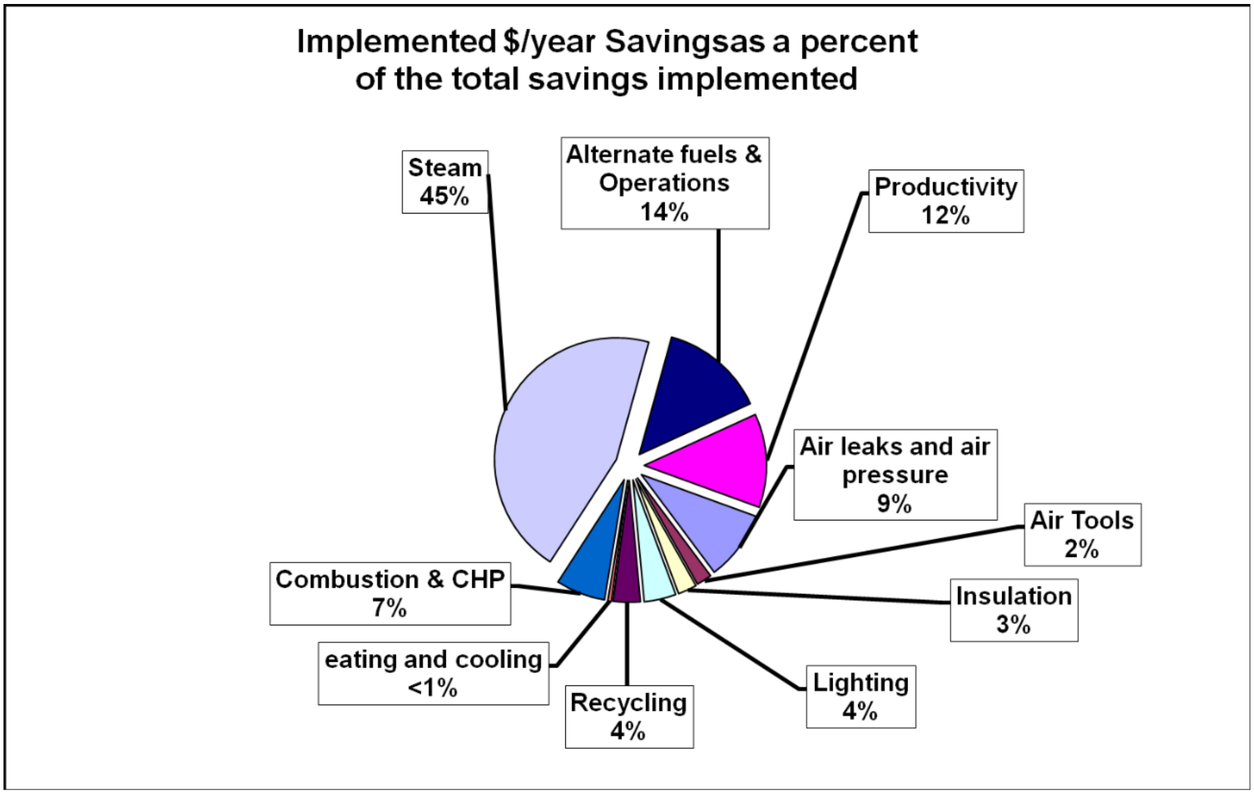
1. Shorter pay-back periods result in a higher implementation rate.
2. Companies with an on-going preventive maintenance program implement a higher percentage of the recommendations made. This is generally because this can be used as fill-in work.
3. In general, energy savings is proportional to energy used.
4. Steam systems (including repair of leaks and faulty traps) yielded the highest dollar savings per recommendation.
5. Repair of air leaks and lowering the operating pressure of the compressed air system are implemented more frequently than any other recommendation. Part of the reason for this is frequently users don't know what the cost of wasted compressed air is.
6. Recycling can be implemented frequently to save waste and disposal costs.
7. Insulation of hot and/or cold surfaces will generally have a payback period of less than one-year.
8. Improving steam system efficiency (overall) can yield a significant savings but may require a plant shutdown for a significant period of time.
9. Lighting and lighting system controller improvements can save significant amounts of energy with pay-back periods of less than one-year.
10. Moving some operations to second or third shift can save money when there is a rate structural differential.
11. Electrically driven tools consume one-sixth to one-eight the amount of energy as air-driven tools
12. The amount of energy used by heating and cooling systems can be conserved with setback devices.

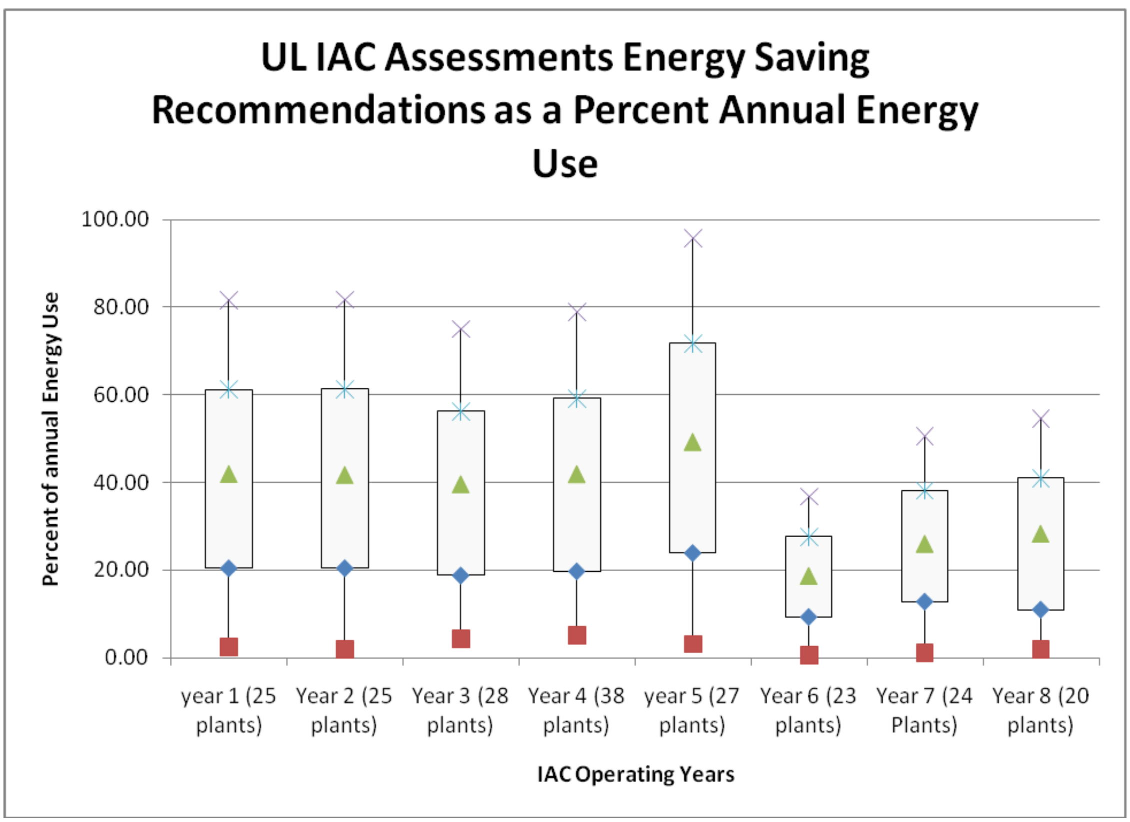

ULL Industrial Assessment Center
Ten years (~250) of Assessments
[from December 2000 through August 2009]
Paper/Cardboard/ Boxes/Bag Manufacturing ~5%
Petrochemicals Refineries ~15%
Oilfield Equipment Manufacturing ~22%
Food/Food Processing ~19%
Other Equipment Manufacturing ~11%
Glass/Ceramics Manufacturing <4%
Machining ~5%
Woodworking, Clothing, & Wire Manufacturing ~5%
Building and Building Materials Fabrication ~4%
Ship Building/Repair ~9%
Printing <5%

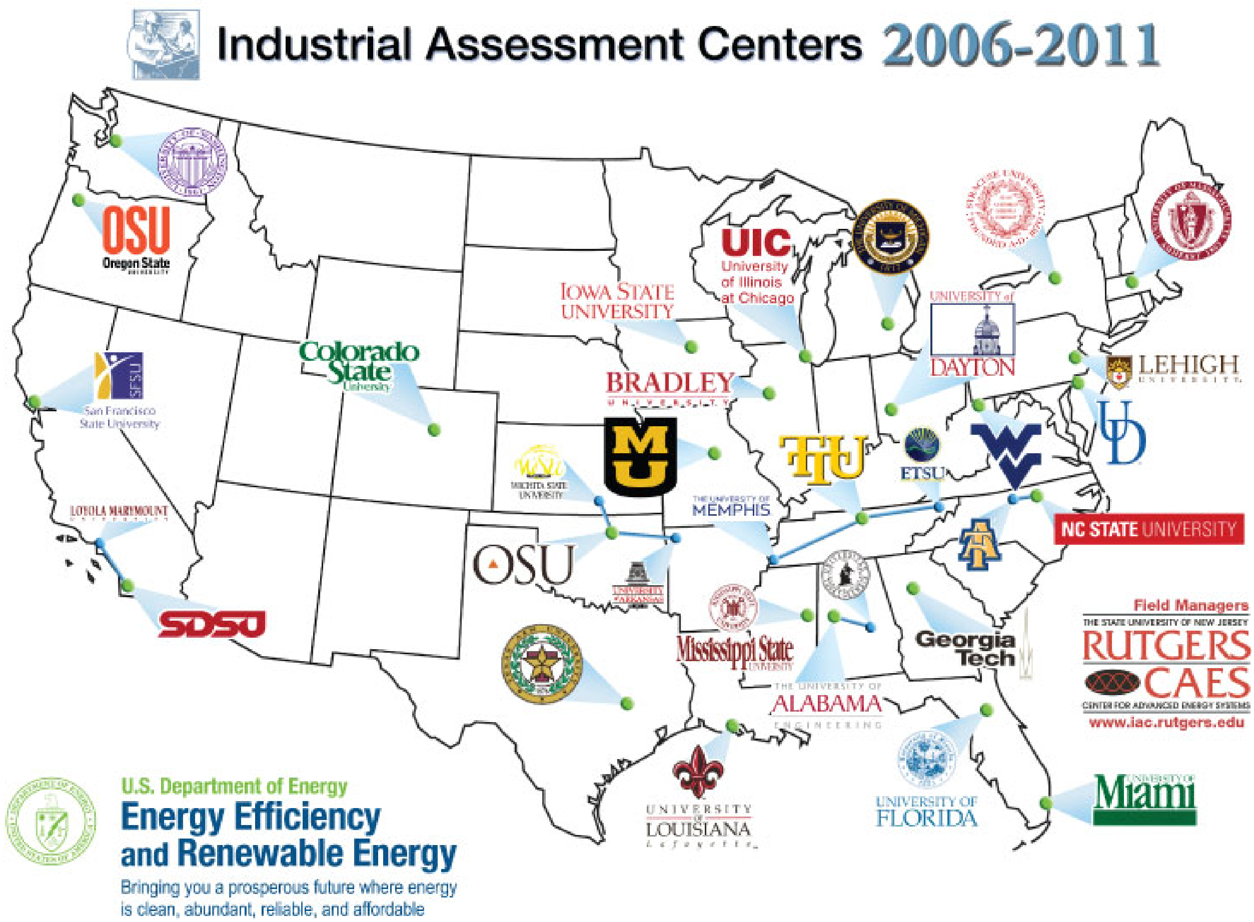

Recommended $/year Savings as a percent of the total savings recommended
Alternate fuels & Ops 13%
Steam 36%
Productivity 18%
Air leaks and air pressure 4%
Air Tools 1%
Combustion & CHP 20%
Insulation 2%
Lighting 3%
Heating and cooling 1%
Recycling 2%


Percent of Recommendations Implemented [by$/year]
100%
80%
60%
40%
20%
0%
Percent implemented
Air leaks and air pressure
Air Tools
Insulation
Lighting
Recycling
Heating and cooling
Combustion & CHP
Steam
Alternate fuels & Ops
Productivity
Recommendation Types


Percent of Recomendations Implemented [by$/year]
100%
80%
60%
40%
20%
0%
Petrochemicals Refineries
Oilfield Equipment Manufacturing
Other Equipment Manufacturing
Machining
Building and Building Materials
Printing
Ship Building/Repair
Woodworking, Clothing, Wire
Glass and Ceramics
Food/Food Processing
Paper/Cardboard Boxes Bags
Industry Type


Implemented $/year Savingsas a percent of the total savings implemented
Steam 45%
Alternate fuels & Operations 14%
Productivity 12%
Air leaks and air pressure 9%
Air Tools 2%
Insulation 3%
Lighting 4%
Recycling 4%
eating and cooling <1%
Combustion & CHP 7%


UL IAC Assessments Energy Saving Recommendations as a Percent Annual Energy Use
Percent of annual Energy Use
100.00
80.00
60.00
40.00
20.00
0.00
year 1 (25 plants)
Year 2 (25 plants)
Year 3 (28 plants)
Year 4 (38 plants)
year 5 (27 plants)
Year 6 (23 plants)
Year 7 (24 Plants)
Year 8 (20 plants)
IAC Operating Years


Industrial Assessment Centers 2006-2011
OSU
Oregon State
San Francisco State University
LOYOLA MARYMOUNT
SDSU
Colorado State University
IOWA STATE UNIVERSITY
BRADLEY UNIVERSITY
UIC
University of Illinois at Chicago
UNIVERSITY of DAYTON
LEHIGH UNIVERSITY
UD
WICHITA STATE UNIVERSITY
THE UNIVERSITY OF MEMPHIS
TTU
ETSU
NC STATE UNIVERSITY
OSU
Mississippi State
THE UNIVERSITY OF ALABAMA ENGINEERING
Georgia Tech
Field Managers
THE STATE UNIVERSITY OF NEW JERSEY
RUTGERS
CAES
CENTER FOR ADVANCED ENERGY SYSTEMS
www.iac.rutgers.edu
UNIVERSITY of LOUISIANA Lafayette
UNIVERSITY OF FLORIDA
UNIVERSITY OF Miami
U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

THE ROLE OF BENCHMARKING IN PROMOTING STRONG ENERGY MANAGEMENT SYSTEMS

Walt Tunnessen
US Environmental Protection Agency

The significance of formalized energy management practices and programs in driving and sustaining energy efficiency improvements within the industrial sector has become more widely recognized over the past several years. The release of the ISO 50001 energy management standard will also further elevate the role of energy management systems. For over the past 10 years, the US EPA's ENERGY STAR Commercial and Industrial program have focused on promoting and supporting the development of strong corporate management programs. A key aspect of facilitating the establishment of energy management programs has been the development of benchmarking tools that help companies evaluate the energy performance and practices.

This paper will examine some of the lessons learned in developing both quantitative and qualitative energy management benchmarking tools and the importance of establishing good energy performance indicators. The paper will examine the pros and cons of different types of quantitative energy performance benchmarks. The value of qualitative benchmarking tools to gauge management practices will also be discussed. Lastly, recommendations for how to further the development energy benchmarks shall be presented.

IMPROVED BOILER SYSTEM OPERATION WITH REAL-TIME CHEMICAL CONTROL

DEBORAH BLOOM
PRINCIPAL CONSULTANT
NALCO COMPANY
NAPERVILLE, IL

BRIAN JENKINS
GLOBAL INDUSTRY DEVELOPMENT MANAGER
NALCO COMPANY
NAPERVILLE, IL

ABSTRACT

The steam boiler system is a critical component of most manufacturing processes. Steam production reliability is often a key component in product quality and overall production efficiency. Hourly steam load demands can swing by as much as 500% in some plants, making responsive water treatment of the boiler system difficult. This challenging production environment is made even more so by volatile economic forces in today's world.

New technologies have been developed that help steam operations staff achieve more consistent, proactive boiler feedwater treatment by detecting system variability, determining the correct chemical or operational action, and delivering measurable environmental return on investment (ROI).

These new technologies will be described and several case histories presented.

INTRODUCTION

One operates a boiler as part of some broader, overall strategy or mission – keeping people comfortable (a hospital, university or other commercial campus); producing steam to drive turbines and generate electrical power (power plant), or to heat a process (numerous manufacturing processes). In the past, the primary goal was to keep the boiler operational; other considerations took a secondary, tertiary or even lower priority.

As time has gone on, the marketplace has become more competitive, and industry's environmental awareness has increased. The competitiveness of the marketplace has resulted in a drive to extend equipment life (equipment such as a boiler system), reduce fuel and water costs, and optimize operational labor costs. The increased environmental awareness has resulted in major corporate initiatives to reduce greenhouse gas emissions, and fuel and water consumption.

A BRIEF HISTORY OF BOILER WATER TREATMENT

There are many water-related challenges encountered when operating a boiler. Two of the most common problems are scale and corrosion.

Scale is the result of dissolved minerals, such as calcium and magnesium, exceeding their solubilities and forming deposits (1). Boiler heat transfer efficiency (Figure 1) can be negatively impacted by scale. In addition scale can also create serious under-deposit corrosion problems. Scaling conditions, when not addressed in a timely fashion or when improperly dealt with, can result in ruptured boiler tubes or other boiler damage. This can cause boiler shutdown and lost or greatly reduced production.

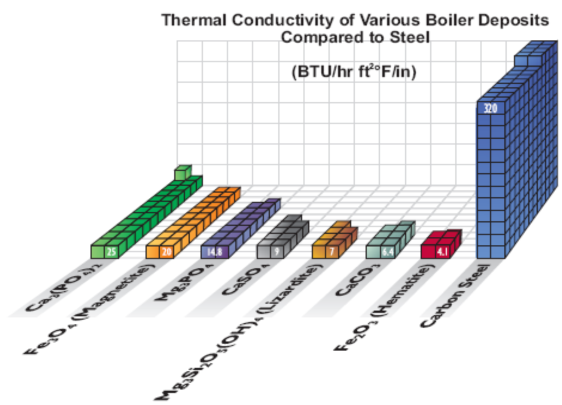


Figure 1. Boiler scale greatly impedes heat transfer and reduces efficiency

Some of the more common ways to prevent scale from occurring in boilers include ion exchange (softening or demineralization) and reverse osmosis. Residual dissolved minerals are prevented from forming scale by the addition of chemical treatment. Table 1 (2) shows a brief history of boiler scale control chemistry.

Table 1 – Summary of Boiler Scale Control History (2)

Type of treatment	Developed (est.)	Major advantages	Major disadvantages
Coagulant / Soda Ash*	1900-1950	Reduced potential for scale compared to no treatment, softens scale for easier removal. Reduced scale means longer boiler life and improved heat transfer compared to no treatment.	Still generates scale, which impedes heat transfer, and can increase energy costs. Treatment adds solids to feedwater, thereby increasing blowdown requirements and energy losses. Soda ash can increase condensate corrosion due to CO_2 generation
Phosphate	1930's	Reduced potential for $CaCO_3$ scale. Reduced solids contribution compared to coagulant programs.	Still has potential for phosphate scale
Chelant	Early 1960's	Maintains hardness in a soluble state, reduces solids contribution to boiler feedwater compared to phosphate or coagulant programs.	Potential for corrosion due to overfeed, and potential for $MgSiO_3$ precipitation.
Phosphonates	Late 1970's		Could result in scale if feedwater hardness not well controlled.
Polymer overlay for chelant or phosphate treatment	Late 1970's	Conditioned specific types of suspended solids (eg, Fe_3O_4, Fe_2O_3, $Ca_3(PO_4)_2$ and $MgSiO_3$) to make them less adherent to boiler surfaces.	Same as listed under "Chelant" and "Phosphate".
Polymer only - first generation – polyacrylic acid	Early 1980's	Maintains hardness in a soluble state, reduces solids contribution to boiler feedwater vs phosphate or coagulant programs; reduced corrosion potential vs chelant programs**,** reduces iron deposition rate by dispersant activity**.**	If overfed, these polymers can complex with boiler metal and corrode equipment. High hardness levels can result in polymer precipitation and deposit in the boiler.
Polymer only – latest generation – sulfonated polymer	2001	Maintains hardness in a soluble state. Less corrosive than chelant. Increased thermal and oxygen stability, keeps suspended solids dispersed, does not precipitate or form precipitates, reduces iron deposition rate**.**	Could be corrosive if overfed.

*(*Although still in some limited use today, modern, more cost effective pretreatment technology has made coagulant programs nearly obsolete)*

Corrosion, the commonly used term to describe the process of returning refined metals (3), such as boiler metal or feedwater piping to its native, oxidized state, is a serious concern in the pre-boiler and boiler system for two reasons. First, it shortens the asset life of the boiler and pre-boiler system. Second, the corrosion by-products resulting from unchecked corrosion can deposit in high heat transfer areas of the boiler as scale. Oxygen corrosion is a specific and particularly devastating type of corrosion (Figure 2). It is a common problem that adversely affects the life of the key steam system components. Pitting attack from oxygen corrosion can cause premature metal failure.

Iron oxide scale, just as the earlier described calcium and magnesium scales, reduces heat transfer efficiency. In uncontrolled scenarios, blown tubes (or other extensive boiler damage), boiler shutdowns and production losses can result.

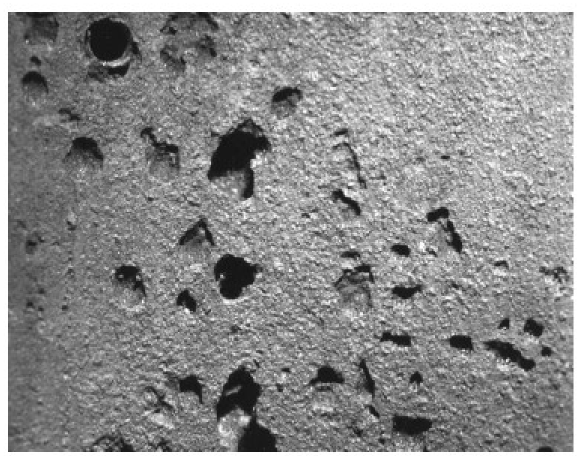


Figure 2. Oxygen attack, characterized by its classic pitting appearance

Historically, the best practice for preventing oxygen corrosion in boiler and pre-boiler systems has been mechanical deaeration for primary oxygen removal, followed by chemical oxygen scavengers to remove remaining trace quantities.

For decades, the traditional practice employed to control many boiler water scale and oxygen control chemistries has been by sampling the blowdown. One primary reason for this was that the boiler concentrated the treatment chemicals sufficiently to enable them to be measured readily. Although modernization and improvement in test methods have enabled feedwater testing (e.g., cycling up is not required to run many of the tests), many operations hold onto the old practices of the 1930s through 1970s and test only in the blowdown. The major drawbacks resulting from this approach are related to the lag time between changes in feedwater conditions and those changes showing up in the blowdown.

In a blowdown based control scenario, the operator would sample the blowdown, perform an array of chemical tests, and adjust the feed rate of the scale inhibitor or the oxygen scavenger. This constant “add chemical - sample – test – adjust” control loop was the standard. This meant that if a test was missed, an opportunity for adjustment was also missed.

In addition to the challenge of the above testing loop, the physical capacity of the boiler often meant that a negative change in feedwater conditions might go completely undetected or not have a notable impact on the boiler blowdown composition for hours or even days. Feedwater conditions that were potentially adverse to system integrity (e.g., an oxygen excursion, a reduction in feedwater pH, or a badly contaminated condensate return stream) would only be seen after they had become history, if they were detected at all, because only the boiler water was being tested. What was missing was a proactive approach to protect the boiler as opposed to a reactive approach that adjusts after damage has occurred.

Ideally, one would want to measure and control boiler chemistry in the feedwater, because that would enable one to make adjustments to changing conditions in real-time, rather than chasing events or missing them entirely and suffering the outcome.

NEW CONTROL TECHNOLOGY:

The new boiler feedwater treatment automation system is a combination of two different Nalco technologies. First is the patented solid state fluorometer, which is used to control boiler internal treatment (4, 5). The second technology is the new, patented Nalco Corrosion Stress Monitor (NCSM). This instrument works by measuring the oxidation reduction potential at the temperature and pressure of the boiler feedwater. The At Temperature Oxidation Reduction Potential, or At Temperature ORP, detects changes in the corrosivity of the feedwater and can be used to control the oxygen scavenger feed. The AT ORP has a design rating up to 500°F and 3,000 psig. A uniquely designed controller controls both the fluorometer and AT ORP. Monitoring, On / Off Control, and PID (Proportional-Integral-Derivative) Control are all possible with this controller.

Scale Control

The use of fluorescent tracers for system diagnostics and dosage control of treatment chemicals is a technology that has been in practice for many years. This method involves adding an inert fluorescent molecule to a water treatment product in a known proportion to the active ingredients. The fluorescent molecules are inert and are unchanged by the conditions in the water being treated. They are also easily detectable in the water with an instrument called a fluorometer, and measurement of the tracer gives a quick and highly accurate value for the amount of treatment that has been added to the system. Typically, tracer measurements are used to control the feed of the scale inhibitor treatment.

Fluorometer

The fluorometer used in this technology application is a new solid-state fluorometer that can measure and/or control proprietary boiler internal treatment products. It automatically responds to boiler system changes and maintains optimum treatment levels of highly effective scale and deposit inhibitors to keep boilers clean and free of scale and deposits.

The online fluorometer consists of a flow cell, LED light source, filters, and detectors. The filters and detectors are tuned to specific light frequencies unique to specific traced internal treatment products and resultant process reactions. The LED light source is extremely bright at the appropriate frequencies to reliably and repeatedly measure the chemical properties of the flowing water.

Corrosion Control

Corrosion of metals involves electrochemical reactions with charge transfer occurring at interfaces. The rate at which this transfer of charge occurs, or current, depends on the driving force, or voltage applied across the local system. Typically, as dissolved oxygen is added to a system, the ORP increases. When oxygen scavenger, or reductant, is added to the system, ORP decreases. The ORP reflects the composition of the system with respect to electroactive species. It is important to note the impact these species have on corrosion. While the ORP is not a direct measurement of corrosion potential, it is a useful indicator of the feedwater corrosivity (6).

At Temperature ORP

Figure 3 shows a commercial AT ORP probe. The probe assembly consists of a system water sample inlet and outlet, a connection for an integral RTD (resistance temperature detector) and platinum electrode (Pt Probe), and a separate external pressure-balanced reference electrode (Reference Probe). The reference electrode is filled with 0.1 N KCl in this case. All of the active portions of the three attached probes reside in close proximity within the cell itself.

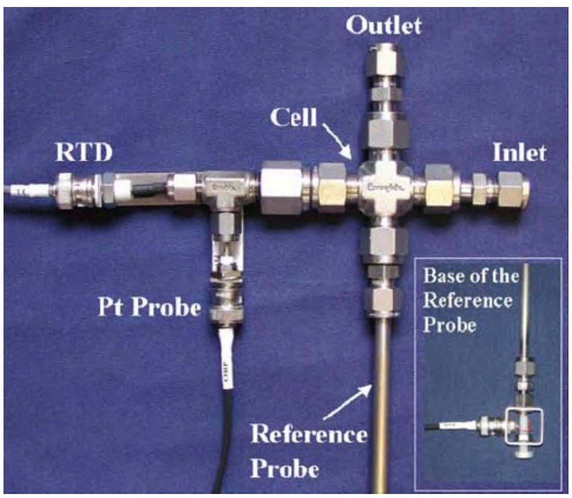


Figure 3. AT ORP Probe Assembly

The cell arrangement also consists of a high-pressure cell and high-pressure fittings that house the electrodes. The potential of the Pt Probe is measured against the external, pressure- balanced silver/silver chloride reference electrode (0.1 N KCl internal filling solution). The temperature of the water flowing through the cell is also recorded as a function of time.

There are a number of reasons why it is important to measure the feedwater ORP value at the boiler feedwater temperature and pressure:

- AT ORP is much more sensitive. It can see effects at high temperature that cannot be seen at room temperature.
- Corrosion rates vary with temperature and pressure. Corrosion is occurring at the operating temperature, so we need this correlation for proper corrosion control.
- AT ORP has a fast response time due to quick probe response coupled with sampling earlier in the stream.
- Scavengers/passivators work better at higher temperatures and pressures so control is more sensitive and realistic with AT ORP.

When comparing ORP readings, it is important to understand the differences between reference electrodes. Relative scales must also be standardized. Since both ORP and corrosion rates are very temperature dependent, AT ORP is a much more useful reading than Room Temperature ORP (RT ORP).

OPPORTUNITIES FOR ENERGY SAVINGS

Controlling boiler scale can have real energy savings benefits. There are many different sources of boiler scale – two of the most common are feedwater hardness and dissolved iron entering the boiler feedwater as the by-product of oxygen corrosion.

The new control technologies can have profound impact on minimizing the potential for scale, as well as mitigating its impact. Since the scale inhibitor is measured in the boiler feedwater and adjusted in real time, regardless of changes in steam load, underdosing and overdosing can almost be completely eliminated. Since the boiler feedwater corrosivity is likewise being monitored and controlled in real-time, feedwater corrosion excursions, and the resultant scale-forming dissolved iron can also be greatly reduced.

Other opportunities for energy savings spring from these technologies. It is important to remember that sulfite, one of the most common oxygen scavengers, contributes dissolved solids to the boiler feedwater. These solids increase boiler water conductivity. In a scenario where excessive levels of sulfite oxygen scavenger are being fed, improved control of oxygen scavenger feed can result in reduced boiler feedwater dissolved solids, higher cycles of concentration in the boiler, and reduced blowdown, all with associated water and fuel savings, Figure 4.

This technology also has the capability of monitoring and controlling feedwater pH, so energy and water savings from reduced feedwater dissolved solids, higher boiler cycles, and reduced blowdown can also be obtained by facilities that use caustic (sodium hydroxide) for controlling feedwater and boiler water alkalinity.

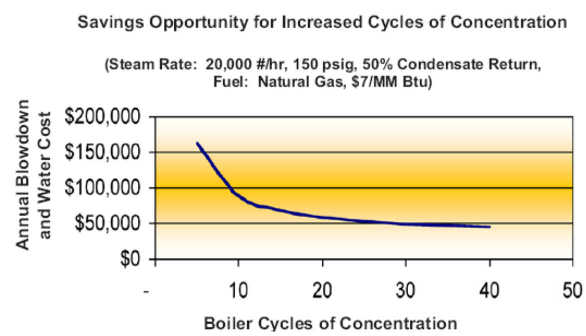


Figure 4. Increasing boiler cycles, properly done, provides great opportunities for energy savings

To show the benefits of this technology, many trials and commercial installations were studied in detail. This paper discusses two applications of this feedwater treatment automation. Both system control improvements and diagnostic benefits are discussed.

CASE HISTORY 1: MIDWESTERN UNIVERSITY(6)

By implementing the new boiler automation, a university was able to improve the operation and energy efficiency through proper internal treatment, reduced boiler scale and increased cycles (approximately $26,910/year water savings). The university was also able to minimize the number of boiler feedwater scale and corrosion events to extend the life of its equipment.

Site Background

A Midwestern university contains three natural gas-fired 175 psig water tube boilers that provide steam to a network of campus buildings, laboratories and a hospital. The university was under pressure to reduce energy costs and water usage while maintaining a sustainable campus. Increasing manpower efficiency was also important to the university. Plant personnel were interested in how the new boiler feedwater treatment technology could address these issues and extend the life of their boiler system assets.

The trial was conducted in three phases: 1. Baseline monitoring to establish our starting point as well as existing control and chemistry; 2. Feed and control of internal treatment using the new technology; and 3. Feed and control of the oxygen scavenger (sulfite) using the new AT ORP.

Trial Findings

Prior to this trial and during the monitoring phase, the feed and control strategy for the internal treatment (polymer based) was to manually feed the scale inhibitor for internal treatment based on steam production and steam tables. The goal was to maintain a constant 4 ppm of product in the feedwater. In addition, oxygen scavenger (powdered sulfite) was fed manually to a day tank and added to the system based on blowdown residual readings. Boiler blowdown was controlled by manual adjustment based on periodic measurement of boiler conductivity resulting in typical blowdown rate of 3.3% or 30 cycles of concentration.

The sulfite was fed to the deaerator very near the drop leg from the storage section. As is common, the pre-trial control method for the oxygen scavenger was to sample the boiler water via grab samples and titrate to determine sodium bisulfite residuals. Once the residual level was determined, then the operators adjusted the sodium bisulfite feed pump accordingly to maintain a target residual. This has been accepted practice for over 75 years. As seen in both Figure 5 and Figure 6, this control method does not minimize the corrosion stresses in the feedwater system. The green color in the figures indicates a "reduced" state of less corrosion, whereas, the red indicates an "oxidized" state, or more corrosive. The operator at the university turned off the sodium bisulfite pump

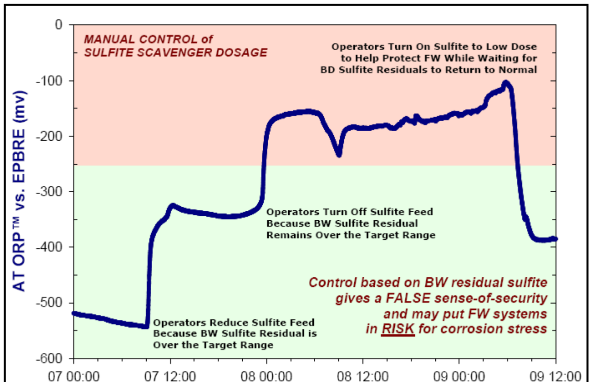


Figure 5. AT ORP during monitoring phase,

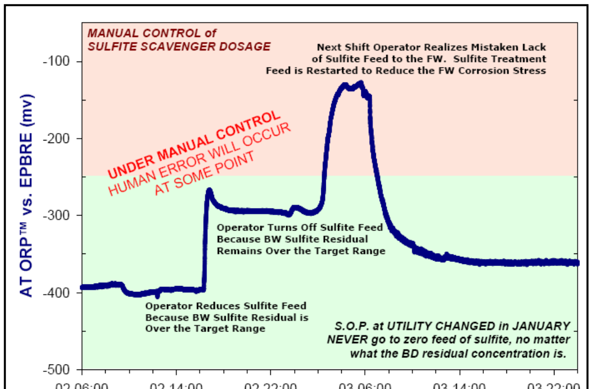


Figure 6. AT ORP during monitoring phase, incident 2

once the residuals were over the target range. Almost immediately, the ORP reading jumped up to an oxidized, or corrosive, state. Once the sodium bisulfite pump was re-started, the ORP reading returned to a reduced state.

The second phase consisted of the internal treatment improvements. The baseline data showed that the plant rarely achieved the proper amount of chemical in the boiler through manual control based on steam production (see Table 2). Since this approach showed sporadic results with constant highs and lows of product in the system, this approach resulted in a higher tendency of scale formation and increased energy costs. Next, the boiler scale inhibitor feed and control was switched to the new boiler controller. The controller uses an inert tracer which directly correlates to the amount of inhibitor in the sample monitored. This guarantees the targeted amount of chemical is fed at the right time and in the right amount. Figure 7 shows the before and after improvement in feedwater scale inhibitor concentrations. Samples were taken and compared to the original control strategy and were found to improve average levels of inhibitor by 30%. See Table 2.

3D TRASAR Control		Manual Control	
TARGET	4.00 ppm	TARGET	4.00 ppm
AVG	3.99 ppm	AVG	3.08 ppm
Std. Dev	0.24	Std. Dev	1.48
3 SIGMA	3.27 ppm	3 SIGMA	0.00 ppm
	4.71 ppm		7.53 ppm
OFFSET	–0.20%	OFFSET	–23%
TIME	92 days	TIME	50 days

Table 2. Control comparison before and after boiler feedwater automation

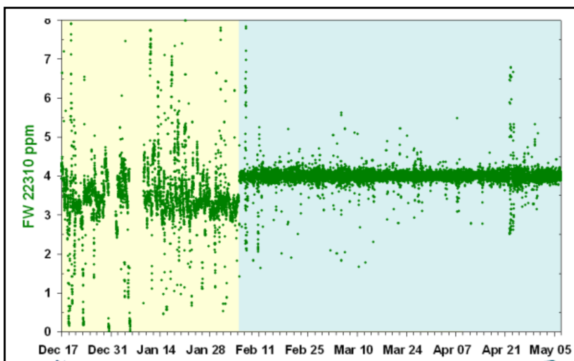


Figure 7. Before / after improvement in feedwater scale inhibitor levels upon implementing one of the new control technologies

The new automation control achieved an average of 3.99 ppm with a target of 4.0 ppm. Even during

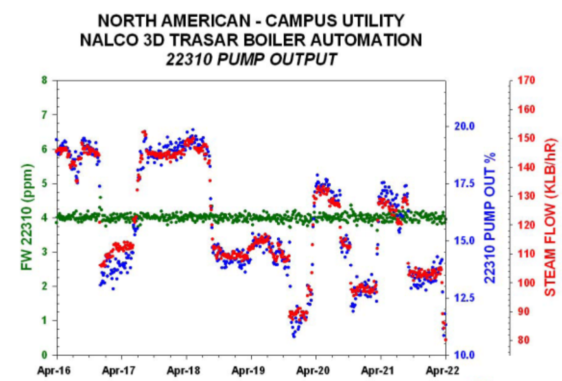


Figure 8. ppm of scale inhibitor, pump output, and steam flow

variable steam loads the boiler controller maintained the consistency of the inhibitor, Figure 8**.** There was no doubt that the new boiler feedwater chemical control ensured the proper levels of scale inhibitor in the boiler.

When the boiler's steam production dropped quickly, the feedwater pumps could not react fast enough. To offset this pressure change, a boiler feedwater pump would recycle or send a portion of the feedwater back to the deaerator to maintain the pressure balance. This recycling process is shown in Figure 9. While this recycling is common, traditional chemical feed methods do not adjust to address feedwater recycle and the overfeed of inhibitor.

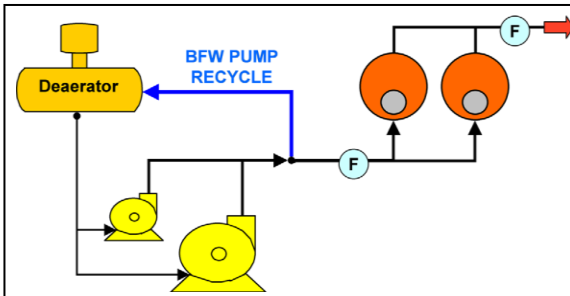


Figure 9 – recycling process flow diagram

Traditional feed and control methods will result in higher chemical usage and costs. The new boiler feedwater treatment automation detected and compensated for the recycle. The controller was able to identify the pre-fed chemical and reduced the chemical feed rate to maintain proper dosage. During this part of the trial, the site also eliminated the use of caustic for alkalinity control. It was observed that there was enough alkalinity in the makeup water to maintain the proper pH. With the elimination of caustic and the associated total dissolved solids contribution, the cycles were increased from 30-50.

This resulted in an annual savings of $26,910. The return on investment for these changes is shown in Table 3.

	Before Installation	After Installation	Difference
Blowdown Energy Cost	38,147	22,577	15,570
Blowdown Sewer Cost	11,114	6,578	4,536
Makeup Water Cost	10,002	3,198	6,804
Sub total (Costs)	59,263	32,353	26,911
NET SAVINGS or (COSTS) $/yr			26,910

Table 3. Energy and Water Costs

The savings amounts do not include labor savings associated with reduced operator testing loads, nor possible chemical savings from reduced chemical usage, due to higher cycles.

CASE HISTORY 2: GULF COAST REFINERY

Situation

A Gulf Coast refinery experienced several boiler tube failures on their 600 psig steam generators resulting in poor steam system reliability. The refinery management team wanted to improve the overall reliability and total system cost of its steam system. An Engineering Approach Analysis was done to understand system gaps and discover opportunities for improvement.

The 600 psig boiler system receives 100% sodium zeolite softened water. Operations was pulling one sample per week to test for boiler feed water total hardness. The results are shown below in Figure 10.

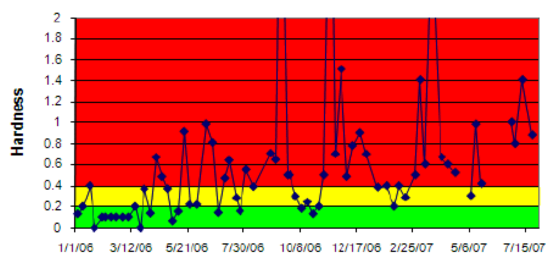


Figure 10. Boiler feed water hardness was in the target zone 45% of the time.

Typical response to elevated boiler feed water hardness levels would include:

- Review of the sodium zeolite operation and corrective action where needed to bring the total hardness levels back into target
- Increased dosage of scale inhibitor
- Increased blowdown

Operations attempted to take corrective action with the tools and knowledge available.

Boiler Cycles

Our analysis of the operational data found that boiler cycles were rather erratic and there was significant room for optimization as shown in Figure 11.

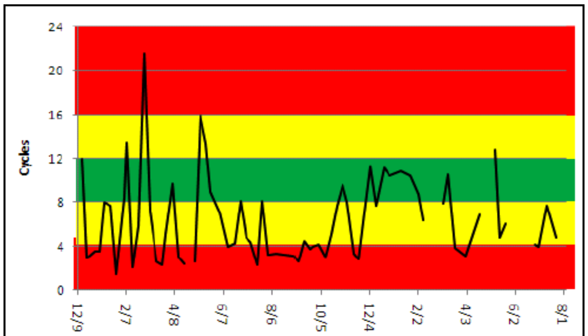


Figure 11. Boiler Cycles - In the Zone Analysis

Refinery Operations was taking daily measurements and attempting to make blowdown adjustments using a manual valve. Achieving good manual control on a highly variable system is very difficult.

Recommendations

After careful review of the customer's system, chemical treatment program, and daily operations using the Engineering Approach Analysis, several recommendations were made.

- Develop a plan to reduce hardness levels in boiler feedwater through additional operator training and implementation of an excursion reaction plan so that, when there is a hardness event, any negative impact can be minimized.
- Replace the current internal treatment product with the most advanced all polymer boiler treatment chemistry.
- Utilize boiler automation to continuously monitor and control the chemical treatment and other critical steam system parameters based on system stress and demand.

Boiler Feed Water Quality Results

The trend in Figure 12 shows the continuous boiler feed water total hardness measurement from the fluorometer. Although there were occasional spikes above the best practice target, the off-spec measurements were quickly brought back into control. Plus, any time the hardness went out of target, the unit went into alarm mode and action was quickly taken to bring the hardness back into specification or control.

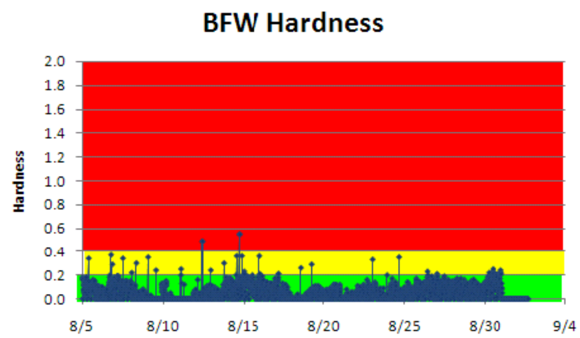


Figure 12. Boiler feed water hardness was in the target zone 89% of the time

In the event of a significant hardness event, the controller would not only alarm, but would also automatically increase the all-polymer treatment dosage to account for the additional stress on the system. At this time, this fail-safe mode has not been required.

Given the system design, an all-polymer/fluorescent tracer set point of 30 ppm was selected. The all-polymer dosage control was achieved by the automation system as shown in Figure 13.

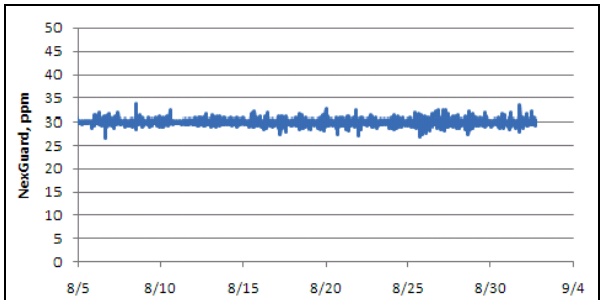


Figure 13. All-polymer internal treatment dosage

The boiler automation controller is able to maintain a precise dosage even when there are system upsets. The trend shown in Figure 14 shows how the all-polymer setpoint of 30 ppm was maintained even with a sudden load increase on the #9 boiler due to another boiler going down unexpectedly. Although the boiler feed water flow rate increased by almost 30% in a matter of minutes, the new automation control system was able to maintain good control, assuring boiler reliability even under stressed conditions.

In fact, boiler automation controller was able to maintain a six sigma control range of 29 to 31 ppm for the all-polymer internal treatment.

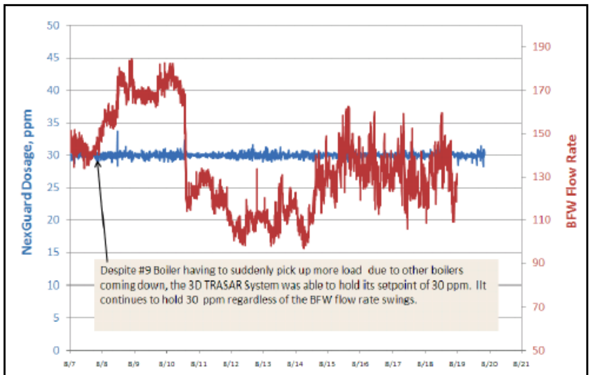


Figure 14. All-polymer dosage vs. feedwater flow

Boiler Cycles Results

Prior to implementation of the new automation control technology, plant operations had to manually control boiler cycles. As a result, the cycles ranged anywhere from 2 to 22 cycles. This variability created stress on the boiler system and resulted in poor reliability as well as wasted water and energy.

The new technology can be used to optimize and automatically control boiler blowdown. With boiler cycles control, the boiler cycles were automatically maintained between 8 and 10 cycles, Figure 15.

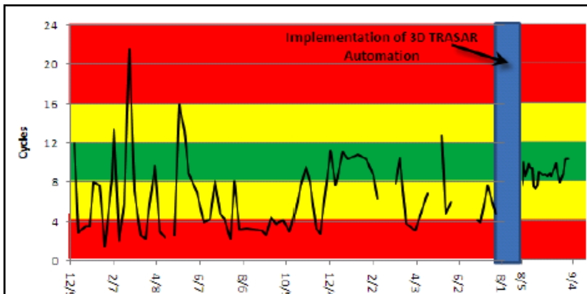


Figure 15. Boiler cycles after automation control

This boiler cycle control will result in significant annualized financial and sustainability savings of over $400K as shown in Table 4. In summary, implementing the new automation technology resulted in tremendous improvement in operational control leading to improved boiler reliability, lower total cost of operations, and a significant environmental ROI.

CONCLUSIONS:

Even the best RT ORP probes are not as sensitive as the AT ORP probes. With this new boiler feedwater treatment automation, chemical is now fed based on a true at-temperature corrosion demand. Production events can occur quickly, and this new automation has shown that it can respond to

Table 4. Energy and Water Costs and Credits

Blowdown Energy Cost	$/year	669,614	334,807	334,807
Blowdown Sewer Cost	$/year	99,749	49,875	49,875
Makeup Water Cost	$/year	235,893	214,448	21,445
Sub Total (Costs)	**$/year**	**1,005,257**	**599,130**	**406,127**
Returned Condensate Fuel (Credit)	$/year	0	0	0
NET SAVINGS or (COSTS)	**$/year**	$/year		**406,127**
Calculated Cost of Steam*	$/1000 lb	9.83	9.39	0.44
NET CO_2 EMISSION SAVINGS (INCR)		fuel is natural gas	Tons CO2 / yr	**3,236**

the events quickly and with the appropriate response. The solid state fluorometer and AT ORP are both valuable instruments that can protect the boiler and feedwater systems from scaling and corrosion events. In addition, this technology can be used as a troubleshooting tool to help diagnose issues and correct them.

Given the recent economy, it is becoming even more important for all boiler house managers, engineers, and operators to take a fresh look at ways to reduce operating costs, protect asset life, and improve productivity. This technology has clearly shown that it can help find issues that previous technologies cannot see, and allows users to protect their pre-boiler and boiler systems.

REFERENCES:

1. Nalco Water Handbook, 2nd Edition, 1988, McGraw Hill Publishing
2. "New Boiler Chemistry Control Technology Helps Reduce Process Variability and Total Operating Cost of Steam Generation", Lynn Alexander, Thomas Hughes, Brian Jenkins, Catherine Stetenfeld, Andrew Trautman, and David Workman, Presented at The International Tire Exhibition and Conference, September 16-18 (2008), Nalco Reprint R-923.
3. Op. cit. Nalco Water Handbook
4. United States Patent #6,255,118 "Method for Using an All Solid-State Fluorometer in Industrial Water Applications"
5. United States Patent #5,736,405 "Monitoring Boiler Internal Treatment with Fluorescent-tagged Polymers"
6. Case History 852 – Nalco Company "Midwest University Improves Boiler Operation Using 3D TRASAR® Boiler Technology"
7. "Monitoring and Control in Boilers With All Solid-State Fluorometers", Martin Godfrey, Corrosion / 2002, Paper No. 02012, NACE International Conference, Houston, TX (2002).
8. "A New Approach to Feedwater Corrosion Control: A Detailed Nalco AT ORP Study at a Paper Mill", Peter Hicks, David Grattan, and Paul Desch, Nalco ADV-1105.

ESL-IE-10-05-14

PETRO CHEMICAL ENERGY

Proceedings from the Thirty-second Industrial Energy Technology Conference, New Orleans, LA, May 19-22, 2010.

The Company

- Petro Chemical Energy
  - We are the global leader in energy loss surveys having over 25 years experience making your businesses more efficient.
  - Highly trained and professional staff.
  - State-of-the-art ultra-sonic equipment.
  - Having uncorrected steam leaks and faulty traps cost your businesses time and money as well as being environmentally unfriendly.

SERVICES

- ✓ Air Leak Surveys
- ✓ Nitrogen Leak Surveys
- ✓ Gas Leak Survey

  (H2, O2, Natural Gas)
- ✓ Steam Leak Surveys
- ✓ Steam Trap Surveys

Our Policies

- **Safe Employees**
  - Yearly Basic Plus Safety classes
    - Houston Area Safety Council
    - Texas City Safety Council
    - Tennessee Valley Training Center
  - Site specific safety classes
    - Petro Chemical Energy employees receive site specific training at over 50 plant sites per year

- **Security Checks**
  - Petro Chemical Energy employee background checks performed by DISA

- **Drugs & Alcohol Free Workplace**
  - Petro Chemical Energy employees are tested for Drugs and Alcohol prior to employment, annually and randomly by DISA

- **Transportation Worker Identification Credential (TWIC)**
  - All Petro Chemical Energy employees have a TWIC card

Our Goals

- Stop the loss of productivity and efficiency
  - Manufacturing productivity
  - Processing efficiency
- Provide recommendations for improvement
- Stop profit loss by conserving wasted energy

Proceedings from the Thirty-second Industrial Energy Technology Conference, New Orleans, LA, May 19-22, 2010.

Undetected Steam leaks

- Rob efficiency in manufacturing and processing
- Lose millions of dollars annually
- Add up to very costly problems
- Are caused by dozens, perhaps hundreds of hard to pinpoint outflows which are caused by vibrations and a corrosive atmosphere.

➢ We can find your leaks in areas that that would be unnoticed and undetected to the human ear

Leaks = Dollar Loss

Our Services Will Save Your Company Money

Petro Chemical Energy's Steam Leak and Steam Trap surveys have helped our clients all over the world shut down boilers. Resulting in saving our customers millions of dollars annually. We have completed surveys that have saved our clients $17,000,000.00 net from our steam leak and trap survey, after they repaired their leaks and faulty traps.

Steam Leak Surveys

- Details
  - Ultrasonic equipment easily locates steam leaks
  - Each leak is tagged with a metal number tag that corresponds with your Excel report.
  - A detailed Excel report is compiled containing:
    - Location and description of all steam leaks
    - Annual dollar loss per leak
    - Analysis are forecasting the price of Natural Gas is going up.

Steam Leak Survey for:
Company Name
City, State

Conducted by:
PETRO CHEMICAL ENERGY
Muscle Shoals, Alabama
(256) 331-2473

SAMPLE

AREA:

DATE: 04-Feb-03

LEAK SIZE	JOB DESCRIPTION AND LOCATION	TAG #	DATE 1ST REPORTED	ESTIMATED DOLLAR LOSS SINCE REPORTED	ESTIMATED DOLLAR LOSS PER YEAR	DATE REPAIRED	ESTIMATED DOLLAR SAVINGS AFTER REPAIRED	STATUS
(S)	PACKING, 6" VALVE, NORTH OF #P-3410 (GRD)	010	04-FEB-03	$0.00	$1,640.00		$0.00	
(M)	HOLE IN 2" LINE, INSIDE WEST WALL OF #F-131 (PENTHOUSE)	027	12-NOV-01	$16,141.86	$13,122.00		$0.00	
(S)	1/2", 1500#, VOGT VALVE LEAKING THROUGH, EAST SIDE OF #P-4424, (GRD)	060	12-NOV-01	$2,017.42	$1,640.00		$0.00	
(S)	PACKING, 6" VALVE, SW SIDE OF HEATER #E-1390, 10' OVERHEAD (GRD)	139	12-NOV-01	$2,017.42	$1,640.00		$0.00	
(S)	1/2" THREADED UNION, SOUTH SIDE OF #P-2089, OVERHEAD (GRD)	143	04-FEB-03	$0.00	$1,640.00		$0.00	
(M)	3", 300#, FLANGE GASKET, ABOVE WEST END OF #E-0984, OVERHEAD (GRD)	149	04-FEB-03	$0.00	$13,122.00		$0.00	
(S)	REPLACE, 10", 150# CRANE BONNET GASKET, SOUTH SIDE OF #F-141, OVERHEAD (2ND PLATFORM)	197	12-NOV-01	$2,017.42	$1,640.00		$0.00	
(S+)	LEAK UNDER INSULATION, WEST SIDE OF #E-1981-A, 10" OVERHEAD (GRD)	467	12-NOV-01	$3,229.11	$2,625.00		$0.00	
(L)	6", 150#, FLANGE GASKET, NW END OF #P-5008-B (GRD)	482	12-NOV-01	$36,321.02	$29,526.00		$0.00	
	TOTALS:			$20,176.71	$18,042.00		$0.00	

Steam Trap Surveys

- Details
  - Temperature and ultrasonic equipment tests each trap
  - Each trap is tagged with a metal number tag that corresponds with your Excel report.
  - A detailed excel report is compiled containing:
    - Location of all traps
    - Trap manufacturer, trap model, trap size, line pressure and service of each trap
    - Annual dollar loss per trap
  - Petro Chemical Energy is not affiliated with any steam trap manufacturer or vendor.

Steam Trap Survey for:
COMPANY NAME
CITY, STATE

Conducted by:
PETRO CHEMICAL ENERGY
Muscle Shoals, Alabama
(256) 331-2473

SAMPLE SHEET

DATE: 29-Nov-04

AREA:

TRAP LOCATION	TAG NUMBER	MFG MODEL NUMBER	SIZE	PRESSURE	SERVICE	TRAP COND	ESTIMATED STEAM LOSS PER YEAR/1000#	ESTIMATED DOLLAR LOSS PER YEAR
SW OF P-72B (GRD)	236	AMW 2010	1/2"	30	TRACER	RCL	852	$3,433.56
SE CORNER OF 3AT-40 (GRD)	238	NIC N-300	3/4"	30	TRACER	OK		
SOUTH END OF 3AT-40 (PLATFORM)	248	AMW 1811	3/4"	30	TRACER	VO		
NE OF 3AT-104 (GRD)	249	AMW 313	1"	600	DRIP	BT	1,691	$6,814.73
NW SIDE OF H-3 HEATER (GRD)	254	NIC N-300	3/4"	30	DRIP	CP		
NW SIDE OF H-3 HEATER (GRD)	255	AMW 1811	3/4"	30	TRACER	BT	552	$2,224.56
SE OF 3AT-14 (GRD)	394	AMW 313	1"	150	DRIP	VO		
SE OF 3AT-14, EAT SIDE OF P-44	395	SARCO UPB-32	1/2"	30	TRACER	OK		
WEST SIDE OF 3AE-44 (GRD)	396	AMW 1811	3/4"	30	TRACER	BT	324	$1,305.72
SOUTH OF 3AE-2 (GRD)	415	SARCO TD-62	3/4"	600	DRIP	OK		
SE OF 3AT-1 (GRD)	416	SARCO TD-52L	3/4"	30	DRIP	CP		
BELOW EAST SIDE OF 3AE-19B (GRD)	434	SARCO UPB-30	1/2"	30	TRACER	VO		
TOTALS:							3,419	$13,778.57

Easy Access to Report

- Multiple Copies, Multiple Formats
  - One large copy (14 x 11) of Excel spreadsheet
    - Cover sheet with all areas surveyed
    - Individual spreadsheet of each area
  - Four letter sized copies of Excel spreadsheet
  - CD containing entire survey data
  - Electronic copy transferred via email

Our Valued Customers

Petro Chemical Energy's Energy Surveys have **saved** our clients **millions** annually including:

- Arkema
- Ascend Chemicals
- American Styrenics
- Bayer Chemicals
- BASF
- Bridgestone Firestone
- BP Amoco
- Cherokee Pharmaceuticals
- Chevron
- Ciba Specialty Chemicals
- Celanese Chemicals
- Columbian Chemicals
- Citgo
- ConocoPhillips, Inc.
- Cooper Tire & Rubber Co.
- Dow Chemical Company
- Daikin America
- Exxon Mobil
- EKA
- Frontier Refining Inc
- GEO Specialty Chemicals
- G E Plastics
- Hercules
- Huntsman
- ISP Chemical
- Koch Refining Co.
- Lion Oil Company
- Lubrizol
- Merck & Company
- Motiva
- Novartis
- Oxy Chemical
- Olin Chemicals
- Placid Refining
- Pasadena Refinery
- Proctor & Gambel
- Rohm and Haas
- Rhodia Chemicals
- Shell Chemical
- Sunoco
- Solutia
- Samref (Saudi Arabia)
- Tennessee Eastman
- Texas Eastman
- Total Petrochemicals
- Texaco
- Vulcan Chemicals
- Valero
- Wise Alloys

GUARANTEE

Petro Chemical Energy guarantees that if your company is not completely satisfied with your survey after completion your company will not be charged.

Generating Electricity with Your Steam System: Keys to Long Term Savings

Bill Bullock Andrew Downing
Turbosteam LLC

Abstract

The application of combined heat and power principals to existing plant steam systems can help produce electricity at more than twice efficiency of grid generated electricity. In this way, steam plant managers can realize substantial savings with relatively quick payback of capital. Carefully planned and executed projects are the key to unlocking the maximum value of generating electricity from an existing steam system. This paper illustrates the key concepts of generating onsite power with backpressure steam turbine generators along with practical considerations.

Introduction

There are many improvements that can be made to existing steam systems to make them more efficient. Tuning combustion controls, replacing a boiler with a more efficient design, decreasing blow down and maintaining steam traps all can boost system efficiency and provide real cost savings. Another option for generating more value from a steam system is the addition of a back pressure steam turbine generator that can create value by generating electricity from an existing steam system.

Many existing steam systems have the capacity to produce electricity at efficiencies much greater than conventional technologies. When steam is produced in a boiler, with any fuel, some of the energy in the steam has the capability of being converted to electricity. In many steam systems, pressure reducing valves (PRVs) are used to control the pressure to process heating uses from a boiler of a higher pressure, as in Figure 1.

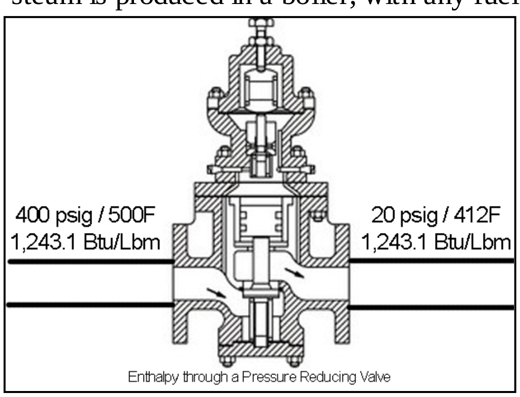


Figure 1

If the boiler is operated at relatively low pressure, say ten times atmospheric pressure, then the quality energy will only be about 10 to 15% of the total. If the boiler is operated at 40 times atmospheric pressure, the potential for conversion to quality energy will be up to 25% of the total. Inserting a backpressure turbine after the boiler extracts some of the potential quality energy from the steam. Typical machines range from very simple, single stage turbines that extract under 50% of the available energy from the steam to multi-stage machines that extract over 80% of the available energy.

The steam that exhausts from the turbine contains less total heat than the steam that went into the machine. Three to four percent of the heat removed from the inlet steam is lost as heat from the generator. The remaining 96% to 97% of the heat that was removed is turned into

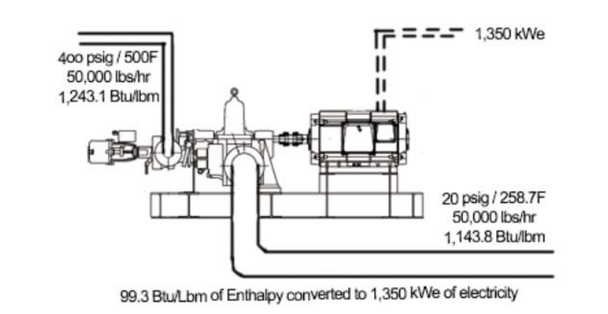


Figure 2

electric power as shown in Figure 2.

In most cases, the lower heat content of steam exhausted by the steam turbine shows up primarily as a lower temperature steam. Therefore for a process that requires a given quantity of heat flow, the mass flow of steam must be increased to deliver the same amount of heat to the process. The objective of any successful back pressure turbine application is that the process realizes no interruption and that the by-product of letting steam down more efficiently is electrical generation.

The high conversion efficiency of the backpressure turbine in this arrangement means that electric power is produced at costs significantly lower than can be generated by standard power plants and with no transmission or distribution losses.

System Design

Maximum value can be generated by a backpressure turbine application by designing the system to generate the maximum number of kilowatt hours (kWh) for a given steam load profile. Ideally, at least a twelve (12) month trailing steam history is used to determine the steam flow over a range of seasonal operating variations. If an accurate steam flow meter is not available, one should be installed to help assess and confirm the sizing criteria of the turbine, to ensure the generation of maximum long term value. Typically, steam flow meter designers have specific installation requirements regarding number of diameters of straight length pipe upstream and downstream of flow meters to ensure accuracy of measurement.

In addition to steam flow, it is critical that the measurements for pressure and temperature to which the system will be designed be taken as close to the final physical location of the turbine installation as possible. Not factoring in pressure losses from the steam piping can reduce inlet pressure and inadvertently reduce electric generation potential, so at the very least, estimates of pressure drop and temperature drop should be made.

Steam Quality and Purity

In some plants, the quality, defined as percent dry vapor, of steam going to heating processes is not critical to the effective operation of downstream process equipment. A steam turbine, however, requires dry and saturated or superheated steam. If wet or saturated steam is used, it is very important that piping be arranged so that condensate cannot be carried over into the turbine. A steam separator of the proper size, with a trap of ample capacity, should be installed before the turbine inlet. All horizontal runs must be sloped up in the direction of steam flow, with drains at the low points.

The performance and reliability of a steam turbine can be adversely affected by the admission of contaminated steam. When contaminants enter the turbine with the steam supply, the usual result is the accumulation of deposits, which can be exacerbated by reactive contaminants that cause corrosive attack of turbine materials.

Adequate boiler water chemistry control and regular equipment inspections can help ensure that water chemistry does not impact the long term savings potential of a turbine generator project.

Another major source of steam contamination is from post installation debris, slag or weld material in the steam piping system. Any welded pipe should be subjected to a rigorous steam blow to ensure that any and all loose material in the pipe is removed before the inlet valve to the turbine is opened. As part of the steam blow, it is important to use highly polished targets to ensure that any material impacts can be readily seen. Typically a good guideline is to consider the pipe clean when three consecutive targets have not been impacted. The industry standard for installation recommendations can be found in NEMA SM 24 "Land-Based Steam Turbine Generator Sets 0 to 33,000 kW" or NEMA SM 23 "Steam Turbines for Mechanical Drive Service".

Turndown

If process steam flows vary across large ranges due to inherent process demand variations or seasonal demand, the addition of automatic hand valves on the turbine nozzles are recommended to help ensure the turbine will operate efficiently at low loads. Automatic hand valves help capture efficiency across a wider flow range and allow the turbine to automatically respond to rapid changes in flow. Such operation is critical to maximizing the energy generated by the turbine and the economic value of the project.

Steam Piping Design

There are a limited number of interfaces to design for a back pressure steam turbine application, but among the interfaces, steam piping design on the inlet and exhaust of the steam turbine generator is arguably the most important. The steam piping design effects how the thermal expansion of the steam piping and resulting forces and moments impact the inlet and exhaust nozzles of the steam turbine. Therefore, it is critical that the steam piping should be designed by professional engineers and to the standards of NEMA. Improperly designed steam piping can contribute to excessive forces on the turbine that can impact the alignment of rotating components, induce vibration problems and impact the long term operability of equipment.

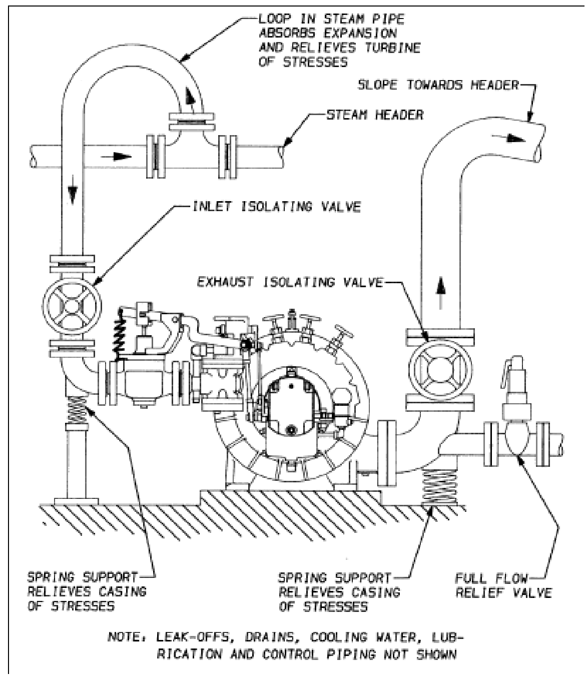


Figure 3

Individual drain lines on the turbine should be piped with isolation valves to drain the turbine and assist in unit start up.

Leak off piping from seals that allow steam leaking from seals to be safely transported away from the system should be drained to an atmospheric drain.

Figure 3 shows inlet and exhaust isolation valves, allowing the turbine to be shut down, along with sealing inlet and exhaust lines if the turbine is to be moved or serviced.

An atmospheric relief valve must be installed between the turbine exhaust flange and the first exhaust line shut-off valve (Figure 3). The purpose of this relief valve is to protect the turbine casing from excessive exhaust pressure. The relief valve must be of ample size to pass the maximum quantity of steam flowing through the turbine at the maximum inlet temperature and pressure steam conditions without allowing the turbine casing pressure to exceed the manufacturer's rated maximum conditions.

Foundation

The foundation is one of the influential factors governing long term reliability of a turbine. A foundation must maintain alignment under all normal and abnormal conditions. This includes the way a foundation is supported on the soil and/or superstructure, soil settling, soil resonances, thermal distortion, piping forces, and vacuum pull or pressure forces in expansion joints.

The turbine, gear reducer and generator should all be mounted on a common foundation. Typically in modular designs, these components share a common steel base plate. Even in such cases, the foundation design and grouting should be given special consideration.

Sufficient space should be provided around and above the foundation to allow for proper installation and maintenance.

The foundation must minimize vibration by being as heavy as possible and nonresonant. It is important that the turbine be isolated from external vibration. Neither the foundation nor related support structure should be resonant within the operating range of the turbine.

Vibration transmissions may occur from the unit to the surroundings, or vice versa; vibration may also be aggravated by resonance at transmission frequencies.

Conclusion

Steam turbines are one of several options to consider when evaluating energy improvements in a steam system. Steam turbine technology is a highly mature technology with low technical risk and the ability produce electricity very efficiently when used in back pressure applications.

Keys to a successful project are properly evaluating the steam load profile and steam conditions to ensure the conceptual design will match actual conditions. Also important to a successful project is managing the completion risks inherent in the project. Doing so will provide a project that will generate electricity and savings for years to come.

REDUCED SAFETY FLARING THROUGH ADVANCED CONTROL

David Hokanson ExxonMobil Chemical
Keith Lehman Empirical Process Solutions
S. Masumoto, N. Takai, Tonen Chemical
F. Takase TonenGeneral

An advanced process control application, using DMCplus® (Aspen Technology, Inc.), was developed to substantially reduce fuel gas losses to the flare at a large integrated refining / petrochemical complex. Fluctuations in internal fuel gas system pressure required changes in C3/C4 make-up gas usage. These changes led, in turn, to some instability in the fuel gas system that sometimes required purge to the safety flare system to stabilize. As the composition of the fuel gas supply changed, so did its heating value, which caused fluctuations in the control of various fuel gas consumers. The DMCplus application now controls fuel gas pressure tightly and also stabilizes the fuel gas heating value. The understanding of each fuel gas provider and user was essential to the success of this application, as was the design of the DMCplus application. SmartStepTM (Aspen Technology, Inc.) – automated testing software – was used to efficiently develop the DMCplus models; however, a number of models were developed prior to the plant test period using long-term plant history data.

THE ROLE OF ADVANCE PROCESS CONTROL IN YOUR ENERGY MANAGEMENT SOLUTION

Kevin Johnson Lize van Wyke
NovaTech LLC

According to Aberdeen Group, "Operational Excellence in the Process Industries – Driving Performance Through Real-time Visibility", the most striking advantage Best-in-Class companies have is being able to compare performance across a portfolio of plants, thus identifying plants doing things right, and having the capability to improve plants falling behind.

In these companies, 60% of executives have real-time visibility into the operational performance of manufacturing operations. 81% of the companies have automated data collection capabilities, and 81% also measure energy consumption. 48% of these companies use energy consumption and cost as KPIs for decision making, and 81% of them can compare performance across plants. 55% use non-conformance alerts in real-time for optimal decision making.

From the above statistics, it is apparent that measuring and managing energy consumption and operational performance is vital to any organization's competitiveness, and even ultimate survival. In this presentation, we will explore ways to do this as efficiently as possible through the effective use of data integration, modeling, economic measurements and visualization in real-time based on an Energy Asset Management Approach.

Reducing Costs & Achieving Superior Plant Energy Performance Using Real-time Information & Best Practices in Energy Management

Shiva Subramanya · Executive Vice President, Strategic Development · EPS Corp · Irvine, CA

Abstract
After years of attempting to streamline operations in an effort to reduce operational costs, many industrial manufacturers are turning to strategic energy management as a potential money-saving strategy. In their efforts, managers face a number of significant barriers such as low awareness and expertise, elevated financial hurdle rate, lack of capital allocation and procurement constraints. In addition, energy efficiency efforts may be hampered by traditional "single point" energy reduction methods such as reviewing utility bills, getting equipment upgrade suggestions from vendors or one-time energy audits. Research demonstrates that these techniques have neither the visibility nor continuity to achieve energy reductions that are consistent and persistent. With the right Best Practices, however, using new methodologies and technologies unavailable only a few years ago, enterprises can achieve dramatic energy reductions and their resulting cost savings. These Best Practices are founded on 1) application of a systematic methodology for understanding where energy is used and how to reduce it; and 2) achieving visibility into sufficiently granular real-time information on key performance indicators; 3) integrating new technology into overall corporate strategy and processes to change behavior.

INTRODUCTION

According to 2009 study by Aberdeen Group (Ref. 1), the U.S. industrial sector accounts for about one-third of total energy consumption – more than any other sector including residential, commercial and transportation. Globally, the industrial base accounts for nearly half of all energy consumed. A McKinsey Global Energy and Efficiency Report (Ref. 2) states that the U.S. industrial sector will consume 51 percent of the 2020 baseline end-use energy in the United States, equivalent to 20.5 quadrillion BTUs of end-use energy. At the same time, the report says that the industrial sector offers 3,650 trillion end-use BTUs of NPV-positive energy efficiency potential. This is equivalent to 18 percent of the industrial energy consumption forecast for 2020. If it was possible to capture this energy efficiency potential, it would save industry $47 billion per year in energy costs. How that number translates to each individual industrial plant depends on many factors, but represents an incredible opportunity to reduce costs and increase competitiveness across the entire sector.

The Aberdeen Group study revealed that the top pressure driving companies to focus on energy efficiency, selected by 80 percent of their respondents, was the need to reduce costs in manufacturing operations (eclipsing sustainability pressures by a wide margin). Companies are looking at energy management because they have already attempted to streamline operations and reduce expenditure through reduction of unscheduled downtime, improving overall yield, increasing quality or reducing inventory among many other strategies.

But Aberdeen researchers discovered that executives managing industrial plants often underestimate the ability of effective energy management to reduce costs. This was particularly true in energy-intensive plants where energy cost is a large percentage, often upwards of 25 percent of the total operational costs of the plant. In such scenarios, even the ability to cut a small percentage of total energy consumption can result in significant savings.

The McKinsey study points out the five principal barriers to capturing energy efficiency:

<u>Low Awareness and Attention</u>
Since energy may represent a relatively low percentage of operating costs as compared to other expenditures, it may receive very little attention from executive management, resulting in limited investment in developing the required technical expertise. Efficiency opportunities often require technical analysis that on-site employees rarely perform because of insufficient training, awareness, or management concern. The savings potential varies by site, ranging from 10 to 40 percent even for sites within the same sub sector, highlighting the need for site-specific analysis.

Elevated Hurdle Rate
Industrial sites work within very tight operational budgets and management tends to focus on quarterly targets, potentially at the expense of projects that pay back over longer periods.

Capital Allocation
Non-core projects such as energy efficiency must compete against core projects for limited capital budget. Often energy-efficiency projects face an elevated hurdle rate and executives are reluctant to raise debt even for desirable projects for fear of adversely affecting balance sheets and credit ratings. In addition, the separation of the plant operations and maintenance budget from capital improvement budgets can create an organizational challenge since the costs of energy efficiency reside in one budget while the savings reside in the other.

High Transaction Cost
Executives' perception of transaction costs associated with energy efficiency include space constraints, invested resource time, process disruptions, potential effects on product quality, and safety concerns.

Procurement and Distributor Availability Constraints
Many procurement systems contain limited inventory and focus on up-front costs rather than total cost of ownership. In addition, plant managers are risk adverse which will often create demand for in-kind rather than more efficient replacements.

On top of these barriers, some executives may have attempted energy efficiency projects and received results that were not consistent and persistent. A 2009 study by the Lawrence Berkley National Laboratory (LBNL) reports that energy savings achieved through a retro-fitting process "can degrade without an explicit effort to monitor and maintain them." (Ref. 3)

The positive side of the message, however, is that the deployment of energy management Best Practices can result in consistent and persistent energy reductions. In fact, each of the five barriers to energy management can be overcome efficiently and cost-effectively through Best Practice methodologies.

In its Energy Intelligence study, Aberdeen takes into consideration how well companies reduce energy and how well this reduction translates to the bottom line. They categorize enterprises according to the top 20 percent, middle 50 percent and bottom 30 percent. The Best-in-Class Top 20 percent achieved a 15 percent real reduction in energy usage which corresponded to a 14 percent gain in operating margin above the corporate plan. The industry average players managed a seven percent reduction in energy use and a two percent improvement in operating margin, while the bottom 30 percent experienced a six percent increase in energy usage and a nine percent drop in operating margin as compared to their corporate plan.

Clearly, the question becomes, "How can Best-in-Class results be achieved?" McKinsey states, "What appears needed is an integrated analysis of energy efficiency opportunities that simultaneously identifies the barriers and reviews possible solution strategies." While McKinsey is talking about the development of a nationwide strategy for energy management, they might well have been addressing the Best Practices of an individual enterprise. Achieving consistent and persistent energy reductions requires:

- Applying a systematic methodology for understanding where energy is used and how to reduce it
- Achieving visibility into real-time information on key performance indicators (KPIs)

Energy must now be treated as a raw material that needs to be carefully and wisely managed against standards for maximum results.

THE TRADITIONAL APPROACH TO ENERGY MANAGEMENT

Before Best Practice techniques and strategies can be developed, it is necessary to examine and understand the typical energy management cycle, potential results and shortfalls to avoid confusion. Frequently, industrial plants will be led to a "point in time" energy view method for finding "Energy Reduction Opportunities." This will generally involve one or more of the following tactics:

Review of Utility Bills
While this approach may seem logical, in fact it provides little meaningful data except to highlight that the cost is higher than the company would like. Utility bills are too macro in view and provide insufficient granularity for meaningful analysis. They do not allow comparisons of different resources such as contrasting gas and electricity or electricity and water since all of these utilities report in different systems on a different timeframe and basis. Equally important, utility bills alone do not identify usage by process or by subsystem, making it difficult to pinpoint the sources of energy usage meaningfully.

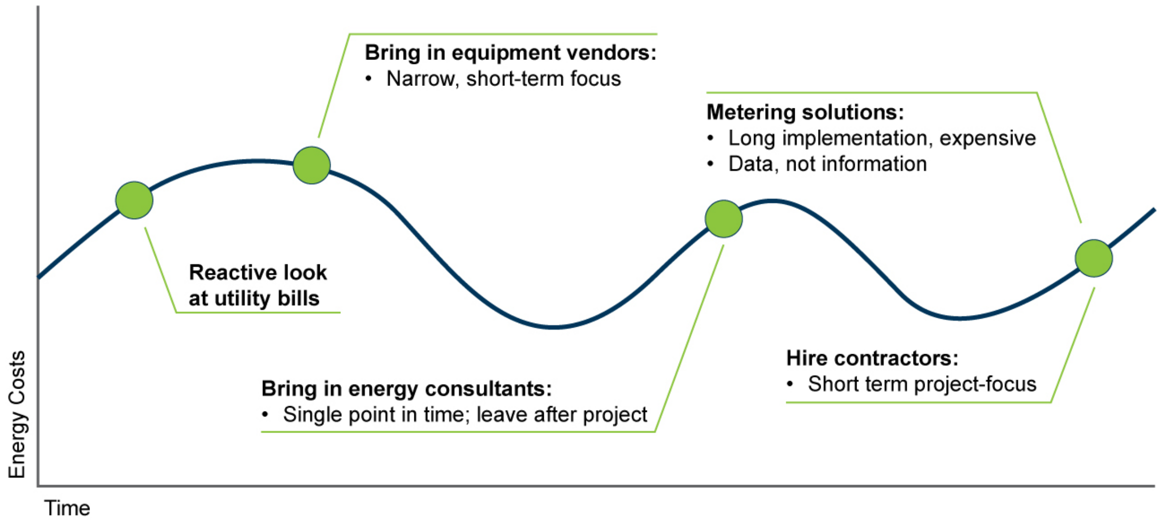


Figure 1. "Traditional Approach to Energy Management"

Equipment Vendor-suggested Upgrades

Most plant managers have had an equipment vendor suggest an equipment upgrade as a method of reducing energy usage. The problem is that such analyses are narrow in scope since their focus is only on one or two pieces of equipment, and often do not factor for interaction with other equipment or processes in the plant. Vendors, of course, have a vested interest in selling new equipment and may not explain or even understand how old equipment might be made more efficient with minor upgrades. Finally, once the new equipment is installed, vendors often leave the responsibility and methodology for ongoing monitoring of the energy efficiency of the equipment with the company.

Energy Audits

When energy consultants do an assessment and recommend changes, the limitation is that they are capturing the situation at a given moment in time. In addition, the consultants often do not handle the implementation of suggested changes, so the end result may fall short of the predicted energy savings.

After companies have used one or more of these "point in time" methods to identify savings opportunities, they may undertake some level of project or equipment-specific monitoring. These approaches are rarely sufficient to make a significant impact since they tend to be conducted right after the energy efficiency project and, due to limited resources, budget or lack of integration into manufacturing operations and corporate culture, the results fade over time.

As Aberdeen has observed, the first recommended action in creating "Best-in-Class" energy reduction is the establishment of a formal corporate strategy focused on reducing overall operational costs through improving visibility of energy usage and optimizing operations based on costs and efficiency. Unquestionably, single-point energy efficiency initiatives may have some positive results when first implemented, but even a few months later, efficiency levels can degrade significantly due to improper maintenance or control.

The key takeaway from an examination of traditional methods of identifying energy efficiency opportunities is this: energy savings left to human and equipment entropy causes inconsistent results. A series of case histories on energy efficiency in buildings described in the Lawrence Berkeley National Laboratory benchmarking study give examples in the commercial sector of similar problems.

In one case, a building experiencing high nighttime natural gas and electricity usage was traced to the fact that the chiller and the heater were both operating overnight along with much of the lighting despite the fact that the building was unoccupied. While these meters were read monthly, no personnel noticed or reported this very obvious problem – a clear case of human entropy. The simultaneous and excessive heating and cooling wasn't discovered until the building was put on a continuous monitoring system.

Equipment entropy is just as common, as indicated by the LBNL study. As an example, the case study indicated significant instability in the direct digital control system which regulated air temperatures in two air handlers. Trending data showed that the preheat valve cycled every 15 minutes between 75 percent open and full closed which produced a supply air temperature variation of 10º F. The chilled water valve had a similar instability resulting in unnecessary heating and cooling. While such problems might be solved once, they continue to arise in new and the same locations like the proverbial Hydra.

Such equipment entropy can lead to expensive and unnecessary decisions. One company was experiencing dramatic shifts in temperature from room to room and was considering replacing its chiller with a more efficient unit. When monitoring showed that many thermostats and actuators were out of calibration or even inoperable, it became clear that there was inadequate electrical load to justify the replacement of the chiller saving the company a considerable expense.

The typical energy reduction from traditional energy efficiency methods might be described as a sinusoidal curve. The manager looks at the utility bills and realizes change is needed. Often, equipment vendors are called in and focus only on their own systems, so results improve briefly and then decline. Occasionally, energy consultants produce a large list of projects that the company must implement themselves or find another consultant to accomplish. The complexity is discouraging, contractors are costly and management has more pressing responsibilities so, again, results decline. When nothing else seems to work, management may consider a metering solution, but these systems are expensive, require lengthy implementation and provide the company with data not information. No one at the firm is trained to interpret the data and performance declines. In addition, since continuous monitoring is not provided, the combination of entropy in human behavior and equipment further degrades performance. This sinusoidal wave of incremental improvement and decline in efficiency might be thought of as the "yo-yo diet" of energy management. Countless companies are on this frustrating regimen, shedding some energy expenditure for a short time but losing those savings over time and ending back where they began or worse.

BEST PRACTICES IN ENERGY MANAGEMENT

Fortunately, achieving persistent energy savings is both simple and cost-effective.

Determine Energy Cost Per Unit

According to Aberdeen (Ref. 4), Best-in-Class companies are using actual energy consumption, at the unit level, to make real-time decisions for optimizing production, maintenance and energy delivery processes among others. Best Practices, then, begin with a detailed understanding of where energy is used in each individual plant and across the enterprise. Managers need to know what their energy cost is per unit of production and what systems comprise that cost. This necessitates a full view of electricity, natural gas, water, etc.

Develop Standards and Targets

The next step is to establish standards for energy that cover each of the areas of use. This determination will be individual to the industry and enterprise. Unlike commercial buildings where many standards have been established for processes like HVAC use, industrial manufacturing is more challenging. Each plant is a unique mix of products, processes, environmental conditions and equipment sub-systems and there are few established industry standards. Manufacturers may know that steam systems including boilers, distribution and condensate recovery processes are typically large consumers of energy, but whether the boilers in an individual plant are over-consuming cannot be easily assessed. It may be argued that the establishment of formalized standards for industrial markets is desirable, but since they do not presently exist, enterprises must establish their own. To determine standards and Best Practice targets, manufacturers can turn to neutral third parties and experts to determine what their energy cost-per-unit-of-production is and what the Best-in-Class target should be. If energy cost today is $.20 and an identified target is $.15, then a 25 percent reduction is the goal. Most manufacturers, however, will require expert assistance to arrive at a realistic target.

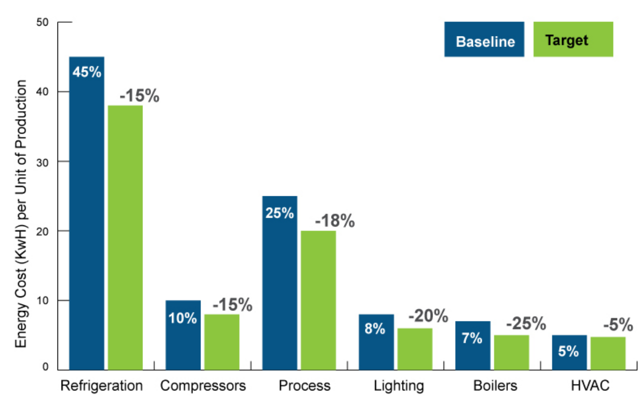


Figure 2. Sample Baseline Energy Usage and Target Reduction Levels.

Implement an Enterprise-wide Energy Visibility, Intelligence and Management System

Aberdeen states that the most common component of what they call Energy Intelligence being deployed by Best-in-Class companies is the automated collection, and centralization, of energy data (Ref 4). This automated data collection is the foundation of real-time decision-making enabling the optimization of operations. It is essential that this automated data collection be integrated with a formal corporate strategy that is focused on reducing operational costs, as well as with the operations and maintenance strategies of the plant. It should not be treated as an isolated system.

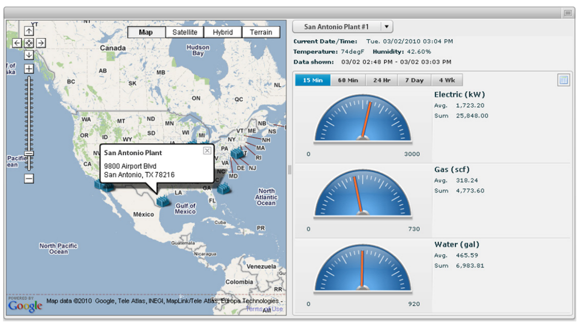


Figure 3. Dashboard Visibility Facilitates Real-time Energy Intelligence

Also key to the success of the energy visibility and management is adoption of Alerts and Event Management, Energy Dashboards and Energy Analytics. These business-intelligence tools enable organizations to effectively leverage collected energy data to contextualize real-time events and make optimal decisions based on historical trends. This real-time approach facilitates optimal energy usage and provides notification when critical conditions are approaching so that actions can be taken to prevent over-usage.

Utilize Real-time Data to Understand Gaps in Plant Standards

Organizations use enterprise-wide visibility, intelligence and management to understand why and how the plant is using more energy than required. This, in turn, leads to steps in real-time to proactively narrow the energy gap. The use of alerts is critical in this strategy, notifying personnel when energy usage is too high or the plant is approaching a critical energy threshold. Such enterprise-wide visibility lets managers see the occurrence of entropy in behavior and equipment and allows that degradation to be reversed before it can impact energy usage.

Aberdeen gives an example of a leading U.S. dairy producer. Dairy is the third highest energy consuming sector in the food industry. This particular company was facing intense market pressure to measure and reduce their carbon emissions in order to maintain shelf space and market share at a leading retail customer. They needed to lower energy usage in their production processes throughout their facilities and to reliably measure and verify their energy consumption and carbon emissions to meet the customers' standards. The company set an aggressive goal of 20 percent reduction over five years.

To accomplish this goal they rolled out a pilot program deploying a real-time energy monitoring system with alerts, energy dashboards and energy analytics. At each site, they collected near real-time data on electric, fuel and weather. The system provided visibility into the performance of the most energy-intensive sub systems which included refrigeration, compressed air, steam boilers and waste water. In the first 90 days one plant discovered that the waste water meter was out of calibration and the utility fresh water meter was overstating consumption by 150 percent. This discovery resulted in a savings of 1.2 million gallons of water per month at a cost of $3,000 per month.

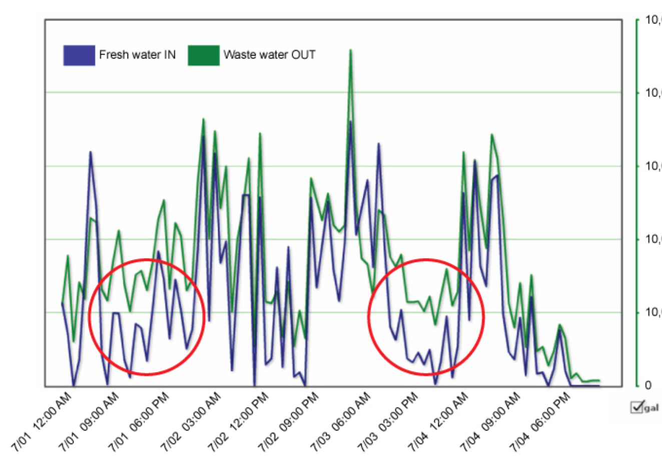


Figure 4. Energy Monitoring Identifies Simple, Low-cost Opportunities for Significant Savings

Additionally, the system identified that by monitoring and shutting down non-critical loads, another plant could lower their electrical demands by 200 to 300 KW translating to a cost savings of $3,000 per month.

Reduce Gaps by Systematically Planning Reduction of Energy Usage

With information in hand, the next step is to deploy and take advantage of the Best Practices developed at each of the plants, implementing projects that deliver ongoing, persistent energy savings. Deployment will involve changes in both people's attitudes and behavior, and technology and equipment (Ref. 5).

The first steps will generally be behavioral, identifying ways in which people can change in order to reduce energy. Such changes often result in quick improvements with little or no investment. For example, one company discovered that the spread between its natural gas flow and boiler feed water was larger than desired. These differences turned out to be periods of non-production. Sending automatic e-notices to personnel reminding them to shut off boilers on non-production days reduced natural gas usage by 20 percent and saved $1,130 per month as shown in Figure 5. Technology such as electronic alerting can be used effectively to avoid peak pricing, schedule preventative maintenance or remotely manage behavior and equipment.

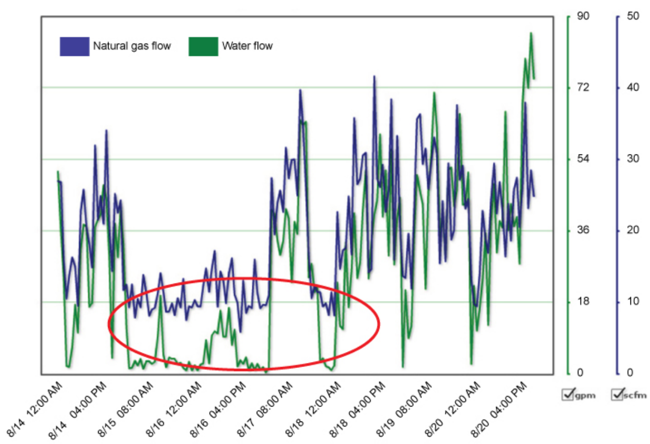


Figure 5. Alerts & Event Management Modifies Behavior for Energy Savings

Today's effective energy management software goes far beyond what was available only a few years ago. One key enhancement is the ability to compare results and characteristics such as resource usage across plants within an enterprise enabling the company to observe the effectiveness of Best Practices at one plant and apply those practices to other plants as appropriate. This is in real contrast to the traditional method of looking at individual pieces of equipment or single plants in isolation. The fixes to over-utilization may be a change of equipment or a change of behavior or both, but the bottom line is rapid response and cost savings.

A logical, systematic approach first addressing low-cost / no-cost opportunities such as process and behavioral changes (based on intelligence gained from real-time performance and energy consumption data) before investing in capital expenditures can provide a quick reduction in energy costs. It can also help foster cultural 'buy-in' to paying more attention to behavior and factors that affect energy consumption and treating energy like any other material resource. This can be an important factor in building the business case for then investing in upgrading, repairing or replacing any energy-inefficient equipment to achieve even greater savings.

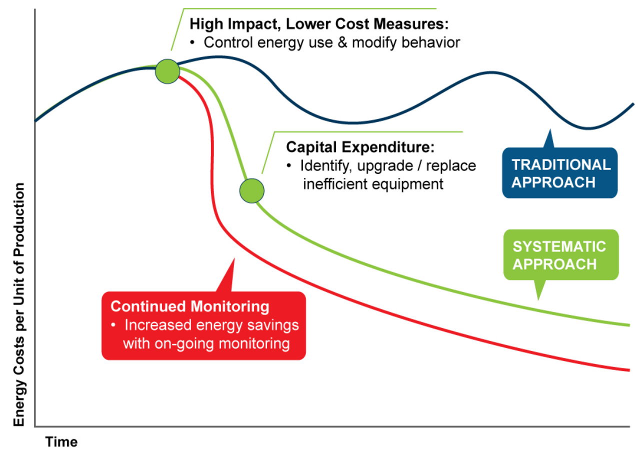


Figure 6. Continuous Monitoring Facilitates Greater Energy Savings

Perhaps the single most critical Best Practice in energy intelligence is to employ the energy management system to continually monitor both personnel behavior and equipment so as to avoid the degradation that is so often a problem in traditional energy usage strategies. As the Lawrence Berkeley National Laboratory report states, "By virtue of the continuous nature of the monitoring – new problems can be identified that emerge after the initial retro-commissioning investigation stage."

Continuous Systematic Monitoring can not only prevent degradation of energy saving practices, but also continue reduce energy consumption and costs. Equipment, controls and personnel change over time, influenced by alterations in environment, addition or removal of equipment, degradation in calibration or optimization. Simple alterations to processes, staffing, training and maintenance (performed at the right time through intelligence provided by ongoing monitoring) can significantly impact energy reduction practices, and effectively lower per-unit-of-production energy costs.

CONCLUSION

Traditional energy management methods too often lead to inconsistent savings and disappointing long-term results. Improvements in controls and information technology, combined with systematic and analytical Best Practices approaches to energy management, are creating a new breed of tools and solutions that promise to enhance corporate-wide sustainability efforts and ensure more persistent and measurable savings. By recognizing energy as a material resource and correcting existing entropy in equipment, along with modifications to human behavior when implementing energy management programs through full integration of the technology into the processes and the corporate strategy, enterprises can begin to treat energy management as a vast resource for cost savings that has not yet been fully realized.

REFERENCES:

1. Shah & Littlefield, Aberdeen Group, "*Energy Intelligence: Creating Data-Driven Efficiency*," January 2010

2. McKinsey & Company, "*Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?*" 2007

3. Mills & Mathew, "*Monitoring-Based Commissioning: Benchmarking Analysis of UC/CSU/IOU Projects*," June 2009

4. Shah & Littlefield, Aberdeen Group, Webcast, "*Energy Intelligence: Creating Data-Driven Efficiency*," January 9, 2010

5. Shah & Littlefield, Aberdeen Group, "*Energy Management: Driving Value in Industrial Environments*," April 2009

SAVING MEGAWATTS WITH VOLTAGE OPTIMIZATION

Tom Wilson
President
PCS UtiliData
Spokane, WA

Ken Benson
Electrical Engineer
Plum Creek Timber
Columbia Falls, MT

David Bell
Principle Engineer
PCS UtiliData
Spokane, WA

ABSTRACT

In September 2008, PCS UtiliData commissioned an Industrial Voltage Optimization system at the Plum Creek Timber Medium Density Fiberboard facility in Columbia Falls, Montana. The system was based upon the AdaptiVolt™ Volt/VAR Optimization system that had been installed at several electric utility distribution substations in the U.S. and Canada. These systems, being operated in Conservation Voltage Regulation mode, have provided significant energy conservation where they have been installed. Algorithms were developed to allow the system to operate with large synchronous motors without approaching pull-out torque points. After more than a year of operation the system has reduced demand at the facility by 3.72% with an annual energy savings of over 9,000,000 kWh per year at full production capacity. Based on verified energy savings Bonneville Power Administration paid Plum Creek over $337,000 for the project. This paper describes the voltage optimization system, the mechanism of energy conservation when voltage is optimized in an industrial facility and the measurement and verification method used to determine actual savings.

INTRODUCTION

According to the US Energy Information Administration industrial customers consumed 1,009,299,195,252 kWh of electrical energy in 2008 at an average cost of $0.0683/kWh. This amounted to over 27% of the energy used in the United States in 2008 [1]. The total cost to industry of this energy was close to $69 billion.

Industries have long put forth great effort to improve overall energy efficiency for all types of processes and facilities and for all types of energy sources. To improve electrical energy efficiency, companies have used more efficient lighting systems, high efficiency motors, variable frequency drive systems (VFDs,) new control systems to improve process efficiency, demand control and energy management systems, better design practices and other measures. There is one area of electrical energy efficiency/conservation that has been almost totally overlooked - That is the energy efficiency that can be gained by optimizing industrial plant distribution voltages.

Conservation Voltage Regulation

Conservation voltage regulation (CVR) is the practice of operating electric distribution systems at voltages in the lower half of ANSI [2] and CAN [3] allowable levels, thereby improving the efficiency of many electric utilization devices. Many if not all utilization devices operate more efficiently in the lower portion of their designed voltage range. If those devices, motors, drives, electronic power supplies, transformers, lighting systems, etc. are applied properly, that is if they are not undersized for their application, virtually all will operate more efficiently.

Conservation Voltage Regulation Factor (CVR_f) is a measure of energy conservation when voltage optimization is implemented.

$$CVR_f = \Delta E\%/\Delta V\%$$

where $\Delta E\%$ is the percent of energy reduced and $\Delta V\%$ is the percent voltage reduction.

History of CVR

Electric utilities began studying the effect of voltage reduction on distribution feeders in the 1980s. EPRI commissioned the University of Texas at Arlington to test and study the effects of reduced voltage on the efficiency of important power system loads in 1981 [4]. That study, which included such utilization devices as television sets, microwave ovens, motors, heat pumps, air conditioners, distribution transformers, resistance heating devices as well as others, showed significant efficiency improvements for almost all properly applied utilization devices. In 2000-01 the California Energy Crisis renewed interest in CVR as a long term conservation and demand reduction measure.

In 2002 PCS UtiliData deployed its first AdaptiVolt™ voltage optimization system at Inland Power and Light Company's Half Moon Substation. That project showed significant energy conservation and demand reduction along with significant kVAR (reactive power) reduction. Additional AdaptiVolt™ projects have shown significant energy conservation when distribution voltages were controlled so that delivered voltages were in the lower half of the ANSI or CAN Standard allowable voltages.

Since the first deployment of AdaptiVolt™ in 2002, PCS UtiliData has installed and operated 11 separate AdaptiVolt™ projects involving 10 electric utilities, 19 different substations and 66 separate distribution feeders.

Industrial CVR

In 1987 Bonneville Power Administration (BPA) commissioned Pacific Northwest National Laboratory to assess CVR applicable in the BPA service area [5]. The assessment concluded that CVR would be an effective energy conservation measure in industrial facilities.

However, the traditional method of implementing CVR on utility distribution systems uses line drop compensation (LDC). With LDC a model of the distribution system is used to compute fixed resistance and impedance settings in voltage regulator controllers. This is workable on radial distribution feeders as found frequently in electric utilities with relatively well known load patterns. Industrial facilities that have several production centers can have widely varying loads depending on work in process and customer requirements. A model would be required for each different load pattern and voltage regulator settings would be changed accordingly. This makes traditional LDC based CVR virtually unworkable in industrial settings.

Using closed loop feedback techniques and advanced process control and signal processing techniques that have been widely used in industrial process control, AdaptiVolt™ does not use models nor does it require constant changing of voltage regulator settings. It actually measures voltages at or near the end of the line and near critical loads. This technological advance in controlling voltage is a breakthrough and allows CVR to be implemented in industrial facilities. The project at Plum Creek Timber was the first installation of AdaptiVolt™ in an industrial facility and the author's research leads to the conclusion that it is the first implementation of CVR in an industrial facility in North America and probably in the world.

CVR, VO, VVO and IVO

Recently the term voltage optimization (VO) has come into use replacing the term CVR. Additionally, with the advent of the smart grid, many electrical utilities are investigating coordinated volt/var optimization (VVO), that is operating capacitor banks and voltage regulation in a coordinated manner to provide optimal voltage and reactive power usage on their distribution feeders. With the advent of the ability to implement VO/CVR PCS UtiliData has coined the term industrial voltage optimization (IVO.)

With VO or VVO installed on a utility distribution system, approximately 15% of the energy conserved is on the utility side of the meter whereas approximately 85% of the savings is on the utility customer side of the meter. This means that the utility sells less energy and revenues are potentially reduced.

The main difference between IVO and VO or VVO is that all of the energy conservation gained by the IVO system is on the customer side of the revenue meter. This reduces the cost of energy as a raw material, reducing overall production costs.

Special IVO Considerations

A very large percentage of industrial load is AC motor load. AC motors in industrial facilities can range in size from small fractional horsepower motors to motors that are several thousands of horsepower. They can be induction motors or synchronous motors. Most are 3 phase motors. Many are started across the line and many have variable frequency drives. Some larger motors may have cyclo-converter drives. Motor voltages can range from 120 V for very small motors to up to 15kV for high voltage motors. Most industrial motors operate at 480 V in the United States and 600 V in Canada.

Properly applied, motors tend to be more efficient at nameplate rated voltage and, if they are not operating at 100% nameplate capacity, they will become more efficient at voltages lower than nameplate rating. For a number of good reasons (and some not so good) most motors are in applications that do not require 100% mechanical output, although some may be required to deliver 100% or more for very short periods.

While energy can be conserved by optimizing voltage, it is imperative that voltage not go below levels that approach the pull-out torque point in synchronous motors and remain below some level of slip in large induction motors. To prevent such occurrences a patent pending AdaptiVolt™ algorithm called VARMINT (**Var**iable **M**oment **Int**egrator) was developed.

Because several voltage monitors may be located at different locations within the industrial facility on the same feeder fed by the same voltage regulator, it is imperative that the lowest voltage is the controlling voltage. At the same time, voltage regulator tap changer operation frequency must be kept as low as possible to avoid undue mechanical wear and tear on the mechanism. A patent pending AdaptiVolt™ algorithm called VIPER[1] (**V**oltage **I**ntegrating **P**robability **E**stimating **R**egulator) prevents excessive tap changer operation while assuring adequate voltage levels at all points in an industrial facility.

PLUM CREEK TIMBER MDF PLANT

Plum Creek's Medium-Density Fiberboard (MDF) facility is located in Columbia Falls, Montana near the western entrance of Glacier National Park. Plum Creek is the largest and most geographically diverse private landowner in the nation, with more than 7 million acres in major timber producing regions of the United States.

The plant buys all its electrical power from Flathead Electric Cooperative (FEC) located in Kalispell, Montana, the second largest electric utility in Montana. Bonneville Power Administration (BPA) supplies wholesale power to FEC.

MDF is an engineered wood product formed by breaking down hardwood or softwood residuals into wood fibers, combining them with wax and a resin binder, and forming panels by applying high temperature and pressure. MDF is denser than plywood. It is made up of separated fibers, (not wood veneers) but can be used as a building material similar in application to plywood. It is much denser than normal particle board. The name derives from the distinction in densities of fiberboard. Large-scale production of MDF began in the 1980s.

Description of Electric Service

The Plum Creek MDF facility has two production lines, Process Line #1 and Process Line #2. Process Line #1 has two plate refiners, each driven by a 10,000 hp synchronous motor manufactured by ABB.

Process Line #2 has one plate refiner driven by a 14,000 hp synchronous motor manufactured by ABB. The facility is fed by Flathead Electric Cooperative's Tamarack Substation, Fig. 1. (The simplified diagram shows only equipment directly related to the AdaptiVolt™ system. It does not show circuit breakers, switches and other substation devices.) Each of the synchronous motors are served by individual 12.47 kV feeders.

Each process line has a 12.47 kV feeder feeding the balance of process line loads. The loads on these feeders includes induction motors ranging from fractional horsepower to 800 hp, variable frequency drives, lighting, HVAC, process controls, and other typical industrial facility loads.

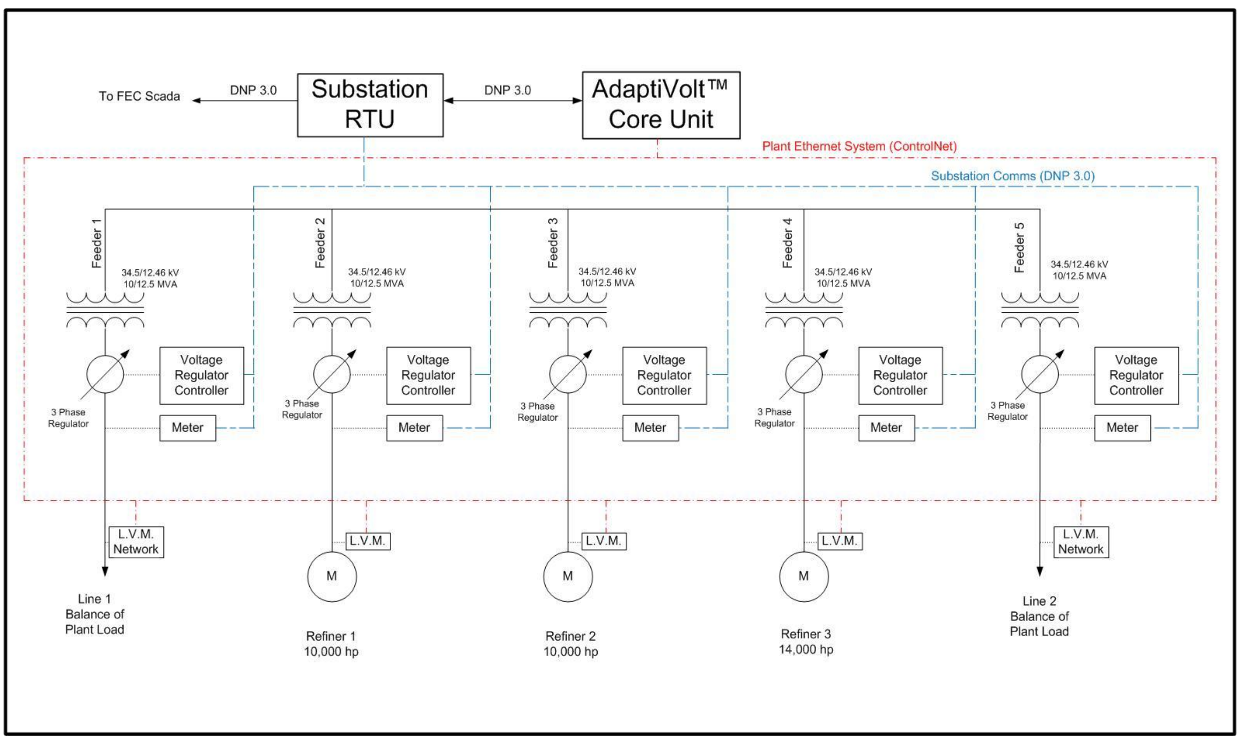


Fig. 1 – Tamarack Substation Simplified Single Line Diagram and AdaptiVolt™ Architecture

[1] While developed for industrial facilities the VIPER algorithm is now being used in electric utility AdaptiVolt™ applications.

PROJECT DESCRIPTION

The overall project consisted of three distinct major project steps - initial feasibility study, deployment and measurement and verification..

Initial Feasibility Study and Report

Prior to beginning a full implementation of the project a study was done to evaluate the potential for energy savings at the facility using voltage optimization. The evaluation included several items:

1. Voltages were measured and recorded at locations in the facility that were electrically farthest from the substation. These included voltages at motor control centers and at the large motor terminals. Voltages were measured and recorded at the substation during the same period. Figs. 2 and 3 show some of those voltage measurement results.

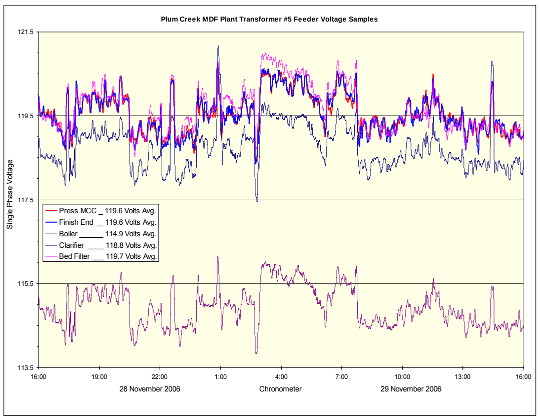


Fig. 2 – Process Line 2 Voltages

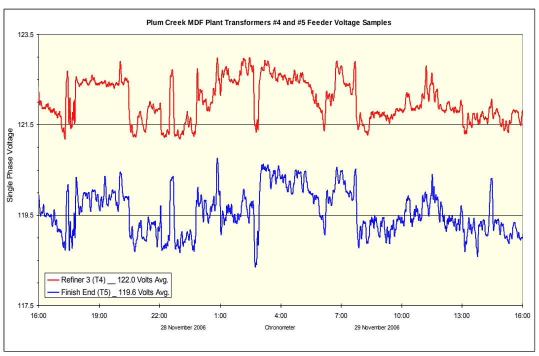


Fig. 3 – Refiner 3 and Process Line 2 Voltages

2. Evaluation of the infrastructure was made to determine the scope of effort required to implement voltage optimization if the decision was to proceed. Voltage regulation capabilities, communications infrastructure existing facility controls systems and other information was gathered.

3. Discussions were held with plant production personnel to determine which plant production variables and processes were most likely to affect electrical energy usage. As a result of this discussion, approximately 60 process variables were recorded at the same time intervals as the voltage, demand, kW and kVAR data to be used in the M&V analysis.

4. Step voltage tests were done on the large refiner motors to determine the likely energy conservation effect of voltage optimization. This was accomplished by operating at reduced voltage for a period of time then operating at the pre-voltage optimization level for a similar period of time. Figures 4, 5, and 6 show the measured voltage step in kV, the measured power in MW, the measured wet wood feed n pounds per hour (PPH) respectively for the first step test on Refiner 3. Figs. 7, 8 and 9 show the same measurements for the second test on Refiner 3.

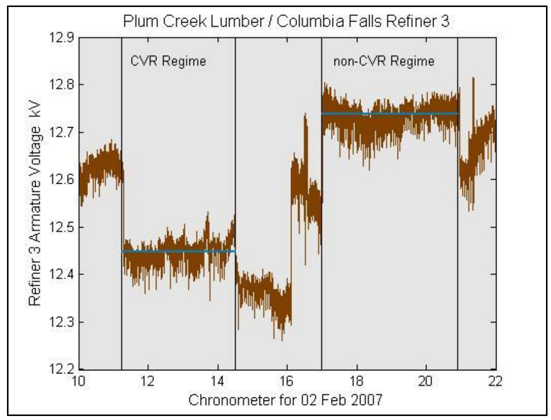


Figure 4 - Refiner 3 Step Voltage Test 1 – Voltage (kV)

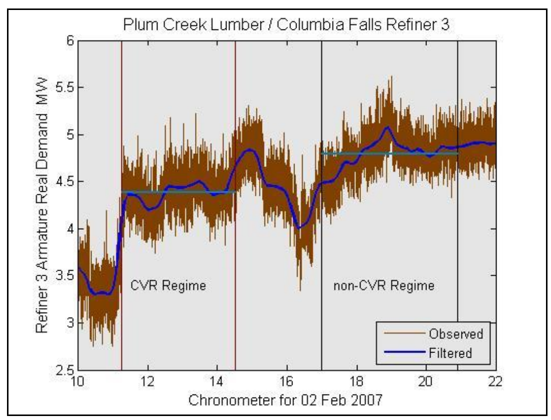


Fig. 5 - Refiner 3 Step Voltage Test 1 – Demand (MW)

5. Upon completion of the previous steps a report was prepared and submitted outlining the findings of the evaluation. The report also included a suggested Measurement and Verification (M&V) Protocol to be

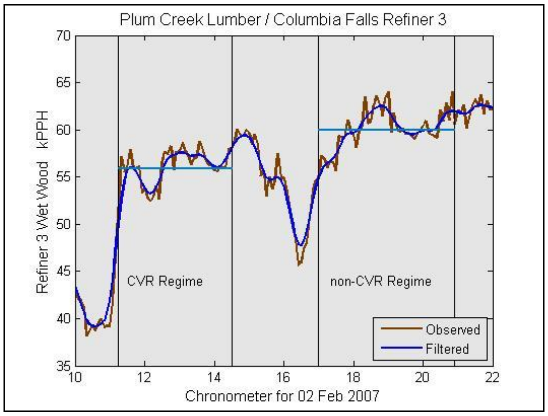


Fig. 6 – Refiner 3 Step Voltage Test 1 – Wet Feed (PPH)

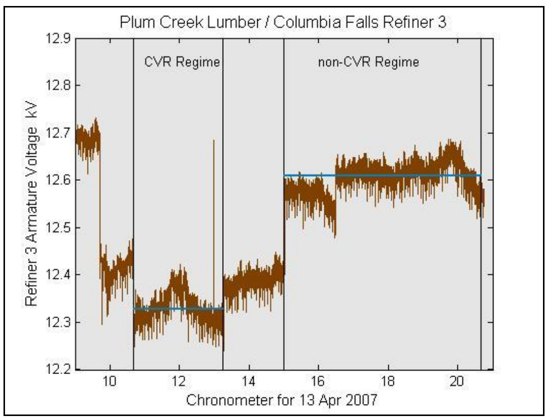


Figure 7 - Refiner 3 Step Voltage Test 2 – Voltage (kV)

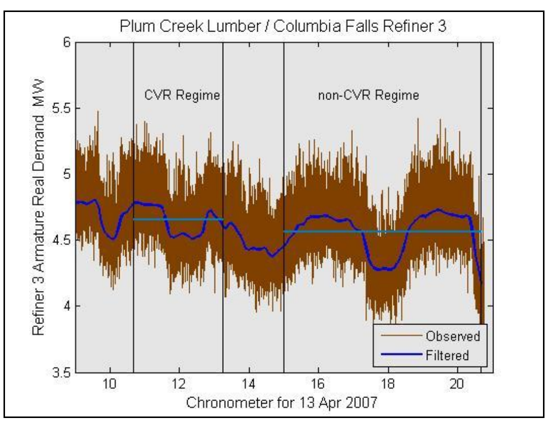


Fig. 8 - Refiner 3 Step Voltage Test 2 – Demand (MW)

used in verifying the conservation effect of operating with voltage optimization. (Because (BPA) was to be providing an energy incentive to Plum Creek the M&V protocol required their prior approval.) Estimates of expected energy conservation with voltage optimization based on voltage measurements and estimated CVR_fs were included in the report.

The evaluation indicated that voltage levels throughout the facility were such that sufficient voltage optimization could be achieved and significant energy conservation would result.

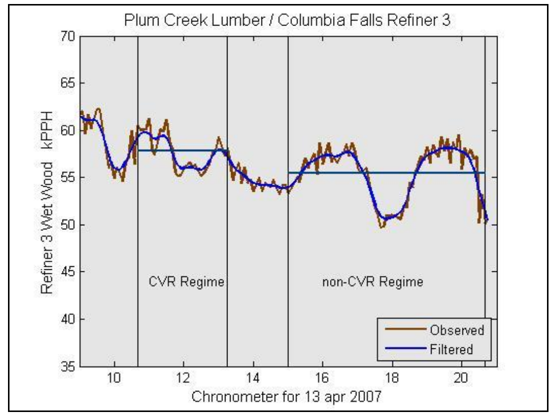


Figure 9 - Refiner 3 Step Voltage Test 2 - Wet Feed (PPH)

The measured results of the step voltage tests on the refiners were used to compute the specific demand during the tests. Specific demand W/PPH is equal to watt-hours per pound or specific energy per pound. As can be seen in Figs. 10 and 11, the step tests showed that the specific energy per pound was lower during voltage optimization than when the voltage was not being optimized.

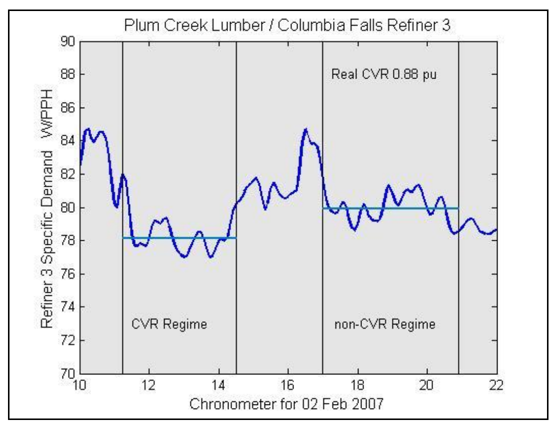


Fig. 10 - Refiner 3 Step Voltage Test 1 - Specific Demand (W/PPH)

IVO Deployment

Based on the initial evaluation and report Plum Creek Timber decided to proceed with full deployment of an AdaptiVolt™ system. System installation began in summer 2008.

The system consisted of an AdaptiVolt™ core unit, Fig. 12, supplied by the author's company, 32 power monitors which were supplied by Plum Creek for voltage monitoring and energy metering, the plant communications system which in large part existed, 3 new voltage regulator controllers and

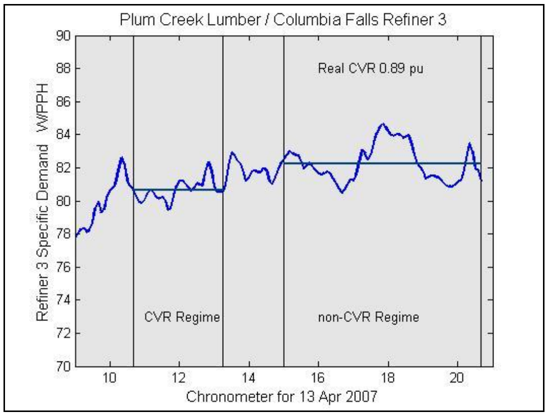


Fig. 11 – Refiner 3 Step Voltage Test 2 – Specific Demand (W/PPH)

communication upgrade kits for two existing regulator controllers. (Refer to Fig. 1 for a simple system architecture.)


Fig. 12 - AdaptiVolt™ Core Unit

Physical installation in the Plum Creek facility was performed by Plum Creek personnel. Installation in the Tamarack Substation was performed by Flathead Electric Cooperative (FEC). System testing and commissioning was performed by PCS UtiliData engineers with the cooperation and assistance of Plum Creek and FEC engineers and technicians. The system completed commissioning and went into operation in September, 2008.

Figs. 13, 14 and 15 show some of the AdaptiVolt™ operational displays.

MEASUREMENT AND VERIFICATION (M&V)

In 2004 the Northwest Regional Technical Forum (RTF,) a subsidiary of the Northwest Power and Conservation Council (NWPCC) approved the M&V protocol *"Protocol #1 for Automated CVR"* (Protocol #1)[2] [6][7] and BPA subsequently approved it to use for determining obtained

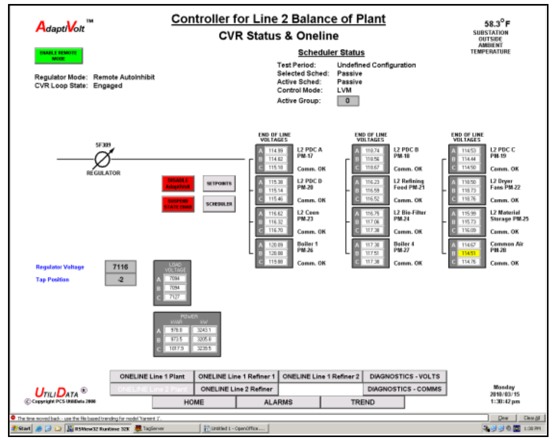


Fig. 13 – Line 2 Balance of Plant Display

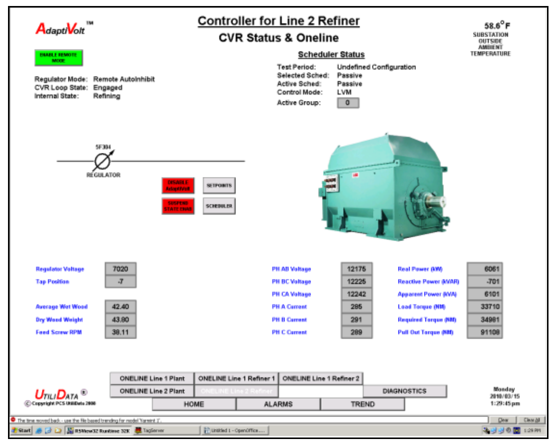


Fig. 14 – Refiner 3 Operational Display

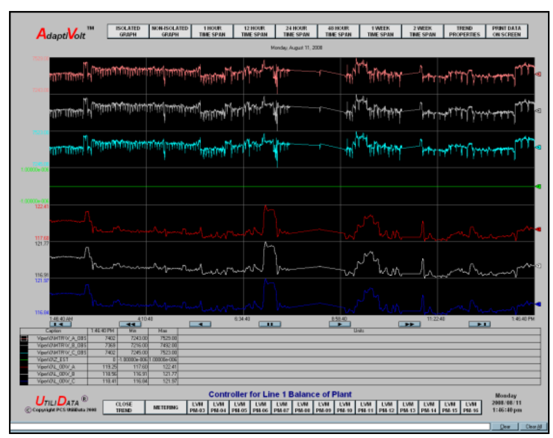


Fig. 15 – Trend Display (Configurable)

2 More detailed information about Automated CVR Protocol #1 is available in the reference documents or can be obtained by contacting the author's company.

conservation results for which they will compensate utilities and other customers. The author's company developed Protocol #1 in close collaboration and cooperation with BPA. The Washington State University Department of Electrical Engineering reviewed the engineering analysis and the use of time series analysis and the Statistics Department at the University of Waterloo in Ontario reviewed the robust statistical methods and analysis. Protocol #1 meets the U. S. Department of Energy's energy conservation measurement and verification guidelines [8].

Protocol #1 uses a set testing period with the automated CVR engaged on alternate days. In verifying energy savings the protocol attempts to eliminate other factors that affect demand such as climate variation, mainly temperature, consumer behavior and other special exceptions.

A combination of time series analysis and robust statistical methods are used to verify energy savings and estimate future savings on each feeder. All the pertinent data is broken into time ensembles for comparison, i.e. data from one time one day is compared only with the data from the same time period on the alternate day. Additionally different types of days are compared with the same type of day, i.e. winter weekends are compared with winter weekends and summer weekdays are compared to summer weekdays.

The methodology of Protocol #1 compares demand on a uniform basis by comparing data from alternate days and as closely as possible demand is based on the same environment. It exploits prior knowledge of the demand processes such as daily periodicity, utilization device efficiency vs. voltage and customer demand behavior. It also applies results only within the bounds of observations.

When evaluating industrial CVR results, time series analysis and robust statistical processes are used very similarly as in Protocol #1. However, rather than using temperature as a correlating factor, one or more process variables are selected to be used as correlating factors[3]. In this case the product feed rate into the refiners was determined to be the most significant correlating factor for regression analysis.

The M&V period began in September, 2008 after the system began full time operations. The M&V protocol that had been approved by BPA had been based upon pre-2008/09 economic downturn production levels. One of the assumptions had been that run-times for specific products would be in the order of days to a week and setup and process changes occur relatively infrequently, that is in the order of once or twice per week. With the economic downturn, production levels had to be reduced and run times became much shorter requiring frequent setup and process changes, sometimes in the order of hours. Due to this the M&V protocol had to be reviewed and modified accordingly with BPA approval required. The M&V period was completed at the end of September. 2009.

[3] While Protocol #1 has been placed in the public domain by PCS UtiliData, the industrial protocol remains proprietary to the company.

RESULTS OF THE M&V ANALYSIS

Fig. 16 shows the voltage levels for voltage optimization (CVR regime) and non-voltage optimization (non-CVR regime) during the M&V testing for Process Line 2 Balance of Plant. Fig. 17 shows the associated demand in MW for that same testing period. Fig. 18 shows the voltage levels for voltage optimization (and non-voltage optimization during the M&V testing for Refiner 3. Fig. 18 shows the associated demand in MW for Refiner 3 during same testing period.

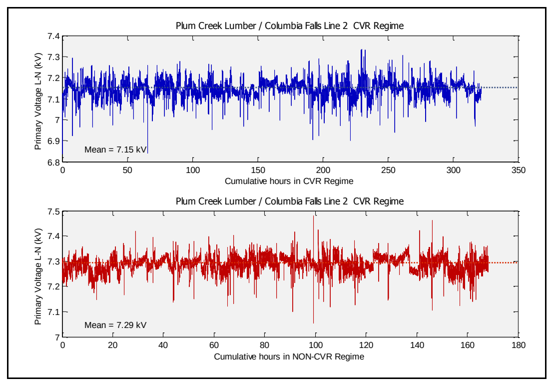


Figure 16 - Line #2, Feeder #5, Balance of Plant – Voltage

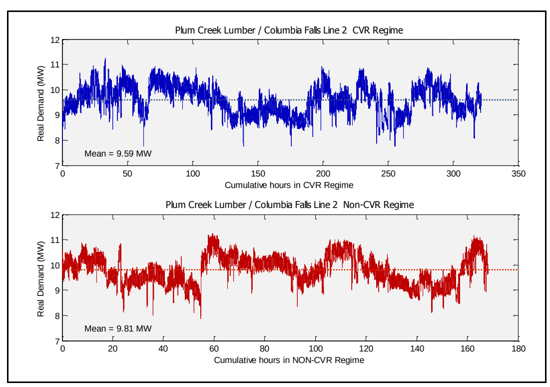


Fig. 17 - Line #2, Feeder #5, Balance of Plant – Real Demand

Table 1 shows a summary of the M&V analysis. Shown in the table are the average % voltage reductions, CVR factors, % demand (MW) reduction, reactive CVR factor (CVRQf), current

CVR factor (CVR_i), and tap changer performance. (In this process % demand (MW) reduction is equivalentto % energy (kWh or MWh) reduction because when a process line is operational the demand is essentially constant over time.)

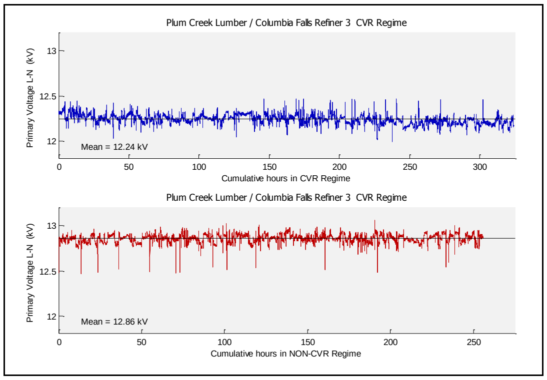


Fig. 18 - Line #2, Feeder #4, Refiner #3 – Voltage

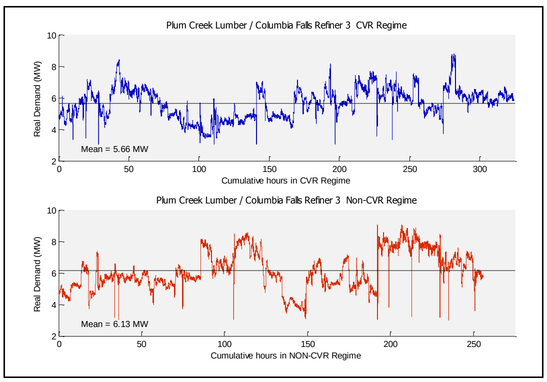


Fig. 19 - Line #2, Feeder #4, Refiner #3 – Real Demand

Discussion of the the results

Average voltage reduction

The minimum average voltage reduction was 2.4% on the two balance of plant feeders, feeders 1 and 5. In an industrial facility it is likely that there will be less available voltage reduction where there are a large number of various size loads connected to a feeder. Where there is a single large load as in the case of Feeders 2, 3 and 4 which feed the refiners the available voltage reduction can be expected to be higher. The maximum average voltage reduction was 4.82% on Refiner 3.

Real CVR factors and demand reduction

CVR factors are a function of the physical characteristics of the loads. The primary causal factor of energy conservation in an industrial facility is the reduction of over-excitation of electric motor iron cores and transformer iron cores. Various tests have shown that CVR factors are non-linear with respect to voltage and vary depending upon the amount of voltage reduction and the range of voltages [9].

Reactive CVR factors and VAR reduction

Because of the reduction in excitation of the magnetic cores of motors and transformers reactive power (kVAR) is normally reduced when voltage is optimized. The reactive CVR factor is a measure of the % load kVAR reduction when voltage is optimized and the actual % kVAR change is included.

$$CVRQ_f = \Delta kVAR\%/\Delta V\%$$

where $\Delta kVAR\%$ = % change in reactive power and $\Delta V\%$ = % reduction in voltage.

Current CVR factors and current change

Because both power and reactive power is reduced with voltage optimization, current is normally reduced. The current CVR factor (CVR_i) is

Plum Creek Timber MDF Facility - AdaptiVolt™ IVO Results					
	Line 1			Line 2	
	Balance of Plant Feeder 1	Refiner 1 Feeder 2	Refiner 2 Feeder 3	Refiner 3 Feeder 4	Balance of Plant Feeder 5
Average Voltage Reduction	2.42% ΔV	3.33% ΔV	3.06% ΔV	4.82% ΔV	2.42% ΔV
Real CVR Factor	0.88 pu	2.16 pu	1.83 pu	0.97 pu	1.03 pu
Reactive CVR Factor	15.97 pu	1.36 pu	2.11 pu	1.02 pu	3.26 pu
Current CVR Factor	0.02 pu	1.31 pu	0.89 pu	-0.04 pu	0.11 pu
Demand Reduction	2.13% ΔMW	7.19% ΔMW	5.60% ΔMW	4.68% ΔMW	2.49% ΔMW
VAR Reduction	38.6% ΔVAR	4.53% ΔVAR	6.46% ΔVAR	4.92% ΔVAR	7.89% ΔVAR
Current Reduction	0.05% ΔI	4.53%ΔI	2.72% ΔI	-0.19% ΔI	0.27% ΔI
Tap Change Performance	Non CVR 8.6/day CVR 11.8/day 37%	Non CVR 8.7/day CVR 8.9/day 2.20%	NA (tap counter not available)	Non CVR 28/day CVR 22.5/day -20.00%	Non CVR 18.5/day CVR 11.3/day -39.00%

Table 1

a measure of the % change in current when voltage optimized.

$$CVR_i = \Delta I\%/\Delta V\%$$

where $\Delta I\%$ = % change in current and $\Delta V\%$ = % reduction in voltage.

(Note that when the voltage was reduced on Refiner 3 the current actually increased a small amount. This is likely due to the fact that this synchronous motor as a active field exciter.)

Tap Changer Performance

The number of tap changer operations per day is well withing acceptable operating limits for all feeders. On the two voltage regulators for Process Line 2 both tap changers experience less operations per day with voltage optimization than when it is not operating. The tap changer on Feeder 1 went from 8.6 to 11.8 operations per day and the tap changer on Feeder 3 went from 8.7 to 8.9 operations a day. A tap counter was not available on the Feeder 3 tap changer.

Operational results

In the 18 months the AdaptiVolt™ system has been operating at Plum Creek there have been no production outages due to its operation.

Prior to the implementation of the AdaptiVolt™ voltage optimization system the plant had occasionally experienced failures of AC variable frequency drives during the times that production levels were ramping down. Since the implementation of voltage optimization these occurences have been greatly reduced. These apparently premature failures are thought to have been caused by high voltage as load was reduced, a condition that does not occur with voltage optimization.

In addition to providing voltage and energy information to the AdaptiVolt™ system, the power monitors that were installed are providing information for additional plant energy management and power quality improvement.

Most of the improved energy efficiency comes from reduced magnet core and other losses which result in less equipment heating. It is known that heat is one of the primary causes of equipment deterioration and while not known precisely it is expected that voltage optimization will also extend equipment life in the plant.

POTENTIAL IVO MARKETS & CANDIDATES

Most large industrial facilities are candidates for IVO. Paper Mills, refineries amd petro-chemical plants, auto manufacturing facilities, steel and aluminum mills, metal processing facilities, water and waster treatment facilities, large pumping plants and data centers are among the candidates.

Large institutions may also be good candidates for IVO. Universities, military bases and other large campus type facilities are among these.

Key issues in determining whether a particular facility is a good candidate for IVO include:

1. The facility should have its own substation (whether owned by the facility or the serving utility) or be the only customer on a utility feeder.

2. The size of the electrical load of the plant and its peak load help determine the economics of an IVO system. The larger the plant load and the higher the peak the more cost justified an IVO system becomes.

3. The plant electrical system must be designed adequately to allow for voltage optimization. If electrical designs are sub-standard, voltages within the plant may already be low in some locations. Rehabilitation of existing in plant electrical systems will have an effect on the economics of an IVO project.

4. If the facility has existing voltage regulation capability the initial cost of an IVO system is minimized. If regulating capacity needs to be added this can be the economic determining factor.

5. If the political jursidiction or the serving utility has an energy conservation incentive available it can enhance the payback and return on an IVO project.

6. Existing plant infrastructure such as metering or energy management systems and communications can reduce the overall cost of an IVO system. On the other hand, an IVO system can often be used to help justify the addition of an energy management system or other infrastructure.

CONCLUSIONS

Overall demand and energy use reduction on Process Line 1 was 4.7%, 2,489,760 kWh for 3744 hours of operation. Demand and energy use reduction for Process Line 2 was 2.8%, 3,168,241 kWh for 6892 hours of operation. The total reduction for the year was 5,658,001 kWh, equivalent to a reduction of 3,497 metric tons of CO2 based on the EPA estimated U. S. average of 1.363 pounds per kWh [10]. As discussed earlier, production levels had been reduced due to the economic downturn. At full production the voltage optimization would have resulted in a total of over 9,000,000 kWh for the year for both process lines, the equivalent reduction of 5,563 metric tons of CO2 per year.

The IVO project at Plum Creek Timber shows that energy costs can be reduced significantly in an industrial facility. It also proves the efficacy of voltage optimization in an industrial environment and shows that IVO can be implemented safely and provides other benefits over and above energy conservation.

The implementation of industrial voltage optimization based energy conservation is a very cost effective efficiency measure. The cost per kWh over the expected 20 year life of the measure for this project is approximately $0.0035/kWh compared to the current average purchase price of $0.045/kWh for industrial customers in the Pacific Northwest.

IVO can save significant kWh when implemented at large industrial facilities. This costly energy, being generated using fossil and nuclear fuels, hydro, solar, wind and other renewable resources is essentially being used to heat the atmosphere through unnecessary losses. Additionally the amount of demand (kW) required by this wasted energy requires generation facilities both to serve it and to provide essential reserves to cover that wasted demand.

U. S. Department of Energy Secretary Steven Chu said in a speech at the St James's Palace Nobel Laureate Symposium in May 2009, "…Energy efficiency is not just low-hanging fruit; it is fruit that is lying on the ground…" [11]. The author agrees!

REFERENCES

[1] US Energy Information Administration, Table 5. Average Monthly Bill by Census Division, and State 2008, http://www.eia.doe.gov/cneaf/electricity/esr/table5.html

[2] ANSI Standard C 84.1 – 1995 “Electrical Power Systems and Equipment – Voltage Ratings”

[3] CAN3-C235-83 (R2000)

[4] M.S. Chen, R.R. Shoults and J. Fitzer, “Effects of Reduced Voltage on the Operation and Efficiency of Electric Loads,” EPRI, Arlington: University of Texas, EL-2036 Volumes 1 & 2, Research Project 1419-1, 1981

[5] De Steese, J.G., Merrick, S. B., Tepel, R. C., and Callaway, J. W. (1987) “Assessment of Conservation Voltage Reduction Applicable in the BPA Service Region,” BPA, PNL 6380, Pacific Northwest Laboratories, Richland, WA

[6] *Protocol #1 for Automated Conservation Voltage Regulation*. Spokane, WA, PCS UtiliData, 2004.

[7] Bell, D. G., *Estimation of PCS UtiliData AdaptiVolt™ System Performance using Observed Energy Demand Profiles.* Spokane, WA: PCS UtiliData, 2004

[8] “M&V Guidelines: Measurement and Verification for Federal Energy Projects,” Version 2.2, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, DOE/GO-102000-0960, September 2000

[9] Wilson, T. L., “Measurement and Verification of Distribution Voltage Optimization Results”, to be presented at the IEEE/PES 2010 General Meeting, Minneapolis, MN, July 25 – 29, 2010

[10] US Environmental Protection Agency eGRID2006 Version 2.1, April 2007

[11] *Secretary Chu Opinion Piece in Times of London*, May 27, 2009 http://www.energy.gov/news/print/7429.htm

U.S. Department of Energy's Industrial Technology Program and Its Impacts

Steven A. Weakley
Senior Research Engineer
Pacific Northwest National Laboratory
P.O. Box 999 Battelle Blvd. MS: K6-05
Richland, Washington 99352

Joseph M. Roop
Staff Scientist
Pacific Northwest National Laboratory
P.O. Box 999 Battelle Blvd. MS: K6-05
Richland, Washington 99352

ABSTRACT

The U.S. Department of Energy's Industrial Technologies Program (ITP) has been working with industry since 1976 to encourage the development and adoption of new, energy-efficient technologies. ITP has helped industry not only use energy and materials more efficiently but also improve environmental performance, product quality, and productivity.

To help ITP determine the impacts of its programs, Pacific Northwest National Laboratory (PNNL) periodically reviews and analyzes ITP program benefits. PNNL contacts vendors and users of ITP-sponsored technologies that have been commercialized, estimates the number of units that have penetrated the market, conducts engineering analyses to estimate energy savings from the new technologies, and estimates air pollution and carbon emission reductions. This paper discusses the results of PNNL's most recent review (conducted in 2009). From 1976-2008, the commercialized technologies from ITP's research and development programs and other activities have cumulatively saved 9.27 quadrillion Btu, with a net cost savings of $63.91 billion.

INTRODUCTION

Working in partnership with industry, the U.S. Department of Energy's (DOE's) Industrial Technologies Program (ITP), previously the Office of Industrial Technologies, conducts research, development, demonstration, and technical assistance efforts that are producing substantial, measurable benefits to industry. This paper summarizes some of the quantifiable impacts of ITP's programs through 2008. The Pacific Northwest National Laboratory (PNNL), operated by Battelle for DOE, assists ITP by tracking the results of its programs and quantifying the energy, environmental, and other benefits of the technologies once they penetrate the market. The following sections provide background information about industrial energy use, describe ITP's strategy and organization, describe the methodology used to track the program's benefits, and summarize the results of the most recent tracking exercise.

INDUSTRIAL ENERGY USE

Total energy consumption in the nation's industrial sector far exceeds any other sector and is more diverse. In 2008, the industrial sector used 31.22

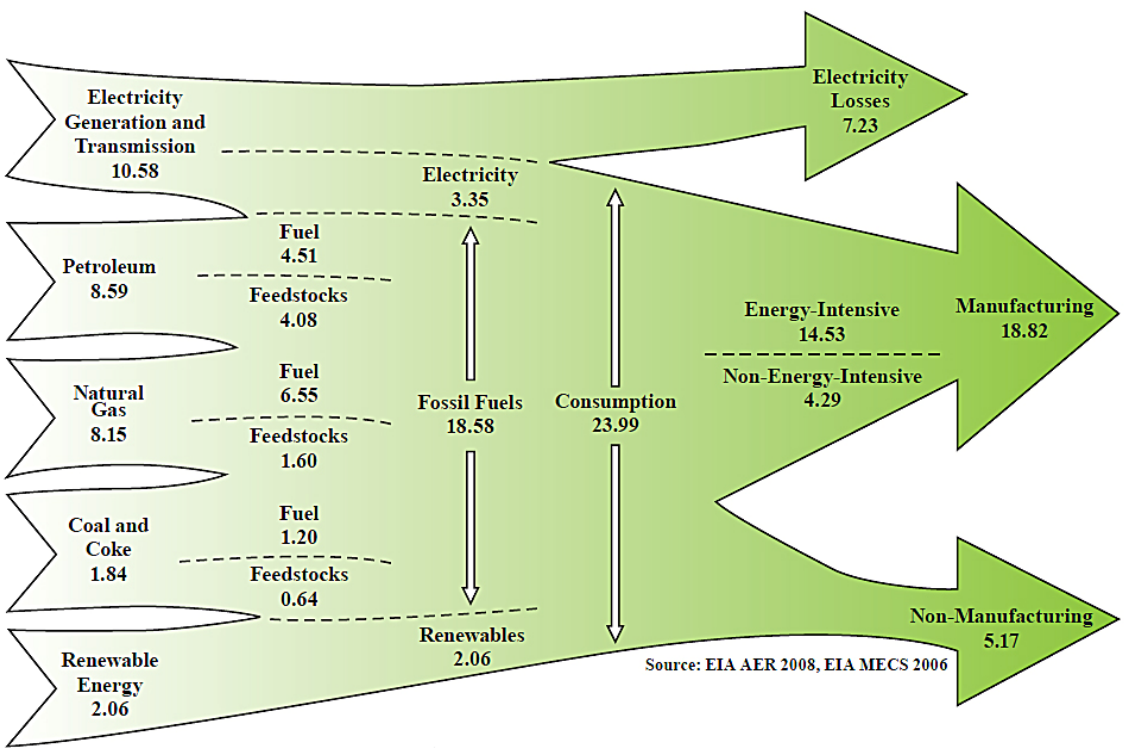


Figure 1. Industrial Energy Flows (Quad), 2008

quadrillion Btu (quad) of all types of energy (slightly less than one-third of the 99.3 quad used by the entire economy), including electricity losses of 7.23 quad (see Figure 1).

Petroleum (8.59 quad), natural gas (8.15 quad), and electricity (3.35 quad delivered) are the three fuels most used by industry, with coal and biomass providing another 3.90 quad combined. The industrial sector consumed 23.99 quad, of which 18.82 quad were consumed by manufacturing industries. Of that 18.82 quad, energy-intensive industries consumed 14.82 quad. The non-energy-intensive industries (4.00 quad) and nonmanufacturing industries (agriculture, mining, and construction – 5.07 quad combined) accounted for the remaining energy consumption. Industry uses nearly 6.32 quad of the fossil fuels for feedstocks – raw materials for plastics and chemicals – rather than as fuels. Energy expenditures in the manufacturing sector are about $104 billion annually.

The energy-intensive industries account for about 79% of all manufacturing energy use (see Figure 2). Many of those industries are limited in their choice of fuels because the technologies currently used in specific processes require a certain fuel. For example, aluminum production requires large amounts of electricity to reduce the alumina to metal.

Paper pulping leaves a large residual of wood lignin that must be reprocessed for its chemical content and consequently supplies the industry with more than half of its primary energy. Therefore, the wide variety of fuels (and feedstocks) used in the industrial sector partially reflects the specific requirements of the processes used to make specific goods or commodities. Because of specific energy requirements, the industrial sector offers a wide variety of opportunities for energy-efficiency improvements that are specific to particular industries (process-specific) and crosscut many industries (common to many industries or needed by many process-specific technologies).

THE INDUSTRIAL TECHNOLOGIES PROGRAM OFFICE

ITP leads the federal government's efforts to improve industrial energy efficiency and environmental performance. The program is part of the Office of Energy Efficiency and Renewable Energy (EERE) and contributes to its efforts to provide reliable, affordable, and environmentally sound energy for the nation's future.

Large opportunities to save energy still exist in U.S. industry. Putting current knowledge to use and continuing research can make a difference. American industry can increase the nation's resilience in the face of current and future energy challenges. Advances in energy efficiency, fuel

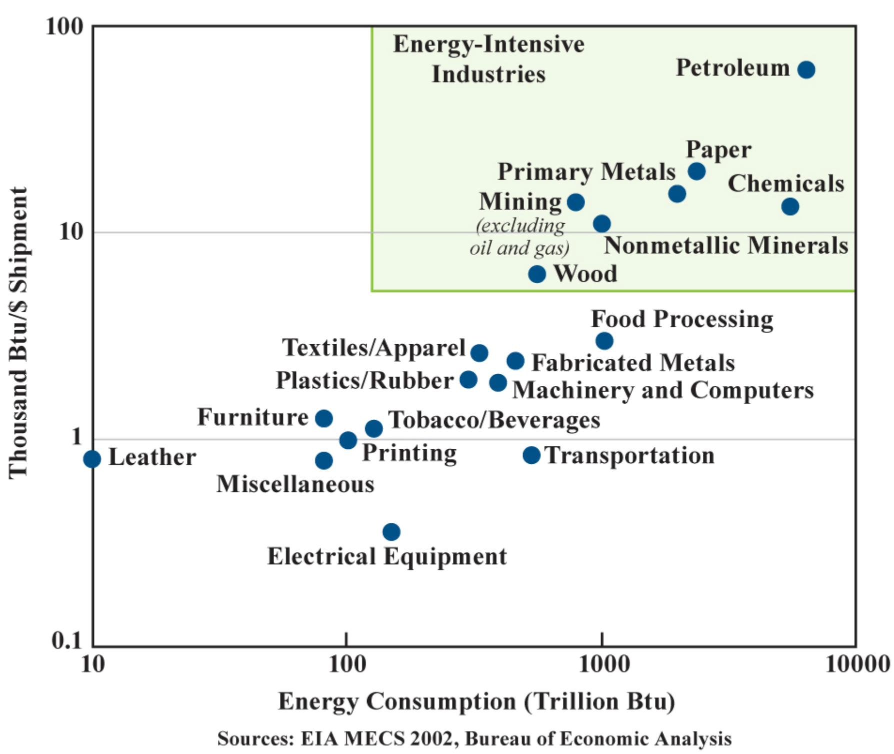


Figure 2. Energy Intensity of Manufacturing Industries

flexibility, and innovative technologies can enhance energy security, economic growth, and environmental quality. Good starting points for reducing industry's energy consumption and reliance on oil and natural gas include the following:

- **More Efficient Operating and Maintenance Practices**. Improved and more energy-efficient operating practices can be adopted rapidly at negligible cost to enhance near- and mid-term operating efficiency in manufacturing facilities.

- **Increased Adoption of State-of-the-Art Technology**. Energy efficiency can be improved in the near- and mid-term by increasing industries' adoption of currently available advanced technologies. For example, waste heat recovery, combined heat and power (CHP), and advanced boiler technologies offer huge energy-saving opportunities.

- **Increased Fuel and Feedstock Flexibility**. Manufacturers need the flexibility to adapt to dynamic energy prices and supply issues. Much of industry's natural gas is used for boilers and process heaters, which present primary fuel switching opportunities.

- **Development of Next-Generation Technology**. Progress toward long-term national goals for energy and the environment rely on continuous technology innovation. The technologies required to address today's challenges can take a decade or more to progress from basic science to commercialization.

National energy security will require widespread industry adoption of innovative technologies and practices that reduce energy demand. ITP leads federal efforts to expedite novel technology research and accelerate market introduction of dramatically more efficient industrial technologies and practices. Over the next few years, ITP will build on accumulated knowledge and strategic partnerships to take full advantage of new opportunities to accelerate and broaden impacts on industrial energy use.

New challenges call for innovative solutions. The development of energy-efficient technologies ready to enter the market in the near term must be accelerated; at the same time, groundbreaking research must be conducted on revolutionary technologies for the future. ITP's focus on applied research and development (R&D) effectively turns knowledge and concepts initiated by others into real-world energy solutions. In addition, novel strategies to expand ITP's partner base will boost program impacts by expediting technology commercialization and adoption of efficient energy management practices. ITP is currently evaluating a number of opportunities to help industry respond to energy challenges today and tomorrow. ITP is exploring 10 new strategies to help industry stay competitive today while preparing for future challenges:

1. **Investigate cross-cutting R&D to save energy in the top energy-consuming processes used across industry**. ITP is focusing on a small number of widely used technology areas that could achieve large energy benefits throughout the manufacturing supply chain.

2. **Exploit fuel and feedstock flexibility to give manufacturers options for responding to energy price and supply pressures**. ITP is seeking to develop alternative fuel and feedstock technologies to replace oil and natural gas in the long term while supporting near-term deployment activities to reduce the impacts of fuel price hikes. By increasing the range of fuel options available to industry, ITP will foster energy independence and economic resilience.

3. **Invest in "next-generation" technologies that are adaptable to processes throughout industry and that could dramatically change the way products are manufactured**. ITP is funding research in mass-scale nano manufacturing, process-integrated predictive tools, and wireless real-time sensor systems that are just a few of the technologies that could bring new, cost-competitive options to American industry.

4. **Strengthen planning and analysis to identify opportunities with the greatest potential for energy savings and develop a robust market transformation strategy.** ITP is conducting a thorough analysis of industry market barriers and challenges that will allow more effective investment decisions with higher impacts.

5. **Institute rigorous stage-gate project and portfolio management procedures to ensure sound project management and funding decisions.** ITP has developed its own program management guidelines based on the conventional Stage-Gate Management™ concept

of R.G. Cooper and Associates (see Figure 3). ITP is examining projects at critical gates throughout the R&D cycle based on carefully defined technical and business criteria. This program management tool provides ITP managers with a straightforward pathway for evaluating progress and imposes discipline in project management, raising the potential for commercial success of ITP's R&D portfolio.

6. **Emphasize commercialization planning throughout the R&D life cycle**. ITP will work with its R&D partners to develop robust commercialization strategies and provide other support to ensure the market success of promising new technologies.

7. **Encourage private investment in energy efficiency through new partnerships and strategies to reach industry**. ITP will expand its alliance with equipment manufacturers who are well positioned to drive new technology to the market and publicize it to their customers. Private industry will also be challenged to increase their investment in advanced technologies, energy management and best operating practices, and the replacement of older, inefficient equipment.

8. **Drive ambitious reductions in industrial energy intensity through Save Energy Now and its related LEADER program.** Since 2006, ITP has sponsored a national initiative, *Save Energy Now*, to drive a 25% reduction in industrial energy intensity in 10 years (25 in 10) through the use of proactive partnerships between government and the private sector. *Save Energy Now* has developed into a robust suite of energy-savings tools and services that ITP provides for partnering with industry to improve energy efficiency.

9. **Promote energy-efficiency improvements throughout the supply chain.** ITP is leading an effort, as part of the *Save Energy Now* initiative, to help drive progress on energy efficiency more aggressively throughout the supply chain. As supply chains for companies have grown increasingly complex, understanding and managing energy waste within them represent a way to reduce energy prices or regulatory risk and increase competitive advantage. Not only can it add to security in a company's operations, it can enhance their suppliers' businesses, as well as provide mentoring and support for these suppliers' energy and emissions management systems.

10. **Help drive the development of energy management standards and the Superior Energy Performance certification program to provide a clear roadmap for continual improvement in energy efficiency.** ITP is working with U.S. industry to support the development of an emerging set of energy management standards and a related certification program anchored to a viable business case. Similar to environmental or quality management systems in industry, much energy efficiency in industry is achieved through changes in how energy is managed in a facility. The energy management standard and certification program will serve as powerful new tools in the arsenal of the broader *Save Energy Now* LEADER program that will assist U.S. industry in continually improving energy efficiency in an accelerated manner.

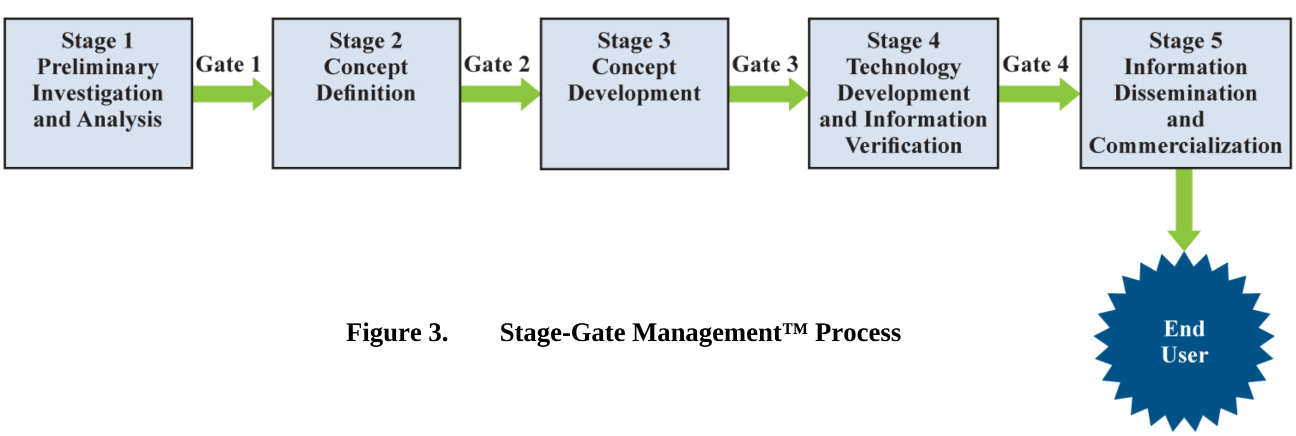


Figure 3. Stage-Gate Management™ Process

In addition to these strategies, ITP partners with other program areas within EERE and performs ongoing program evaluation, including assessing past programs and the benefits that have accrued from investments.

ITP's website (http://www.eere.energy.gov/industry) provides a wealth of information about the program, and the EERE Information Center (1-877-337-3463, eereic@ee.doe.gov) fields questions and facilitates access to ITP resources for industrial customers.

HOW BENEFITS ARE QUANTIFIED

ITP program managers recognize the importance of developing accurate data on the impacts of their programs. Such data are essential for assessing ITP's past performance and guiding the direction of future research programs.

PNNL estimates energy savings associated with specific technologies using a rigorous process for tracking and managing data. When a full-scale commercial unit of a technology is operational in a commercial setting, that technology is considered commercially successful and is on the active tracking list. When a commercially successful technology unit has been in operation for about ten years, that unit is then considered a mature technology and typically is no longer actively tracked. The active tracking process involves collecting technical and market data on each commercially successful technology, including details on the following:

- Number of units sold, installed, and operating in the United States and abroad (including size and location)
- Units decommissioned since the previous year
- Energy saved
- Environmental benefits
- Improvements in quality and productivity
- Other impacts such as employment and effects on health and safety
- Marketing issues and barriers.

Information on technologies is gathered through direct contact with either vendors or end users of the technology. These contacts provide the data needed to calculate the unit energy savings associated with an individual technology, as well as the number of operating units. Therefore, unit energy savings are calculated in a unique way for each technology. Technology manufacturers or end users usually provide unit energy savings or at least enough data for a typical unit energy savings to be calculated. The total number of operating units is equal to the number of units installed minus the number of units decommissioned or classified as mature in a given year – information usually determined from sales data or end user input. Operating units and unit energy savings can then be used to calculate total annual energy savings for the technology.

The cumulative energy savings represent the accumulated energy saved for all units for the total time the technology has been in operation. This includes previous savings from now-mature units and decommissioned units, even though these units are not included in the current year's savings.

Once cumulative energy savings have been determined, long-term impacts on the environment are calculated by estimating the associated reduction of air pollutants. This calculation is based on the type of fuel saved and the pollutants typically associated with combustion of that fuel and uses assumed average emission factors. For example, for every million Btu of coal combusted, about 1.25 pounds of sulfur oxides (known acid rain precursors) are assumed to be emitted to the atmosphere. Therefore, every million-Btu reduction in coal use eliminates 1.25 pounds of sulfur oxides.

The cumulative production cost savings minus the cumulative ITP appropriations and implementation costs provide an estimate of the direct **net** economic benefit of the ITP program since its inception. The program's benefits are based on the following:

- **Estimated energy savings** – Since the program began in 1976, the energy savings (Btu) produced by ITP-supported, commercialized technologies have been tracked. As of 2008, the cumulative value for energy savings of all commercial and historical ITP technologies was 3.63 quad.
- **The cost of industrial energy saved** – The nominal prices (in dollars per million Btu) for various fuels are reported in the Energy Information Administration's Annual

Energy Review (AER). The 2008 AER extended these nominal fuel prices back from 2008 to 1978. These prices are adjusted for inflation based on an index of all fuels and power as reported by the Bureau of Labor Statistics, but normalized to 2008 so that all prices are in current dollars. These annual fuel prices are multiplied by the amount of energy saved per fuel type per year for each of the ITP commercialized and tracked technologies.

The program's costs are based on the following:

- **ITP appropriations** – Appropriations are R&D dollars spent by ITP each year since the program began, adjusted for inflation. As of FY 2008, the cumulative ITP spending since 1976 is $3.00 billion.

- **Assumed cost of implementation** – Because reliable information about the costs of installing the new technologies is not available, an assumption was made to account for these costs. Industry is assumed to require a two-year payback period on investments. To account for implementation costs, the first two years of the cumulated energy savings for each technology are ignored because these saving are needed to "recoup" the capital costs of adopting the new technology. Again, these costs are normalized for inflation just as are the fuel prices for savings.

For each technology, the annual energy savings by fuel type are multiplied by the real price of that fuel. The sum of all energy saved times the average real energy price yields an estimate of the annual savings for all technologies in that particular year. In addition to technology energy savings, savings from two technology delivery programs, the Industrial Assessment Centers (IACs) and BestPractices, and CHP activities were also determined on an annual basis.

The economic benefits are the accumulation of these savings over time adjusted for inflation, as described above. The economic costs are two-fold: ITP appropriations and the implementation costs reflected in the two-year payback period. The appropriations are adjusted for inflation by using the implicit deflator for nondefense federal government expenditures, as published by the Bureau of Economic Analysis of the U.S. Department of Commerce. The implementation costs are adjusted for inflation in the same manner as fuel savings. The net economic benefits are then the benefits minus the costs.

Several factors make the tracking task challenging. Personnel turnover at developing organizations and at user companies makes it difficult to identify applications. Small companies that develop a successful technology may be bought by larger firms or may assign the technology rights to a third party. As time goes on, the technologies may be incorporated into new products, applied in new industries, or even replaced by newer technologies that are derivative of the developed technology.

Program benefits documented by PNNL are conservative estimates based on technology users' and developers' testimonies. These estimates do not include either derivative effects, resulting from other new technologies that spin off of ITP technologies, or the secondary benefits of the energy and cost savings accrued in the basic manufacturing industries downstream of the new technologies. Therefore, actual benefits are likely to be much higher than the numbers reported here. Nonetheless, the benefits-tracking process provides a wealth of information on the program's successes.

RESULTS of ITP R&D

ITP's R&D has resulted in over 200 successfully commercialized technologies. In addition to technology energy savings, savings from the IACs, BestPractices and CHP activities are also determined annually. Table 1 provides information on all the commercialized technologies currently tracked. The table shows energy savings in 2008, as well as cumulative energy savings and pollution reductions. Note that for some technologies, energy savings values are unavailable or too difficult to quantify. In 2008, these commercialized technologies and the IACs, BestPractices and CHP activities saved more than 760 trillion Btu (estimated annual savings), which translates to a $6.86 billion savings to industry. While the energy savings are impressive, industry has reaped even greater benefits from the productivity improvements, reduced resource consumption, decreased emissions, and enhancements to product quality associated with these technological advances. The cumulative emission reductions associated with these commercialized technologies and ITP programs are estimated to equal 206 million ton of carbon, 1.75 billion ton of NO_x, and 3.73 billion ton of SO_x. In addition, many ITP-supported projects have significantly expanded the basic knowledge about complex industrial processes and laid the foundation for developing future energy-efficient technologies.

Figure 4 shows the net benefits curve (described in the previous section) for ITP. The values shown for each year represent the cumulative energy savings (in dollars) of all the technologies and programs, minus the cost of installing the technologies (assuming a two-year payback as described earlier) and also subtracting ITP's cumulative programmatic costs. Cumulatively, since 1976, ITP's commercialized technologies and programs have saved 9.27 quad of energy and $63.91 billion.

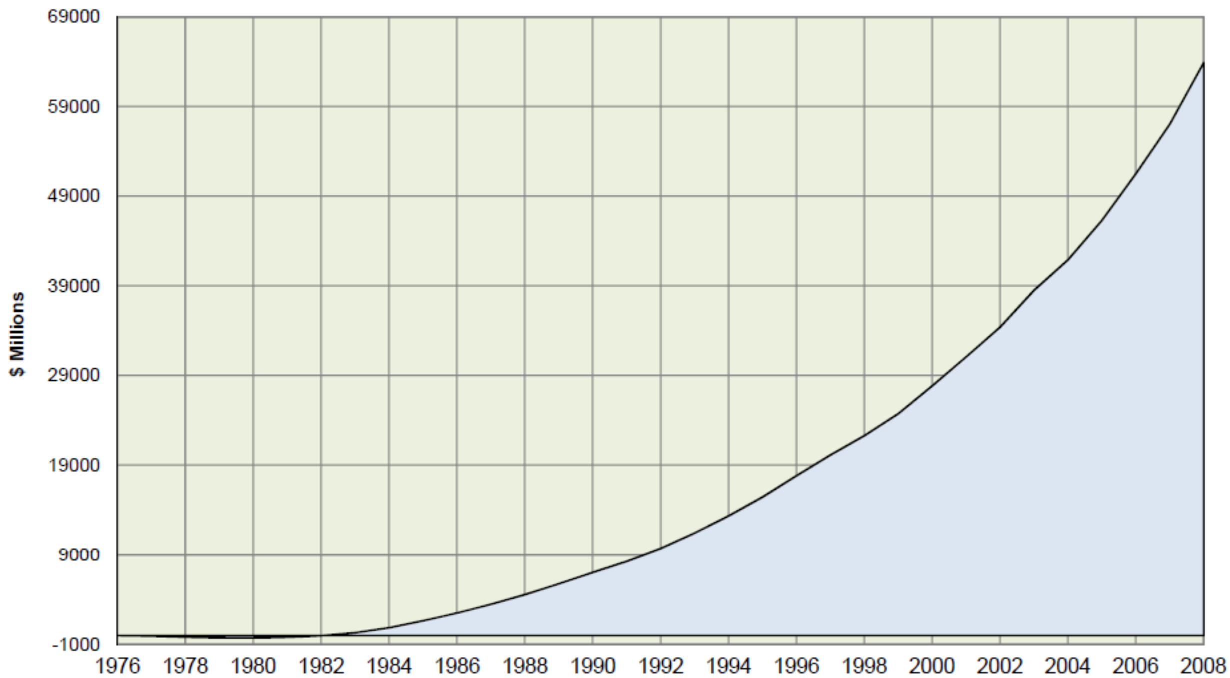


Figure 4. Cumulative Production Cost Savings Minus Cumulative Program and Implementation Cost

Table 1. ITP Technology Program Impacts

Technologies Commercially Available	Cumulative Energy Savings (10^{12} Btu)	Current 2008 Energy Savings (1012 Btu)	Cumulative Pollution Reductions (Thousand Tons): Particulates	VOCs	SOx	NOx	Carbon
ALUMINUM							
Aluminum Reclaimer for Foundry Applications	0.003	0.001	-	0.000	-	0.000	0.051
Aluminum Scrap Sorting	2.048	0.338	0.009	0.007	0.442	0.330	40.253
Isothermal Melting	0.010	-	0.000	0.000	0.002	0.002	0.203
Oxygen-Enhanced Combustion for Recycled Aluminum	0.025	-	-	0.000	-	0.003	0.400
CHEMICALS							
Cavity-Enhanced Gas Analyzer for Process Control	-	-	-	-	-	-	-
Dry Wash®	0.076	0.012	0.000	0.000	0.011	0.011	1.399
Hollow-Fiber Membrane Compressed Air Drying System	0.012	0.006	0.000	0.000	0.003	0.002	0.233
Improved Methods for the Production of Polyurethane Foam	0.193	0.087	0.000	0.001	0.020	0.027	3.421
Low-Cost, Robust Ceramic Membranes for Gas Separation	0.027	0.008	-	0.000	-	0.003	0.429
Low-Frequency Sonic Mixing Technology	-	-	-	-	-	-	-
Membranes for Reverse-Organic Air Separations	0.124	0.120	0.001	0.001	0.072	0.019	2.694
Micell Dry-Cleaning Technology	0.034	0.003	0.000	0.000	0.005	0.005	0.624
Mixed Solvent Electrolyte Model	-	-	-	-	-	-	-
Nylon Carpet Recycling	-	-	-	-	-	-	-
Pressure Swing Adsorption for Product Recovery	0.515	0.111	-	0.002	-	0.060	8.170
Process Heater for Stoichiometric Combustion Control	1.796	0.338	0.002	0.006	0.106	0.221	29.792
Titania-Activated Silica System for Emission Control	-	-	-	-	-	-	-
Total Cost Assessment Tool	-	-	-	-	-	-	-
TruePeak Process Laser Analyzer	-	-	-	-	-	-	-
FOREST PRODUCTS							
Advanced Quality Control (AQC) Solution for Thermo-Mechanical Pulping	1.077	0.154	0.005	0.004	0.233	0.173	21.159
Biological Air Emissions Control	0.704	0.347	0.000	0.002	0.002	0.083	11.214
Borate Autocastizing	0.035	0.015	0.000	0.000	0.020	0.005	0.766
Continuous Digester Control Technology	9.000	-	-	0.032	-	1.053	142.862
Detection and Control of Deposition on Pendant Tubes In Kraft Chemical Recovery Boiler	5.434	1.584	0.041	0.024	3.157	0.840	118.301
MultiWaveTM Automated Sorting System for Efficient Recycling	-	-	-	-	-	-	-
Screenable Pressure-Sensitive Adhesives	-	-	-	-	-	-	-
ThermodyneTM Evaporator – A Molded Pulp Products Dryer	0.409	0.068	-	0.001	-	0.048	6.486
GLASS							
Advanced Temperature Measurement System	-	-	-	-	-	-	-
High Luminosity, Low-NOx Burner	-	-	-	-	-	-	-
Process for Converting Waste Glass Fiber into Value-Added Products	0.245	0.105	-	0.001	-	0.029	3.889
METAL CASTING							
Ceramic Composite Die for Metal Casting	-	-	-	-	-	-	-
CFD Modeling for Lost Foam White Side	-	-	-	-	-	-	-
Die Casting Copper Motor Rotors	0.237	0.125	0.001	0.001	0.051	0.038	4.658
Improved Magnesium Molding Process (Thixomolding)	0.146	0.072	-	0.001	-	0.017	2.325
Improvement of the Lost Foam Casting Process	2.119	0.326	0.004	0.007	0.197	0.288	37.081
Low Permeability Components for Aluminum Melting and Casting	-	-	-	-	-	-	-
Rapid Heat Treatment of Cast Aluminum Parts	-	-	-	-	-	-	-
Simple Visualization Tools for Part and Die Design	-	-	-	-	-	-	-
Titanium Matrix Composite Tooling Material for Aluminum Die Castings	0.050	0.017	-	0.000	-	0.006	0.800
MINING							
Belt Vision Inspection System	-	-	-	-	-	-	-
Fibrous Monoliths as Wear-Resistant Components	-	-	-	-	-	-	-
Horizon SensorTM	0.251	0.020	0.001	0.001	0.054	0.040	4.931
Imaging Ahead of Mining	6.786	1.404	0.031	0.024	1.466	1.093	133.372
Lower-pH Copper Flotation Reagent System	3.892	0.973	0.018	0.014	0.841	0.627	76.502
STEEL							
Aluminum Bronze Alloys to Improve Furnace Component Life	0.064	0.018	-	0.000	-	0.007	1.014
Automated Steel Cleanliness Analysis Tool (ASCAT)	-	-	-	-	-	-	-
Dilute Oxygen Combustion System	28.743	7.173	-	0.101	-	3.363	456.248
Electrochemical Dezincing of Steel Scrap	0.283	0.016	0.004	0.000	0.177	0.079	7.926
HotEye® Steel Surface Inspection System	8.290	1.915	-	0.029	-	0.970	131.591
H-Series Cast Austenitic Stainless Steels	0.000	0.000	-	0.000	-	0.000	0.006
Laser Contouring System for Refractory Lining Measurements	-	-	-	-	-	-	-
Life Improvement of Pot Hardware in Continuous Hot Dipping Processes	-	-	-	-	-	-	-
Low-Temperature Colossal Supersaturation of Stainless Steels	-	-	-	-	-	-	-
Microstructure Engineering for Hot Strip Mills	-	-	-	-	-	-	-
Shorter Spherodizing Annealing Time for Tube/Pipe Manufacturing	0.130	0.008	-	0.000	-	0.015	2.059
Transfer Rolls for Steel Production	0.155	0.017	-	0.001	-	0.018	2.456
Vanadium Carbide Coating Process	0.000	-	-	0.000	-	0.000	0.000

			Cumulative Pollution Reductions (Thousand Tons)				
Technologies Commercially Available	Cumulative Energy Savings (10^{12} Btu)	Current 2008 Energy Savings (1012 Btu)	Particulates	VOCs	SOx	NOx	Carbon
CROSSCUTTING							
Adjustable-Speed Drives for 500 to 4000 Horsepower Industrial Applications	1.100	0.455	0.005	0.004	0.238	0.177	21.617
Advanced Aerodynamic Technologies for Improving Fuel Economy in Ground Vehicles	0.041	0.040	0.000	0.000	0.024	0.006	0.884
Advanced Reciprocating Engine Systems (ARES)	-	-	-	-	-	-	-
Aerogel-Based Insulation for Industrial Steam Distribution Systems	0.031	0.025	-	0.000	-	0.004	0.492
Autotherm® Energy Recovery System	0.100	0.033	0.001	0.000	0.058	0.016	2.187
Barracuda Computational Particle Fluid Dynamics (CPFD) Software	-	-	-	-	-	-	-
Callidus Ultra-Blue (CUB) Burner	68.688	21.900	-	0.240	-	8.036	1,090.319
Catalytic Combustion	-	-	-	-	-	-	-
Composite-Reinforced Aluminum Conductor	-	-	-	-	-	-	-
Cromer Cycle Air Conditioner	0.668	0.369	0.003	0.002	0.144	0.108	13.126
Dual-Pressure Euler Turbine for Industrial and Building Applications	0.187	0.074	-	0.001	-	0.022	2.967
Electrochromic Windows - Advanced Processing Technology	0.001	0.001	0.000	0.000	0.000	0.000	0.021
Energy-Conserving Tool for Combustion-Dependent Industries	0.016	0.005	0.000	0.000	0.003	0.003	0.316
Fiber Sizing Sensor and Controller	-	-	-	-	-	-	-
Fiber-Optic Sensor for Industrial Process Measurement and Control	-	-	-	-	-	-	-
Foamed Recyclables	-	-	-	-	-	-	-
Freight WingTM Aerodynamic Fairings	0.219	0.157	0.002	0.001	0.127	0.034	4.759
Functionally Graded Materials for Manufacturing Tools and Dies	-	-	-	-	-	-	-
Ice Bear® Storage Module	0.002	0.001	0.000	0.000	0.000	0.000	0.036
Improved Diesel Engines	1,140.960	34.200	8.557	5.134	662.898	176.278	24,839.270
In-Situ, Real Time Measurement of Elemental Constituents	0.927	0.001	-	0.003	-	0.108	14.719
Materials and Process Design for High Temperature Carburizing	-	-	-	-	-	-	-
Mobile Zone Optimized Control System for Ultra-Efficient Surface-Coating	0.052	0.007	0.000	0.000	0.004	0.007	0.900
Portable Parallel Beam X-Ray Diffraction System	-	-	-	-	-	-	-
Predicting Corrosion of Advanced Materials and Fabricated Components	-	-	-	-	-	-	-
Process Particle Counter	-	-	-	-	-	-	-
Pulsed Laser Imager for Detecting Hydrocarbon and VOC Emissions	1.406	0.386	-	0.005	-	0.165	22.321
Radiation-Stabilized Burner	0.337	0.083	-	0.001	-	0.039	5.344
Simple Control for Single-Phase AC Induction Motors in HVAC Systems	-	-	-	-	-	-	-
Solid-State Sensors for Monitoring Hydrogen	-	-	-	-	-	-	-
SpyroCorTM Radiant Tube Heater Inserts	5.221	1.830	-	0.018	-	0.611	82.876
Three-Phase Rotary Separator Turbine	0.036	0.001	0.000	0.000	0.008	0.006	0.704
Ultra-Low NOX Premixed Industrial Burner	-	-	-	-	-	-	-
Ultrananocrystalline Diamond (UNCD) Seal Faces	-	-	-	-	-	-	-
Uniform Droplet Process for Production of Alloy Spheres	-	-	-	-	-	-	-
Uniformly Drying Materials Using Microwave Energy	0.186	0.024	0.000	0.001	0.007	0.023	3.086
Vibration Power Harvesting	-	-	-	-	-	-	-
Wear Resistant Composite Structure of Vitreous Carbon Containing Convoluted Fibers	0.003	0.000	0.000	0.000	0.002	0.000	0.061
Wireless Sensors for Condition Monitoring of Essential Assets	-	-	-	-	-	-	-
Wireless Sensors for Process Stream Sampling and Analysis	-	-	-	-	-	-	-
OTHER INDUSTRIES							
Advanced Membrane Devices for Natural Gas Cleaning	-	-	-	-	-	-	-
Deep-Discharge Zinc-Bromine Battery Module	-	-	-	-	-	-	-
Irrigation Valve Solenoid Energy Saver	0.017	0.001	0.000	0.000	0.004	0.003	0.342
Long Wavelength Catalytic Infrared Drying System	0.009	0.003	-	0.000	-	0.001	0.139
Plant Phenotype Characterization System	-	-	-	-	-	-	-
Plastic or Fibers from Bio-Based Polymers	0.106	0.018	0.001	0.000	0.061	0.016	2.299
Textile Finishing Process	0.227	0.023	0.000	0.001	0.021	0.031	3.972
Commercial Technologies Total	**1,293**	**75.02**	**8.69**	**5.67**	**670**	**195**	**27,366**
IAC Total	**1,957**	**243.28**	**9.47**	**7.16**	**625**	**301**	**38,922**
Best Practices Total	**1,141**	**239.90**	**5.54**	**4.21**	**369**	**175**	**22,699**
CHP Total	**2,537**	**204.71**	**32.55**	**2.82**	**1,585**	**700**	**70,487**
Historical Technologies Total	**2,337**	**N/A**	**9.23**	**17.09**	**477**	**381**	**46,082**
GRAND TOTAL	**9,266**	**762.91**	**65.46**	**36.95**	**3,726**	**1,752**	**205,556**

ACHIEVING SUPERIOR ENERGY PERFORMANCE

Kathey Ferland
Texas Industries of the Future

Ms. Ferland will be presenting the plant energy-efficiency certification program developed by the US Council for Energy Efficiency Manufacturing over the last two years. The foundation of the program is the proposed ISO 50001 standard on energy management. Superior Energy Performance combines an outcome based approach (energy intensity improvement) with a commitment to continual improvement (conformance with the ISO standard). The program is now in the demonstration phase in a number of states.

RETROFIT OF TEHRAN CITY GATE STATION (C.G.S.NO.2) BY USING TURBOEXPANDER

Ramin Taheri Seresht
Chairman of the Board of
Directors in Yasun Farayand Co.
Tehran, Tehran, Iran
00989123705741,
rntaheri@yahoo.com

Hassan Khodaei Jalalabadi
Engineering Department
Manager in Yasun Farayand Co.
Tehran, Tehran, Iran
00989132966879,
hn_khodaie@yahoo.com

Babak Rashidian
Vice Chairman of the Board of
Directors in Yasun Farayand Co.
Tehran, Tehran, Iran
00989122044418,
babakrashidian@gmail.com

ABSTRACT

Worldwide energy crisis makes it necessary to optimize consumption. One of the fundamental ways to reduce energy consumption is recovery from wasted energy. This can be applied in oil, gas and petrochemical industries in which large amounts of energy waste occur. We can refer to gas transportation when there is a pressure reduction at natural gas pressure reducing stations. In common classic methods, this reduction is accomplished through regulators or throttle valves which the great amount of energy existing in pipelines lost by them.

In this paper, it has been suggested to use expansion turbine for achieving pressure reduction, as well as energy recovery goals. In this regard, Tehran City Gate Station No.2 which is one of the large natural gas pressure reducing stations in Iran (both from capacity and inlet pressure perspectives), has been selected as a case study. In first step waste of energy was calculated by using exergy analysis and in second step, by using expansion turbines that are used parallel in the station for achieving the goals of gas reduction pressure and power recovery was simulated in four scenarios by Thermoflow1 software. The results show undeniable fact that the Energy loss at this station has been 38,443,578 KWhr for a year. As a result of using turboexpander , the exergy recovery will be 96%. At the final step, one scenario was selected as the best which its period of payback was about 2 years.

INTRODUCTION

In recent world, energy has a great value and many countries are compiling some programs for future years in order to supply and maintain their energy needs. Most efforts have been assigned to exploit efficiently energy and optimize installations, equipment and processes as well as energy recovery.

One of the reasons for energy consumption is consumption in order to transfer energy because energy transportation requires energy. Natural gas is known as an important energy carrier in worldwide, requiring energy for transferring gas in pipeline is provided by gas pressure increasing station. At these stations, gas pressure is increased by compressors using gas fuel. It then is reduced at entrance to cities or consumption points by pressure reducing stations. Optimizing and recovery of energy can be fulfilled at both increasing and reducing stations independently as well as simultaneously. This paper addresses just energy recovery at pressure reducing stations. At conventional pressure reducing station, the large amount of existing energy is lost with the aim to pressure reduction in throttle valves or regulators. One method to recover energy at such stations is to install turboexpander paralleled with reduction pipelines direction. exergy analysis can be used to calculate energy loss.

The follow is a brief description of exergy analysis history in turboexpanders utilization. Much research has been done studying the use of natural gas pressure exergy, focusing on the pressure drop stations. One example is the work of Bisio (1995). He examined systems to use this exergy, including a mechanical system to compress air.[1] Expansion turbines (Turboexpanders) are also available for generating electricity from this exergy. A wide range of turbo-expander models are available, ranging in size from 75 kW to up to 130 MW, as mentioned by Bloch (2001) and the Dresser-Rand products website. Typical isentropic efficiencies range from 84% to 86%.[2,3,4] Greeff et al. (2004) have studied the integration of turbo-expanders into various high-pressure exothermic chemical-synthesis processes.[5] Hinderink et al. (1996) proposed a method for calculating the absolute exergy of multi-component liquid, vapour or two-phase flows. This method enabled the clear division of the total exergy of a material stream into three terms, thus the exergy change of mixing was calculated separately from the chemical and the physical exergy.[6] Rosen and Scott (1998) used computer process simulation to perform energy and exergy analyses of low-pressure processes for methanol production from natural gas.[7] Pozivill (2004) has studied the use of turbo-expanders in natural-gas pressure-drop stations with commercial software, AspenTech's HYSYS process simulator. He investigated the effects of turbo-expander isentropic efficiency on temperature reduction and power generation.[8] Farzaneh and Magrebi (2007) studied exergy destruction in Iran's natural gas fields. They concluded that one could generate 4,200 MW of electricity from this pressure exergy.[9] Farzaneh et al. (2007) studied methods of using the pressure exergy of natural-gas in the Bandar Abbas (Iran) refinery pressure-drop station. They investigated the effect of gas pre-heating on the amount of electricity generation. They have also proposed some thermodynamics systems to produce and use refrigeration.[10]

In this paper, after calculating the amount of lost exergy by using different mentioned methods on months of a year, the application of turboexpander in natural gas pressure reducing stations in four scenarios has been suggested with the aim to prevention of exergy destruction and power generation. Different method on several months, turboexpander advantage aiming at prevention of exregy destruction and power generation in four different scenarios has been suggested. These scenarios have been studied on the base of current station status and with regards to economic situations.

NOMENCLATURE

a	constant coefficient
b	constant coefficient
c	constant coefficient
C_P	constant pressure specific heat
d	constant coefficient
ex	exergy
ex_{Ch}	chemical exergy
ex_{Di}	diffusion exergy
ex_K	kinetic exergy
ex_P	potential exergy
ex_{Ph}	physical (thermodynamical) exergy
h	enthalpy
P	pressure
R	universal gas constant
T	temperature

Greek letters

$\sum$	summation symbol

Subscripts

0	base condition
i	i^{th} component

1. Introducing Tehran City Gate Station as Case Study

1.1. Tehran City Gate Station (C.G.S.No.2)

Tehran City Gate Station consist of three similar separate station units that have been placed parallel, each station unit composed of four pressure reducing run similar and separate assimilate pressure and one bypass run that all of them placed in parallel form .Also each station unit has one independent heater. (Fig. 1)

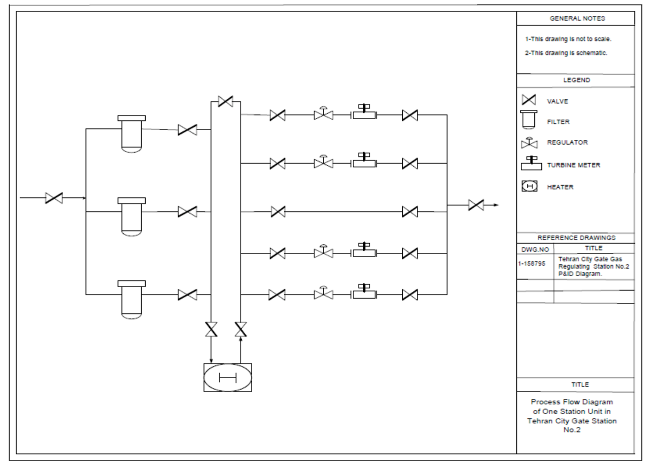


Fig. 1. Process flow diagram of Tehran city gate station (C.G.S.No.2)

1.2. Characteristic Design of Tehran City Gate Station

Inlet pressure design is 6.8 MPa (1,000 psi) and outlet pressure design is 1.7 MPa (250 psi).Nominal capacity of this station is 400,000 Nm^3/hr also the type of station is flat.

1.3. Composition and Specification of Gas Flow

Chemical composition and physical specification of gas flow in this station have been presented as table 1 and table 2.

No.	Component		Mole Fraction
	Name	Symbol	
1	Nitrogen	N_2	3.70
2	Methane	C_1	89.80
3	Carbon Dioxide	CO_2	1.10
4	Ethane	C_2	3.70
5	Propane	C_3	0.98
6	Iso Butane	IC_4	0.22
7	Normal Butane	NC_4	0.29
8	Iso pentane	IC_5	0.10
9	Normal pentane	NC_5	0.07
10	Hexane	C_6	0.04
Total			100.00

Tab. 1. Chemical compounds of the natural gas that passes from the station

No.	Physical Specification	Unit	Amount
1	Calculated Average Molecular Weight	gr/mol	17.93
2	Calculated Gas Specific Gravity, Air = 1.000 (MW of Air = 28.964 gr/mol)	---	0.619
3	Calculated Gas Density (P = 1013.25 mbar , T = 15 °C)	kg/m^3	0.758
4	Calculated Net Calorific Value (P = 1013.25 mbar , T = 15 °C)	MJ/m^3	34.4
		Btu/ft^3	920.4
5	Calculated Gross Calorific Value (P = 1013.25 mbar , T = 15 °C)	MJ/m^3	38.2
		Btu/ft^3	1020.1

Tab. 2. Physical specification of the natural gas that passes from the station

1.4. Inlet and Outlet Gas Flowrate Data in Tehran City Gate Station

Monthly average values of inlet pressure, outlet pressure, outlet temperature and flowrate in this station have been summarized as table 4 on different months in 1385 Iranian year (that is equal from March 2006 till March 2007). It should be noted that in table 3 Iranian months have been equaled according to Christian era.

Iranian Year	Iranian Seasons	Iranian Months	No.	Equal Christian Months	Christian era
1385	Spring	Farvardin	1	21 Mar. – 20 Apr.	2006 - 2007
		Ordibehesht	2	21 Apr. – 21 May	
		Khordad	3	22 May – 21 Jun.	
	Summer	Tir	4	22 Jun. - 22 Jul.	
		Mordad	5	23 Jul. – 22 Aug.	
		Shahrivar	6	23 Aug. – 22 Sep.	
	Autumn	Mehr	7	23 Sep. – 22 Oct.	
		Aban	8	23 Oct. – 21 Nov.	
		Azar	9	22 Nov. - 21 Dec.	
	Winter	Day	10	22 Dec. – 20 Jan.	
		Bahman	11	21 Jan. – 19 Feb.	
		Esfand	12	20 Feb. – 20 Mar.	

Tab. 3. Changing of Iranian months with Christian era

Iranian Months	Monthly Average Values							
	Inlet Pressure		Outlet Pressure		Outlet Temperature		Flowrate	
	MPa	psi	MPa	psi	°C	°F	Nm^3/hr	kg/sec
Farvardin	4.4	644	1.7	250	7.7	45.9	176,880	37.24
Ordibehesht	4.6	670	1.7	250	10.7	51.3	104,105	28.31
Khordad	4.9	726	1.7	250	8.0	46.4	170,514	35.90
Tir	5.3	775	1.7	250	8.7	47.7	154,239	32.48
Mordad	5.3	775	1.7	250	8.8	47.9	132,929	27.99
Shahrivar	4.9	726	1.7	250	10.2	50.4	184,663	38.88
Mehr	4.2	619	1.7	250	10.4	50.6	178,689	37.62
Aban	3.9	566	1.8	259	10.4	50.6	262,381	55.25
Azar	2.4	350	1.8	270	10.8	51.4	346,470	72.95
Day	2.3	337	1.7	257	10.9	51.7	427,071	89.92
Bahman	3.2	470	1.8	271	10.3	50.5	398,845	83.98
Esfand	3.0	445	1.8	267	10.4	50.8	355,395	74.83

Tab. 4. Monthly average values of inlet pressure, outlet pressure, outlet temperature and flowrate

The curve of changing monthly average value of inlet and outlet pressures as well as flowrate in different months has been mentioned in figure 2 and figure 3 respectively.

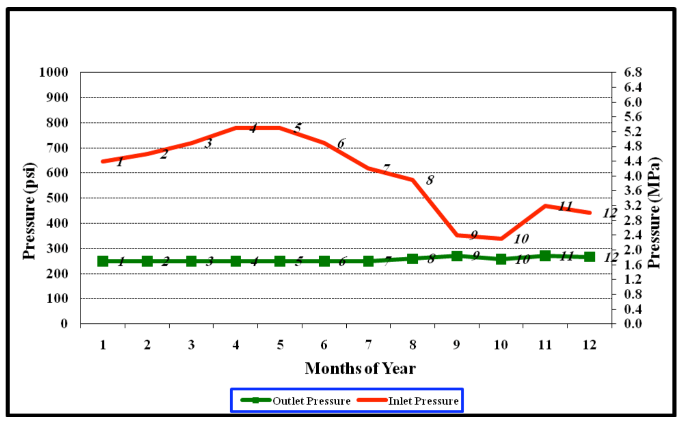


Fig. 2. The curves of average inlet & outlet pressure profiles in the year of 1385 (21 Mar. 2006 – 20 Mar. 2007)

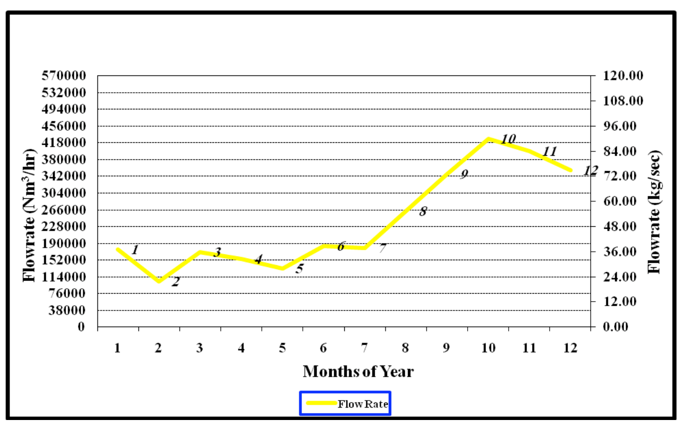


Fig. 3. The curve of average flowrate profiles in the year of 1385 (21 Mar. 2006 – 20 Mar. 2007)

2. Exergy Analysis

Exergy analysis that has been explained on the base of first and second laws of thermodynamic, it is possible that we calculate the amount of wasted energy in the station. In order to calculating the total value of exergy, different components of exergy should be attained by using follow correlation.

$$ex = ex_K + ex_P + ex_{Ph} + ex_{Di} + ex_{Ch} \quad (1)$$

In this correlation ex_K, ex_P, ex_{Ph}, ex_{Di} and ex_{Ch} represent kinetic, potential, physical (thermodynamical), diffusion and chemical exergy respectively. In this case study, components of kinetic, potential, diffusion and chemical exergy are zero so total exergy is equal to physical (thermodynamical) exergy of station. This exergy could be calculated from equation 2.

$$ex_{Ph} = C_P\left[(T - T_0) - \left(T_0 \ln\left(\frac{T}{T_0}\right)\right)\right] + \left[RT_0 \ln\left(\frac{P}{P_0}\right)\right] \quad (2)$$

The above correlation has been derived from general following correlation for state of gas expansion.

$$ex_{Ph} = (h - h_0) - T_0(S - S_0) \quad (3)$$

For each of gas component, C_P in 25 ºC has been obtained by using equation 4 and then C_P of the mixed gaseous has been calculated from correlation 5 (Coefficients a, b, c and d for different substances have been mentioned in the handbooks) [13].

$$C_P = a + bT + cT^2 + dT^3 \quad (4)$$

$$C_{Pmix} = \sum x_i C_{Pi} \quad (5)$$

Then with knowing molecular weight of mixed gaseous also knowing pressures, average inlet and outlet temperatures as well as flowrates, the monthly average amount of exergy in the station could be calculated in 1385 Iranian year (that is equal from March 2006 till March 2007 Christian era).

The results of this calculation have been presented in table 5 and figure 4 shows monthly average exergy profiles in 1385 Iranian year (March 2006 - March 2007). It is necessary noted that inserted pressures and temperatures in table 3 are proportional values and for using equation 2, they should be changed to absolute values. Since the gas inlet temperatures are not available, these temperatures are assumed 25 ºC that is a conventional assuming.

With more attention to table 5 it has been cleared that just in one station of city gate stations in Iran, the value of wasted energy is about 40,000,000 KWhr.

Iranian Months	Monthly Average Values of Exergy		
	kJ/kgmole	KW	KWhr
Farvardin	2,158.452	4,483.031	3,335,375
Ordibehesht	2,277.888	3,596.599	1,812,686
Khordad	2,406.358	4,818.085	3,584,655
Tir	2,591.160	4,693.858	3,492,230
Mordad	2,591.866	4,046.087	3,010,288
Shahrivar	2,420.588	5,248.882	3,905,168
Mehr	2,066.357	4,335.548	3,121,594
Aban	1,768.406	5,449.216	3,923,436
Azar	660.584	2,687.652	1,935,110
Day	691.912	3,469.981	2,498,386
Bahman	1,314.629	6,157.422	4,433,344
Esfand	1,167.514	4,872.566	3,391,306
Total Annual Exergy			38,443,578

Tab. 5. Monthly average values of exergy at Tehran city gate station in the year of 1385 (21 Mar. 2006 – 20 Mar. 2007)

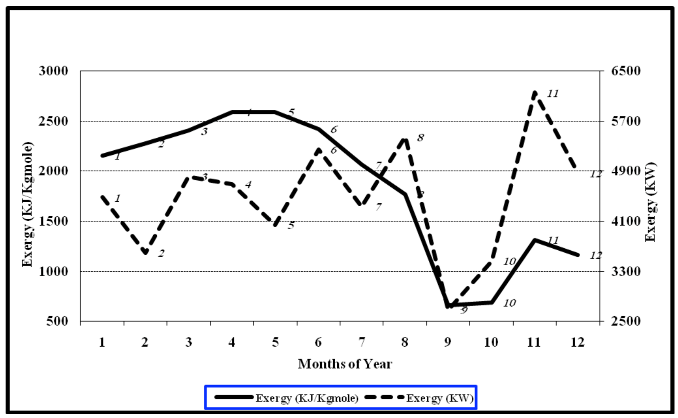


Fig. 4. The curves of monthly average exergy profiles in the year of 1385 (21 Mar. 2006 – 20 Mar. 2007)

It must be considered that total of pressure reducing stations (including T.B.S, C.G.S, compound stations and power plant stations) exist in Iran are about 3,000 stations. Unexpected and shocking numbers are concluded just by a thumb calculation. It is clear that even recovering little section of this huge source of energy not only save energy but also increase profitability.

3. Scenario Suggestion and Simulation

3.1. Scenario Suggestion

In this section two general scenarios have been suggested which including one Turboexpander and three Turboexpanderes that are parallel with whole station and each of station units respectively. And also each mentioned scenarios divided two detailed scenarios with (or without) preheating respectively (table 6). Moreover figure 4 shows the monthly average exergy profile in the Iranian year of 1385 (March 2006 –March 2007).

Scenario	Preheating	Turboexpander(s) No.
1	✗	1
2	✓	1
3	✗	3
4	✓	3

Tab. 6. Proposed scenarios with using turboexpander(s)

3.2. Simulation

In order to simulating, the efficiency of expansion turbine, the altitude of station as well as the flowrate of station (maximum flowrate) have been considered 96%, 1500 m and 600,000 Nm^3/hr (126 kg/sec) respectively. According to the data and curves existing in the handbook[14], in the process of natural gas expanding from 6.7 MPa (1,000 psi) to 1.7 MPa (250 psi) and in the case of natural gas contains water ,the natural gas should be preheated up to 45 ºC to prevent the hydrate formation in gas flow.

In the next step, suggested scenarios have been modeled in Thermoflow software environment. Figures 5 to 8 illustrate simulated scenarios 1 to 4 respectively.

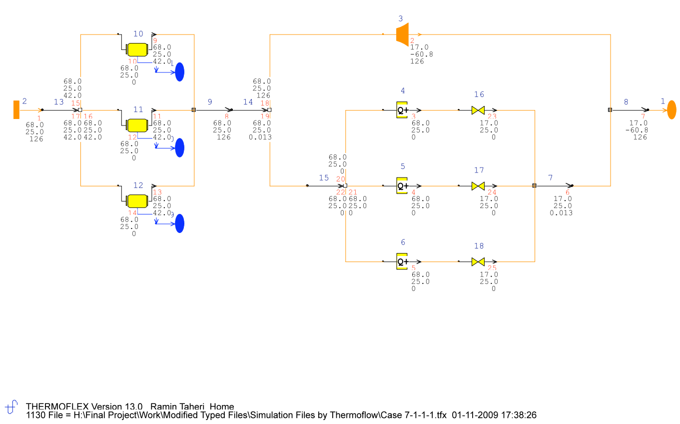


Fig. 5. Scenario of one turboexpander paralleled to whole station without preheating (No. 1)

4. Results and Discussion

Acquired results of four simulated scenarios are indicated in table 7 so that it presents the value of annual generated power and energy by expansion turbine.

Economical analyses and considering to global price of energy for scenario 2 (One turboexpander with preheating) and scenario 4 (three turboexpenderes with preheating), payback periods are 1.7 and 2.3 years respectively. Acquired result from

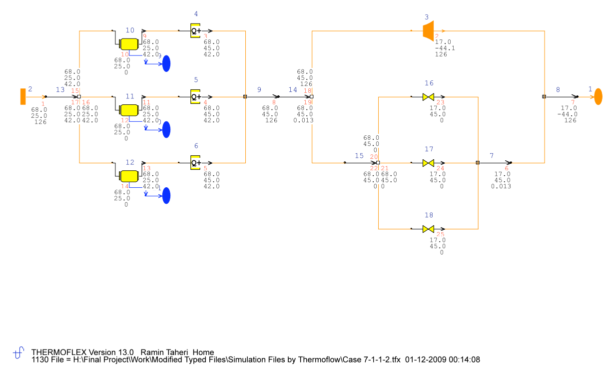


Fig. 6. Scenario of one turboexpander paralleled to whole station with preheating (No. 2)

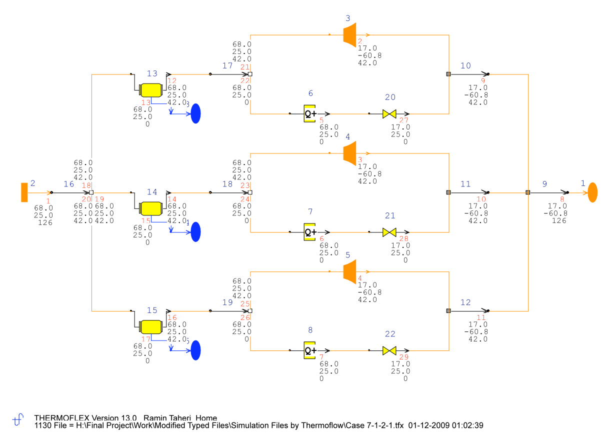


Fig. 7. Scenario of three turboexpanders paralleled with each unit of station without preheating (No. 3)

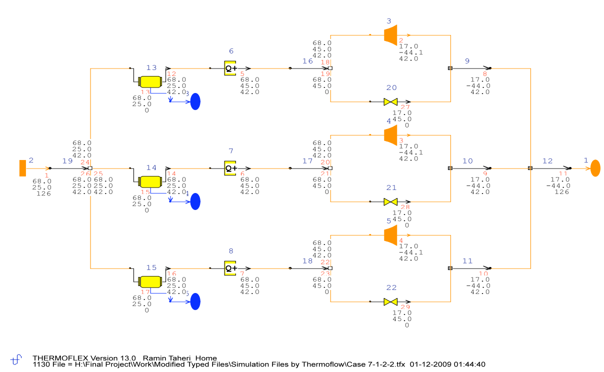


Fig. 8. Scenario of three turboexpanders paralleled with each unit of station with preheating (No. 4)

Simulation State	Scenario	Produced Power (KW)	Annually Produced Energy (KWhr)
One Turbine without Preheating	1	19,347.6	164,841,552
One Turbine with Preheating	2	20,728.1	176,603,412
Three Turbines without Preheating	3	19,347.6	164,841,552
Three Turbine with Preheating	4	20,728.5	176,606,820

Tab. 7. The values of produced power and annually produced energy with Turboexpander(s) in four scenarios

simulation indicated that the value of recovery power in the cases of one and three Turboexpander(s) is equal together. In presence of preheating the value of recovery power has been increased 7%. Among the mentioned scenarios, forth scenario (three turboexpanders with preheating) considered as the best choice because of the bellow reasons:

4.1. Using of three turboexpanders decreases the days of a year that turboexpanders ought to work in off-design conditions.

4.2. Due to the fact that for that three heaters are existing and working in this station now, therefore gas preheating not only wouldn't be incurred further cost but also would be increased 7% in generated power.

4.3. Using of three turboexpanders makes increase the value of controlling on station so that one or two turboexpander(s) could be shutoff in necessary time.

4.4. Althought using of three turboexpanders increases the cost of buying and installation it could be justifiable because of mentioned advantages and trivial difference in period of payback (1.7 and 2.3 years).

5. Conclusion

In this paper at the first step, the value of lost exergy in typical year at Tehran City Gate Station (C.G.S. No.2) has been calculated 38,443,578 KWhr. This huge value of energy wasted in the throttle valves of station. In second step four scenarios have been proposed for application of turoboexpanders that are parallel with whole of station and each of station units. In the third step each of scenarios has been simulated by Thermoflow software. According to acquired result of stations, three turboexpanders with preheating (forth scenario) has been selected as the best choice. The results show that 96 % of exergy loss could be recovered by application turboexpanders in this station. The economical view points are also justifiable and the period of payback is about two years.

ACKNOWLEDGMENTS

This research is supported by Yasun Farayand Co.(Pjs).

REFERENCES

[1] Bisio, G., "Thermodynamic Analysis of the Use of Pressure Exergy of Natural Gas", Energy Vol. 20, No. 2, pp. 161–167, 1995.

[2] Bloch, H. P., "Consider Turbo Expanders", Editorial Comment, Hydrocarbon Processing 2001; 80(1):1.

[3] Bloch, H. P., "Become Familiar with Turbo Expander Applications", Reliability, Hydrocarbon Processing 2001; 80(2):17–8.

[4] Dresser-Rand Products Website, "FCC Power Recovery Expanders", http://www.dresserrand.com/turbo/eq/expand.asp.

[5] Greeff, I. L., Visser, J. A, Ptasinski, K. J., Janssen, F. J. J. G., "Using Turbine Expanders to Recover Exothermic Reaction Heat - Flowsheet Development for Typical Chemical Processes", Energy, Vol. 29 (2004), pp. 2045–2060.

[6] Hinderink, A. P., Kerkhof, F. P. J. M., Lie, A. B. K., De Swaan Arons, J., Van Der Kooi, H. J., "Exergy Analysis with a Flowsheeting Simulator—I. Theory; Calculating Exergies of Material Streams", Chemical Engineering Science, Vol. 51, Issue 20, Pages 4693–4700, Oct. 1996.

[7] Rosen, M. A., Scott, D. S., "Energy and Exergy Analyses of a Production Process for Methanol from Natural Gas", International Journal of Hydrogen Energy, Vol. 13, Issue 10, Pages 617–623, 1998.

[8] Pozivill J., "Use of Expansion Turbines in Natural Gas Pressure Reduction Stations", Acta Montanistica Slovaca Rocník 9 (2004), císlo 3, 258–260.

[9] Farzaneh-Gord, M., Magrebi, J., "Exergy of Natural Gas Flow in Iran's Natural Gas Fields", forthcoming in International Journal of Exergy.

[10] Farzaneh-Gord, M., Manzari, M., Magrabi, M., Hashemi, S., Eftekhari, H., Farokhi, A., "Using Pressure Exergy of Natural Gas in Bandar-Abbas Refinery Gas Pressure Drop Station", The second International conference on Modeling, Simulation, And Applied optimization, Abu Dhabi, UAE, March 24–27 2007

[11] T. J. Kotas, "Exergy Method of Thermal Plant Analysis", Butterworths, London, (1985).

[12] Jan Szargut, David R. Morris, Frank R. Stewarad, "Exergy Analysis of Thermal, Chemical and Metallurgical Processes", Hemisphere Publication Corporation, 1988.

[13] David M. Himmelblau, "Basic Principles and Calculations in Chemical Engineering", Prentice-Hall Inc., New Jersey 1991.

[14] Donald L.Katz, David Cornell, John A. Vary, Riki Kobayashi, Jack R. Elenbaas, Fred H. Poettmann, Charles F. Weinaug, "Handbook of Natural Gas Engineering", McGraw-Hill, 1959.

ENERGY USE IN DISTILLATION OPERATION: NON-LINEAR ECONOMIC EFFECTS

Douglas C. White
Emerson Process Management

Distillation operations are major consumers of energy, by some estimates comprising forty percent of the energy usage in the refining and chemicals industry. Obtaining the maximum energy efficiency from this unit operation is obviously very important. For many distillation columns there is a tradeoff in operation between energy usage and product recovery and setting the proper usage target involves a calculation of the economic tradeoff between these two factors. However, distillation is a non-linear process and normal economic evaluations add more non-linearities to the economic objective functions. In addition, the normal product quality variability observed leads to requirements for statistical evaluation. Hence, calculation of the correct target can be complicated. In this paper, these non-linear economic effects are reviewed and techniques to calculate the correct usage targets presented.

Use of Statistical Approach to Design an Optimal Duct System for On-demand Industrial Exhaust Ventilation

Ales Litomisky, Krystof Litomisky

This paper elaborates on how to use statistics to calculate optimal parameters (including duct diameters) of energy–efficient industrial ventilation systems. Based on the fan-law, on-demand ventilation can save up to 80% of electricity compared to classical systems. For the purposes of this paper, we consider a classical exhaust ventilation system one that uses constant fan RPM and air velocity in the ducts.

There are multiple design and operational challenges to successfully implementing an on-demand system. Several of these challenges and their solutions are described in this paper.

The basic idea behind on-demand ventilation is to close ventilation outlets at workstations that are not producing dust (or fumes or mist) and adjust the fan speed accordingly [1].

It is easy to implement such a system if there is no requirement for minimum transport velocities in the ducting, as is the case in fume collection systems (such as welding shops). The task becomes challenging when particulate matter has to be transported in the duct system because minimum air velocities have to be maintained in every part of the ducting in order to prevent settling (which presents a fire and explosion hazard [3]).

The challenge is knowing what air volume will be in different parts of the duct system when the outlets at workstations are open at some times and closed at others, and, consequently, how we can calculate appropriate duct diameters. We are limited from below by the minimum air velocity required to transport particles and from above by friction losses and noise generated by moving air.

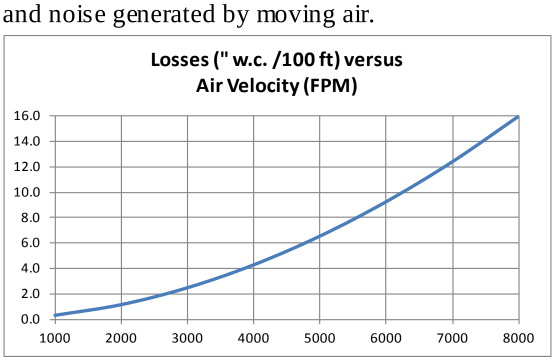


Fig 1

Fig. 1: friction losses in a circular 6” duct in galvanized steel with turbulent flow are increasing nonlinearly with air velocity

As you see from Fig. 1, these friction losses for a given duct (friction loss in a circular 6” duct in galvanized steel with turbulent flow) increase nonlinearly with air velocity/air volume. For example, for sawdust, the minimum transport velocity is about 3,800 FPM, and the maximum (practically useful) velocity is about 6,500 FPM. These values can vary with each system and design.

HOW TO COLLECT DATA ABOUT WORKSTATION UTILIZATION

There are several ways how to obtain data about workstation utilization which vary in accuracy and difficulty. We define workstation utilization **U** as the fraction of time when active ventilation is needed because dust/fumes/mist are being produced:

$$U = \frac{\text{time ventilation needed}}{\text{total shift time}} \qquad [1]$$

This is to be distinguished from the time when the workstation is on but not producing dust (such as time when material is being moved in or out, programming time, and maintenance). An appropriate sensor or signal will address this distinction.

The first method to obtain utilization data is to simply ask the plant manager to fill in a survey form. This is fast, but usually not reliable (managers tend to overstate utilization).

The second method is to observe the working cycle for each particular workstation and to measure utilization using a stop-watch. This is reliable, but prohibitively time-consuming when the factory is large (with tens or hundreds workstations).

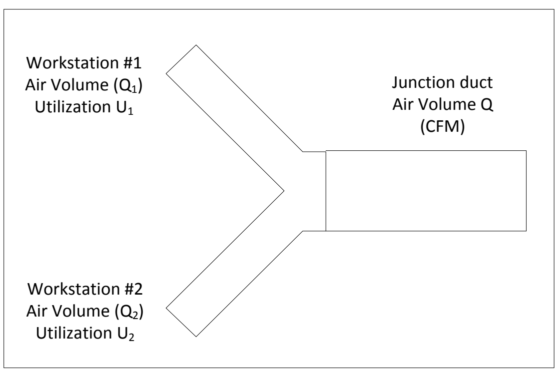
The third way is to use data loggers installed on the workstation. Data loggers, such as those made by HOBO, record the time and date of the workstation’s activity and save it to internal memory. Loggers should collect the data for at least a week (preferably a month) to collect a representative sample. Afterwards the data are downloaded to a PC and analyzed.

The last method of data collection uses data from a similar factory. This is useful for instance when a corporation has similar factories in different locations. Usually the data collected at one factory can be used for another factory, making corrections for known differences. When a factory has been equipped with an on-demand ventilation system, the utilization data are continuously collected, providing highly accurate information. For utilization data from several factories in different industries, see Industrial Ventilation Statistics [3].

STATISTICAL ANALYSIS

When we have obtained reliable utilization data, the next step is statistical analysis and use of this information for practical ventilation system design.

In the following discussion, we look at a system of 30 workstations connected step-by-step to one main duct with one exhaust fan. Let' start with the first two workstations.



First two workstations #1 and #2 connected to junction duct   Fig 2

Workstation # 1 has air volume Q_1 (CFM) and utilization U_1. This means that workstation # 1 is active (i.e. producing dust/fume/mist) with a probability of U_1 and inactive (i.e. not producing dust/fume/mist) with probability $1-U_1$.

Similarly, workstation # 2 has air volume Q_2 (CFM) and utilization U_2. We have such data available for all workstations in the system.

With two workstations, there are four possible combinations of active/not-active workstations: both not active, workstation #1 active and workstation #2 not active, workstation #1 not active and workstation #2 active, and both workstations active. See Table 1.

Workstation #1	Workstation #2	Air Volume [CFM]	Probability P	P * Air Volume [CFM]
0	0	0	$(1 – U_1) * (1 – U_2)$	0
0	I	Q_2	$(1– U_1) * U_2$	$Q_2 * (1 – U_1) * U_2$
I	0	Q_1	$U_1 * (1– U_2)$	$Q_1 * U_1 * (1 – U_2)$
I	I	$Q_1 + Q_2$	$U_1 * U_2$	$(Q_1 + Q_2) * U_1 * U_2$

Two workstations #1 and #2 connected to junction duct, air volume & probability   Table 1

In the above table, 0 means a workstation is inactive and 1 means workstation is active, as defined in the previous section.

The values in the rightmost column of the table are the air volume multiplied by the probability of that air volume occurring. The sum of these values, Q, represents the mean (average) air volume at the conjunction of the first two ducts.

$$Q = \Sigma(Q_i * P_i) \qquad \text{(CFM)} \qquad [2]$$

We can further analyze this by plotting the air volume vs. probability – the probability distribution. We also calculate standard deviation, σ, which measures the fluctuation of air volume from the mean. Standard deviation is a way to measure the amount of variability (or dispersion) in the data set.

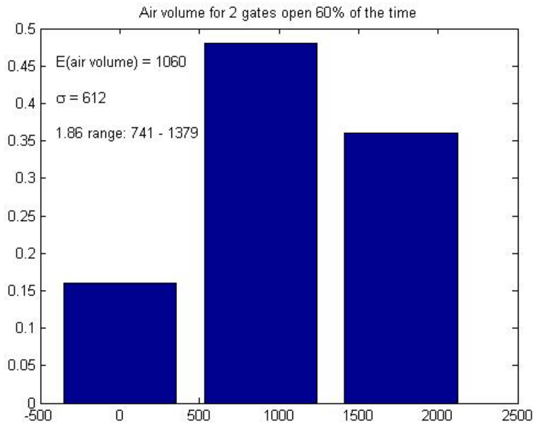
$$\sigma = \sqrt{\frac{\Sigma (Q - Q_i)^2}{n - 1}} \qquad \text{(CFM)} \qquad [3]$$

(where **n** is the total number of workstations)

Let's fill Table 2 with some sample values: two 6" gates (884 CFM air volume at the industry standard air velocity of 4,500 FPM) with utilization 0.6 (60%).

Workstation #1	Workstation #2	Air Volume (posibilities x)	Probability U (%)	Air volume (CFM)
0	0	0	16,0%	0
0	1	884	24,0%	212
1	0	884	24,0%	212
1	1	1767	36,0%	636

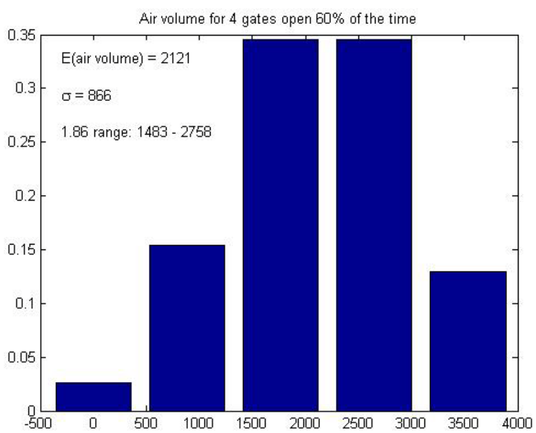
Two workstations #1 and #2 (6" ducts & 0.6 utilization) - air volume & probability   Table 2



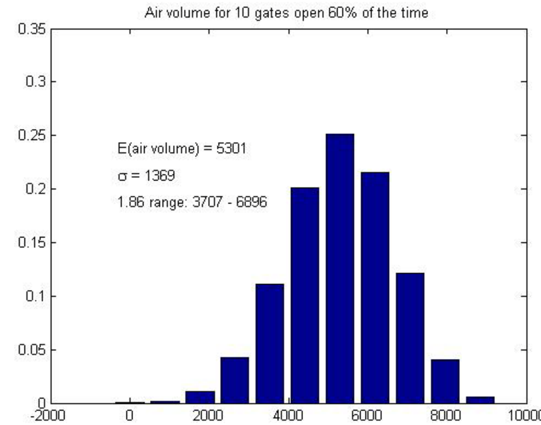
Probability distribution, total & mean air volume, standard deviation for two workstations Fig 3

The probability distribution is in Figure 2. The mean (average) air volume is 1,060 CFM, with standard deviation = 612 CFM.

In the same way, we get table for data for 4…30 workstations (6" diameters, utilization 0.6). The results are summarized in following charts and table.

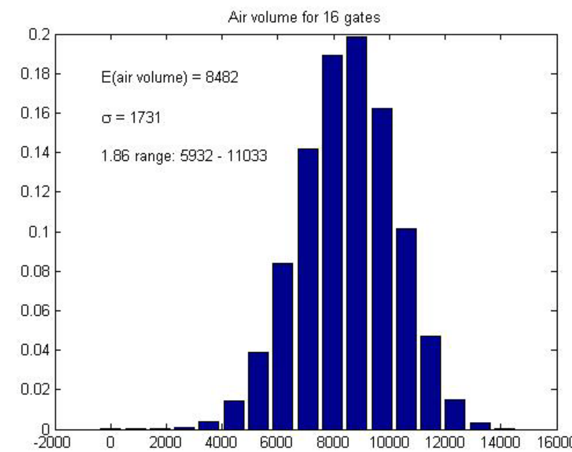


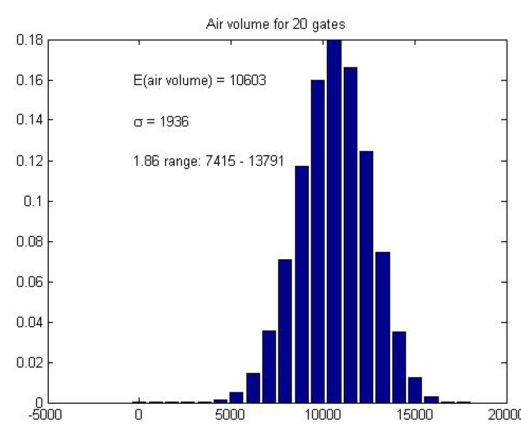
Probability distribution, total & mean air volume, standard deviation for four workstations Fig 4



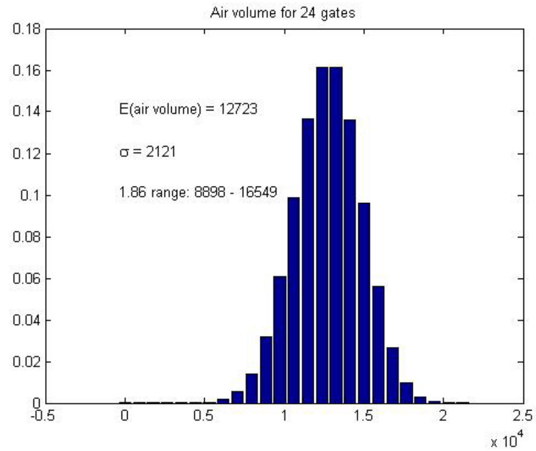
Probability distribution, total & mean air volume, standard deviation for ten workstations Fig 5

Probability distribution, total & mean air volume, standard deviation for sixteen workstations Fig 6

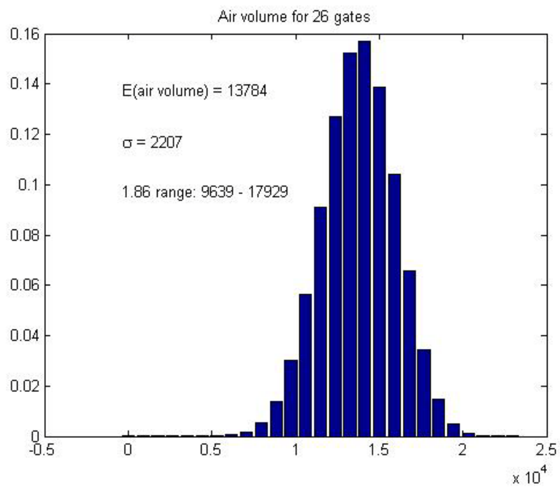




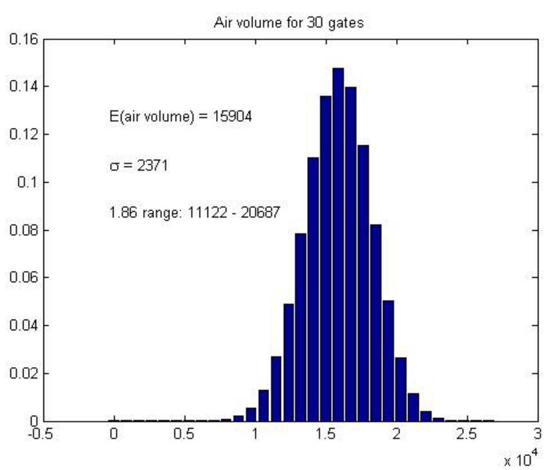
Probability distribution, total & mean air volume, standard deviation for twenty workstations Fig 7



Probability distribution, total & mean air volume, standard deviation for twenty four workstations — Fig 8



Probability distribution, total & mean air volume, standard deviation for twenty six workstations — Fig 9

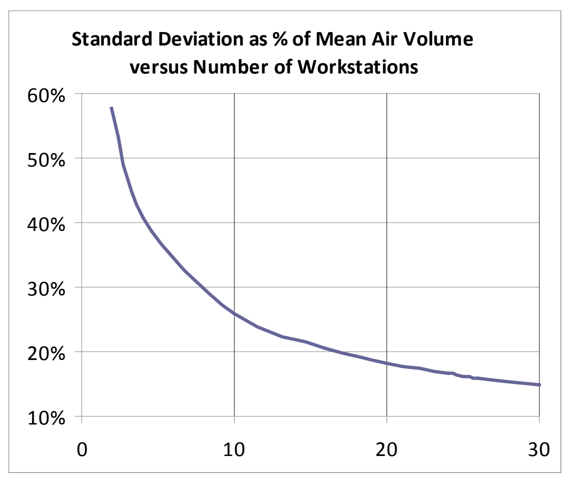


Probability distribution, total & mean air volume, standard deviation for thirty workstations — Fig 10

As you see from the above results, the standard deviation (expressed as percentage) from the mean (average) air volume decreases with an increasing number of conjunctions (number of workstations) – the charts are taller and thinner. The following table summarizes the above results.

# of Workstations	Total Air Volume (CFM)	Mean Air Volume (CFM)	Standard Deviation (CFM)	% of mean
2	1 768	1 060	612	58%
4	3 536	2 122	866	41%
10	8 840	5 304	1 369	26%
16	14 144	8 482	1 731	20%
20	17 680	10 603	1 936	18%
24	21 216	12 723	2 121	17%
26	22 984	13 784	2 207	16%
30	26 520	15 904	2 371	15%

Summary of systems simulation from 2 to 30 workstations (6” drops, 0.6 utilization) — Table 3



Standard Deviation (in percentage of mean air volume) decreases with higher number of workstations (duct junctions) — Fig 11

The practical result of this is that with the decreasing variability of the mean air volumes, it is easier to select the appropriate duct diameter of a junction deeper in the system (with a larger number of incoming ducts).

How do we select the appropriate duct diameter?

Let Q = air volume (CFM)

V = air velocity (FPM)

A = area of the duct (square foot). Then

$$Q = V * A \qquad (CFM) \tag{4}$$

Therefore

$$V = \frac{Q}{A} \qquad (FPM) \quad \text{and} \tag{5}$$

$$A = \frac{Q}{V} \qquad (\text{squarefeet}) \quad \text{then}$$

$$d = 2\sqrt{\frac{A}{\pi}} \qquad (\text{inches})$$

Where **d** is duct diameter

For a typical on-demand system, it is recommended that the air velocity at the mean air volume be 4,000 FPM. The air velocity at maximum air volume will be approximately 6,500 FPM. As you can see from the probability distribution, a system will run at this velocity less than one percent of the time. Based on practical experience, the range of usable air velocities (for example for woodworking) is about 3,500 – 6,500 FPM, as mentioned above. This is a ratio of maximum to minimum air velocity of 1.86 : 1 (6,500/3,500 = 1.86). (Note: the above air velocity range is just an example; these velocities depend on the material transported and other particulars of the project.)

A practical example is shown in the following table.

# of workstations	4	10	20	30	
Total Air Volume	2 122	5 304	10 603	15 904	CFM
Duct diameter for on-demand system	10	16	22	27	inches
Duct diameter for classical design	13	20	28	35	inches
Mean Air Volume	2 122	5 304	10 603	15 904	CFM
Air Velocity at mean Air Volume	3 891	3 799	4 017	4 000	FPM
Air Volume @ minimum transport velocity	1 909	4 887	9 239	13 916	CFM
Standard Deviation	866	1 369	1 936	2 371	CFM
Minimum Air Volume as percent of (mean - deviation)	25%	30%	70%	84%	

Example of the duct diameters for 4…30 workstations both for classical and on-demand systems — Table 4

The spread is larger for lower-grade junctions. There are two ways to address this.

The first one is to connect more than two workstations in the first junction to reduce the variation (spread) in air volume. If this approach is not possible (or if the variation is still too high), we can pre-program the on-demand control system to maintain the desired minimum air volume (air velocity) by opening additional outlets on non-active workstations.

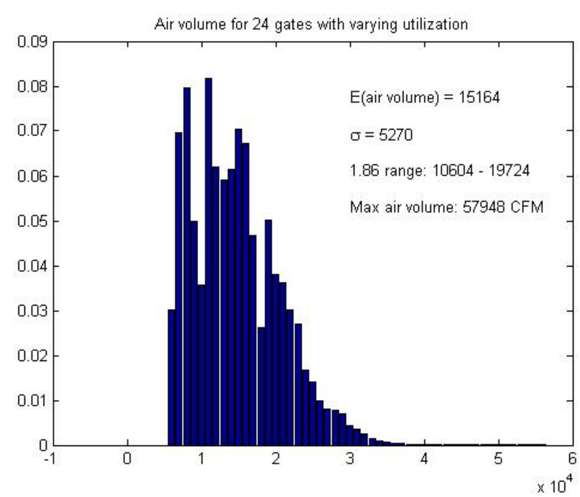
Other steps in designing the ducting for the on-demand system are similar to classical design; thus, we start with creating the junctions from the outlets most distant from the fan and continue toward the main duct. Importantly, we consider the statistical analysis when determining the duct diameter.

MATLAB SIMULATIONS

To simulate a complete ventilation system with ten or more workstations and with varying duct diameters cannot be simply done in an Excel spreadsheet, because for 30 gates, 2^{30} rows (more than 1 billion) would be necessary.

To simulate such an on-demand system, we wrote a program in the Matlab programming language. To calculate the mean air volume in a system with ten workstations requires less than a tenth of a second on an average PC. On the other hand, some of the simulations for a system with 30 workstations took over ten hours of processing time.

Below is the result of the same simulation for a real dust collecting system in the woodworking industry. The system has 24 workstations with duct diameters between 4” and 18” and utilizations between 0.11 and 1.

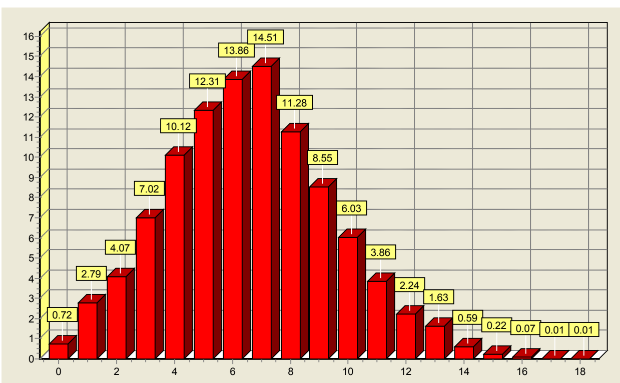


Simulated probability distribution, total & mean air volume, and standard deviation of a real dust collecting system (woodworking industry — Fig. 12

The total air volume is 57,948 CFM, the mean air volume 15,164 CFM, and the standard deviation is 5,270 CFM (35% of mean air volume). Compared with the simulations on systems with identical gate sizes and utilizations, the distribution is not as smooth, and the variation is higher. Some of this can be attributed to the unusual particulars of the system (for instance, the range of utilizations is much higher than normal). This increase in variation will be straightforwardly addressed by opening additional gates to maintain minimum airflow. As a result, this on-demand system is expected to achieve savings of around 70% compared to classical systems.

COMPARISON TO MEASURED DISTRIBUTION CHARTS

We can compare these simulation charts to actual data measured on installed on-demand systems (for detailed statistics, see Industrial Ventilation Statistics [3]).



Measured probability distribution of the real dust collecting system (woodworking industry) Fig 13

CONCLUSION

Contrary to the common belief that it is difficult to predict air volume in on-demand systems, this analysis shows that the average air volume and its variance (spread) can be calculated with good accuracy. Because of this, we can design an optimized duct system for each particular application. When such a duct system is combined with an appropriate on-demand system which maintains minimum transport velocities, energy savings of up to 80% compared to classical systems have been achieved on real installations. If the duct design is not optimized for an on-demand system (and an on-demand system is used), energy savings with the on-demand are significantly lower (typically 30-50%).

Bibliography

[1] Ales Litomisky: On-Demand Ventilation Energy Saving in Industrial Applications. WEEC Washington 2006
[2] http://www.csb.gov
[3] Ales Litomisky: Industrial Ventilation Statistics, IETC 2006

The Role of Incentives in Promoting CHP Development

Nate Kaufman
Industry Research Staff

R. Neal Elliott, Ph.D., P.E.
Associate Director of Research

American Council for an Energy-Efficient Economy
Washington, DC

ABSTRACT

Conventional wisdom suggests that financial incentives should be sufficient to spur the installation of combined heat and power (CHP) systems. However, the states with the most CHP development are often not the states with the most generous financial incentives. ACEEE has collected data on state regulatory policies that suggest that states with a regulatory structure favorable to CHP have more implementation activity. The four regulatory factors that stick out are: 1) fair interconnection standards; 2) output-based emissions regulations; 3) fair utility standby rates; and 4) that CHP is encouraged within a clean or renewable energy standard.

We anticipate that these four regulatory factors correlate more strongly with empirical CHP implementation than the presence of financial incentives for CHP, which suggests that getting regulatory and market conditions "right" may be more important than providing incentives. This finding could also apply to many other facets of energy efficiency policy.

INTRODUCTION

Many state policy makers recognize the energy, environmental, and economic benefits of combined heat and power (CHP) systems. Acknowledging that one of the greatest obstacles to CHP development is the upfront capital cost, a number of states have offered financial incentives in the form of grants, bonds, tax credits, and loans for CHP developers or owners to install new systems or retrofit existing systems with CHP. In many cases, financial incentives on both the state and federal levels have effectively led to increased installations of the efficient technology. However, CHP systems currently comprise only 12.6% of U.S. electricity generation and 8.6% of total generating capacity (9).

In addition to first cost, however, other market barriers exist to system development that must be addressed before the technology can reach its full potential throughout the U.S. Among these key barriers are (5):

- utility interconnection standards and practices;
- utility tariffs; and
- air quality regulations that do not reflect the reduced emissions associated with displaced utility emission.

These market hurdles have the potential to create uncertainty, delay projects, and thus increase overall project costs. Further confusing the matter is the wide variance of regulatory and market landscapes from state to state. In the past 15 years, however, we have seen significant advances in all of these areas, including the establishment of a technical standard for interconnection and the issuance of guidance on output-based emissions regulations at the federal level (5).

For more than a decade ACEEE has studied market barriers to CHP and over the past three years has tracked which states have the most practical and effective policies in place for CHP development as part of the annual State Energy Efficiency Scorecard (5). In the absence of strong federal regulations, state lawmakers and regulators are instrumental in the establishment of interconnection standards, tariff designs, environmental regulations, and other policy measures that dramatically impact the attractiveness of CHP projects. State activity is essential to creating a market environment that encourages CHP. Over the past several years, an increasing number of states have worked to develop and implement "CHP-friendly" policies, while others have done little.

This paper will focus on the role of state financial incentives compared with efforts to remove regulatory and market barriers. We will examine the regulatory policies of each state as well as state financial incentives intended to promote CHP. These more qualitative indicators will be compared with more quantitative data detailing the actual installation of CHP systems over the last five years. Based on this comparison, we will show that while financial incentives for CHP may indeed encourage development, they may not be sufficient alone to create a favorable market for CHP. Rather, the removal of regulatory and market barriers is often fundamental to the successful implementation of CHP systems. In the current fiscal environment, expanding state financial incentives may be difficult. Because our research indicates that addressing regulatory barriers can be effective even in the absence of incentives, state policymakers should make it a priority in the current economy to remove these regulatory barriers.

BACKGROUND ON CHP

Combined heat and power (CHP) systems, sometimes called cogeneration, generate power and thermal energy in a single, integrated system. CHP is more energy-efficient than separate generation of electricity and thermal energy because heat that is normally wasted in conventional power generation is recovered as useful energy. The recovered energy is used to satisfy an existing onsite thermal demand, such as the heating and cooling of local buildings or a hot water load. CHP systems can save customers money and reduce overall net emissions, offering a cost-effective way to address increasing concerns about greenhouse gas emissions (6).

Rather than a single technology, CHP represents the application of a suite of technologies in a particular system context. CHP systems can use a variety of fuels, and their configurations are site specific. While the parameters of a system's design can vary over a continuum, we can envision two conceptual business models: the power sales model and the onsite power model. In the power sales model, electricity generation is maximized, with the economic focus being on sales of power to the wholesale market—a model consistent with the Public Utility Regulatory Policies Act (PURPA), which established modern CHP in the 1980s.[1] In the onsite power model, the focus of power output is matched onsite demand so as to maximize the avoided purchase of utility-supplied electricity. The difference between these two conceptual models is that in the first, revenue from wholesale power sales drive the economics, while in the latter, the avoidance of retail power purchases drives the economics. Both models can work, depending on electricity and fuel prices.

Because CHP installations are capital-intensive projects, financial barriers can represent a key hurdle to project implementation. While financial incentives can help to mitigate costs associated with market barriers, in many cases developers and owners often find their projects stymied by regulatory and market uncertainty, most notably for smaller CHP systems for which regulatory compliance costs and utility fees represent a large portion of project costs relative to large systems (6).

Despite the widely acknowledged benefits of CHP, many of the above-stated considerations still present barriers to its adoption. Some of these barriers exist simply because of a lack of understanding about their impacts by lawmakers and regulators, or a lack of staff time to address them. Others exist because there is a difference of opinion among decision-makers over which policy positions most reflect the public good or how CHP impacts incumbent market players.

Review of CHP Incentives

Financial incentives for CHP may take the form of grants, loans, tax credits, rebates, or bond financing. Because CHP projects are more capital-intensive than most end-use energy efficiency projects, incentives can play an important role in encouraging project implementation, and developers tend to actively seek out all possible financial incentives before taking on a project.

Financial incentives for CHP are often bundled with either incentives for end-use energy efficiency technologies or with incentives for other so-called clean energy sources that may include renewables. Therefore, not all incentive pools that could apply to CHP will necessarily be available to a specific CHP project. When incentive pools—for grants, loans, or bond financing, for example—are limited, CHP may be forced to compete with renewable energy projects, often making it more difficult for CHP projects to receive funding awards.

Many CHP developers are especially supportive of tax credits for CHP projects. CHP tax incentives at the state level can come in the form of corporate tax incentives, property tax incentives, and sales tax incentives. However, despite tax incentives' apparent appeal, they favor for-profit companies, as tax-exempt organizations such as hospitals, universities, and colleges are not eligible for these incentives. For universities especially, where CHP installations have proven particularly beneficial, tax credits provide no incentive (11).

In October 2008, Congress enacted a federal investment tax credit for CHP systems up to 50 MW in capacity (2). While this federal incentive will be available through 2016, it is unlikely that the credit

[1] For a regulatory history of CHP and PURPA see Elliott and Spurr 1999.

has yet to manifest a significant impact on CHP installations, because CHP systems typically take between 24 and 48 months to develop (6). We can therefore discount the impact of this development on installation data at this point.

AVAILABLE CHP DATA RESOURCES

In order to compare the relative impact of state financial incentives compared to regulatory structures, we have drawn from ACEEE's State Energy Efficiency Scorecard (3, 4, 5) for qualitative policy and regulation assessments as well as ICF International's database of CHP installations (7). The CHP portion of the State Energy Efficiency Scorecard ranks each state in five categories:

1. presence of an interconnection standards that explicitly establishes parameters and procedures for the interconnection of CHP systems;
2. standby rates used by the largest utilities in each states to charge for standby service provided to CHP systems;
3. the presence of output-based emissions regulations; and
4. the eligibility of CHP for credit in a renewable portfolio standard (RPS) or energy efficiency resource standard (EERS); and
5. the presence of financial incentives for CHP.[2]

ICF International's CHP database contains comprehensive information on CHP installations throughout the United States by year and by state. The database includes data on each CHP system installed in every state, including information on capacity, fuel, and the year in which it began operating.

DATA METRICS

The ACEEE State Energy Efficiency Scorecard identifies several states that have shown leadership in providing financial incentives for CHP (See Figure 1), with varying degrees of accessibility, longevity, and substantiality. Not surprisingly, many of the states that have exhibited leadership on CHP regulatory policies are also the states offering incentives. Connecticut, Ohio, Oregon, New York, and Pennsylvania—all states with favorable regulatory environments for CHP—have also offered incentives for development over the past few years. A number of states that have poor regulatory environments for CHP do not offer any incentives for development, reflecting a lack of state attention to this efficiency opportunity. Examples of these laggard states include Virginia, Iowa, Louisiana, Georgia, and Wyoming. Several examples exist of states that offer financial incentives but have not implemented good regulatory policies, and vice versa. These instances are the most interesting for examining the relative impacts of incentives and regulatory reform. The states with good regulatory environments but modest or no incentives include Texas, Massachusetts, Maine, and Indiana, while states with more generous incentives but poor regulatory environments include Vermont, Michigan, Alaska, and Idaho.

		Regulatory environment	
		Good	Bad
Incentives	Good	CT, OH, OR, NY, PA	VT, MI, AK, ID
	Bad	TX, MA, ME, IN	VA, IA, LA, GA, WY

Figure 1. Incentives vs. Regulatory Environments

These policy data, combined with the data on new CHP capacity in each state over the five year period from 2005 to 2009, can provide insights into the relative impacts of state regulatory policies and incentives.

<u>Total Capacity</u>

There are a number of perspectives from which we can analyze new construction of CHP systems. The logical one is total capacity installed, which reflects one of the primary benefits of CHP—displacement of electricity generation from the grid. However, because of the wide range of system capacity (ranging in the ICF database from 1.2 kW to 224 MW), this metric can be misleading, since a few large projects can cause their host states to appear to have more active CHP markets than they do. Texas far surpasses every other state in capacity, with over 300 MW installed over the last five years (see Figure 2).

In the context of our analysis, capacity should not necessarily be viewed as the most significant parameter. Although Texas leads every other state in new capacity, one installation accounts for 75% of it.

[2] For the purpose of this paper's analysis, financial incentives have been isolated from other state policies as a metric.

State	Capacity Added 2005-2009 (MW)	Number of New Sites (2005-2009)	Avg. Capacity of New Sites	Average ACEEE Scorecard incentives Score (Max 4)	Average ACEEE Scorecard regulatory policy score (2007-2009) (Max 5)
Texas	380.8	8	47.6	0	5
Connecticut	181.9	61	3.0	3	5
California	113.0	137	0.8	1	5
New York	98.8	94	1.1	3	5
Washington	97.6	8	12.2	1	3
Wisconsin	83.0	20	4.2	1	4
Nebraska	70.0	1	70.0	0	1
Pennsylvania	50.9	24	2.1	2	4
Ohio	48.6	7	6.9	4	4
Alabama	47.0	3	15.7	2	1

Figure 2. State Leaders, New Installed CHP Capacity, 2005-2009

State	Number of New Sites (2005-2009)	Capacity Added 2005-2009 (MW)	Avg. Capacity of New Sites	Average ACEEE Scorecard incentives Score (Max 4)	Average ACEEE Scorecard regulatory policy score (2007-2009) (Max 5)
California	137	113.0	0.8	1	5
New York	94	98.8	1.1	3	5
Connecticut	61	181.9	3.0	3	5
Massachusetts	32	36.7	1.1	0	4
Pennsylvania	24	50.9	2.1	2	4
Wisconsin	20	83.0	4.2	1	4
New Jersey	18	14.1	0.8	1	5
North Carolina	13	17.6	1.4	2	3
Oregon	10	38.8	3.9	4	5
Vermont	10	3.2	0.3	3	3

Figure 3. State Leaders, New CHP Installations, 2005-2009

Nebraska ranks seventh in new capacity from 2005 to 2009, but all of its capacity is associated with one project. This finding does not imply that financial incentives and regulatory policies had no impact on the development of the Nebraska system, but we should not let one large capacity installation overshadow the significance of a number of smaller systems in other states where policies may have had much greater impact that could be longer lasting.

Number of Installations

Because of the impact of a single large facility on installed capacity, we also chose to examine the number of new systems installed in each state (See Figure 3). Here, we find Texas moves down in rank significantly. However, larger states will certainly have a higher probability of any new capacity installation, regardless of fuel type or system type.

Average Capacity

When states are sorted by average capacity of new installations, a majority of the leading states are ones with unfavorable regulatory environments and poor financial incentives. This market effect can be attributed in part to the fact that large CHP systems installed at energy-intensive manufacturing facilities are often much easier to finance and push through regulatory hurdles as a result of internal capability within in the firms and the ability to procure expertise to address these barriers. In addition, many of these large firms choose to go the route of PURPA qualifying facilities,[3] which can bypass local utility barriers. In this category, we find states in the top tier that have not appeared as leaders in any other category—e.g. Florida, Missouri, and Arizona—

[3] See Elliott and Spurr 1999 for a discussion of PURPA and CHP.

simply because of the small number, but large sizes, of new installations.

Normalized Capacity and Normalized Number of Installations

Normalizing the new CHP capacity in each state by the state's energy consumption provides us with another metric for state-by-state comparison. Connecticut and Nebraska hold the lead in capacity per capita, with South Dakota, North Dakota, and Montana not far behind. Similarly, a normalized capacity figure based on state population (which eliminates the factor of disparate consumption levels per capita in each state) yields the same states in the top five spots. Similarly, a normalization of the number of installations by state energy consumption and by state population places Connecticut and Vermont as the leading states.

ANALYZING THE DATA

Sorting by Capacity

When the states are sorted by new installation capacity from 2005 to 2009, we find that a clear majority of the top 15 states have favorable regulatory policies and favorable incentives for CHP. The notable exceptions are Texas, Washington, Nebraska, and Alabama. Texas, as mentioned above, has a very favorable regulatory environment but no financial incentives. Like Texas, Washington has offered poor state financial incentives, but a relatively amenable regulatory environment. In contrast, Alabama has had some level of financial incentives over the past three years—though only three CHP systems have been installed—and Nebraska has offered little in the way of incentives, though its high level of installation capacity is reflective of only one project, as noted above. Discounting Alabama and Nebraska, then (as the state in the top 15 of capacity with the next fewest new installations over the last five years had eight), we see that the most significant exceptions to the rule in terms of capacity are Texas and Washington, both examples of where financial incentives played little or no role, while some of the most capacity of CHP in the country was still installed. Conversely, some states that have offered modest incentives for CHP but have unfavorable regulatory policies—such as Alaska, Mississippi, Vermont, and Idaho—saw less than 4 MW in total new installation capacity over the past five years.

Sorting by New Installations

Using the number of new installations rather than total capacity as a metric, we find that of the top 15 states, nine have favorable regulatory environments and four have moderately favorable regulatory environments. Only one state in the top 15, Vermont, has an unfavorable regulatory environment. Vermont is also the state with the most financial incentives offered of all the states in this grouping. This could be construed to counter our hypothesis, at least in part. However, Vermont is a fairly unique state with respect to energy and energy efficiency (see the full discussion on Vermont below). When states are ordered by number of new installations, we again find some states with financial incentives, but prohibitive regulatory environments, exhibiting a dearth of new CHP construction, including Alaska, Idaho, Mississippi, and Michigan.

Sorting by Normalized Capacity

We can then look at the normalized forms of both our capacity and new installations metrics. When capacity is normalized by either energy consumption or population, it is unsurprising that several of the top-performing states are states with low populations and low total energy consumption, such as Nebraska, North Dakota, Montana, and South Dakota. These states all have relatively unfavorable regulatory environments and have offered few if any financial incentives for CHP over the past three years. It is worth noting, therefore, that these states installed only one, four, seven, and three new CHP systems respectively over the last five years, and their placement at the top is reflective of the relatively large combined capacity of these installations (between 16 and 70 MW) and their low populations and energy consumption levels.

Sorting by Normalized New Installations

Looking at the new installations metric normalized by population, we find that most of the leading states are simply states with low populations—Vermont, Montana, Rhode Island, North Dakota, Wyoming, and South Dakota—with a few states with high populations mixed in simply because they installed so many new systems—Connecticut with 61, Massachusetts with 32, and New York with 94. Each of the low-populated states in this top tier installed fewer than 8 new systems, with the exception of Vermont, which installed 10. Each one of these states also maintains an unfavorable regulatory environment and offers poor financial incentives, once again with Vermont as the exception with regard to incentives (see the full discussion on Vermont below). The new installations metric normalized by energy consumption yields mostly the same results, though interestingly California moves into the top 10—presumably because of its low energy consumption levels per capita—and Wyoming plummets out of the top 10—

presumably because of its high energy consumption levels per capita.

Sorting by Regulatory Policies

Looking at our data in the opposite direction, we can sort the states based on the favorability of their regulatory policies, as well as based on the extent of their financial incentives. When sorted based on regulatory policies, we find that most of the top-ranked states have seen substantial new CHP installations over the past five years. The leaders in regulatory rank—Texas, Connecticut, California, Illinois, and Ohio—have all installed over 25 MW of CHP in the past five years, and have all installed seven or more systems. Illinois has seen the smallest capacity of new installations of these states, with 26.8 MW, and Ohio has installed the fewest systems, with seven. Examining the new state order for outliers based on capacity and number of new installations, we find that a few states with poor regulatory environments have high new capacity numbers—Alabama with 47.0 MW, Nebraska with 70.0 MW, and North Dakota and Montana with 23.0 and 23.3 MW, respectively. As has already been discussed, these were either were very large systems on average or there were simply too few new installations—three, one, seven, and four respectively—to warrant inferences with regard to the regulatory environments in these states.

Sorting by Financial Incentives

Sorting states by financial incentives offered presents a different picture. While several states with good financial incentives also have favorable regulatory policies—e.g. Ohio, Oregon, Connecticut, and New York—several states appear in the top tier that have previously not been leaders in any category, such as Florida, Idaho, North Carolina, and Alaska. Vermont, with its relatively strong incentives, also ranks highly. Of the states the have strong incentives but unfavorable regulatory policies, we see some disparities in the seeming efficacy of the incentives. Florida has installed only three new systems with an average capacity of 14.6 MW; Vermont has installed 10 new systems with an average capacity of 0.3 MW; Idaho has installed two new systems with an average capacity of 1.9 MW; North Carolina has installed 13 new systems with an average capacity of 1.4 MW, and Alaska has installed one new system with a 0.4 MW capacity. It should be noted that both Florida's and North Carolina's regulatory environments are ranked in the third highest tier out of six, as opposed to Vermont, Idaho, and Alaska, which were ranked in the fourth tier.

Little consideration should be given to Idaho and Alaska in this category, as there were only two new installations and one new installation, respectively, in those states. Financial incentives certainly could have played a role, but again, the installation of so few systems cannot reasonably be extrapolated as a justification for the efficacy of financial incentives in a prohibitive regulatory environment. Florida, North Carolina, and Vermont warrant some closer attention, as outlined below.

Conversely, several states that notably lack strong financial incentives for CHP still exhibit impressive new installation figures. The most notable is Massachusetts, which despite only installing 36.7 MW of capacity over the past five years, did so with 32 new systems. In fact, Massachusetts ranks fourth in the country in new installations. Other states with no financial incentives but relatively many new installations include Colorado with nine installations and Texas with eight installations. Indeed, Texas offers no financial incentives for CHP but leads the nation in newly installed capacity. Other states with relatively high new capacity but with no financial incentives include Missouri with 10.7 MW, Arizona with 16.3 MW, Iowa with 16.9 MW, South Dakota with 16.5 MW, and Montana with 23.3 MW. However, each of these states has an unfavorable regulatory environment and installed few new projects over the past five years, so they do not lend credence to either the argument in support of or that in opposition to the thesis posited here.

Florida. Florida, which maintains a mediocre regulatory environment, saw three new systems installed from 2005 to 2009 with a combined capacity of 43.9 MW—one site representing 36.5 MW and the other two at 3.2 and 4.2 MW. The large site, installed by Smurfit Stone Container Corporation at a wood products plant, was a qualifying facility under PURPA. Therefore, it was able to bypass regulatory processes at the state level, per PURPA Section 210. This data point, a significant one, is therefore not relevant to our analysis. The other two systems installed in Florida were both undertaken by municipal utilities—Ocala and Gainesville, respectively. CHP systems installed by utilities are inherently exempt from utility-related barriers, and municipal utilities lie outside the state regulatory environment scored in ACEEE's annual scorecard. Thus, Florida is essentially a null case study for the purpose of this analysis.

North Carolina. North Carolina received a moderate ranking for its regulatory policies primarily for its strong interconnection regulations. However, in practice, other regulatory barriers prove burdensome for CHP development (8). The 13 sites that have been installed in North Carolina over the past five years are almost all in municipal utility territory; that is, they are not subject to the same regulations as systems in investor-owned utility (IOU) territories. They are also almost all located in the eastern part of the state, where a company called PowerSecure works with municipal utilities and electric cooperatives to contract with IOUs for the purchase of electricity. These contracts include a significantly punitive coincidental peak clause, encouraging the use of distributed generation for reducing peak demand. The new CHP projects are also all PURPA qualifying facilities, further allowing them to circumvent regulatory hurdles.

Vermont. Vermont is the only state where we find especially strong financial incentives, an especially weak regulatory environment, and relatively impressive numbers for new CHP installations and normalized new capacity. However, before Vermont may be viewed as a rejection to our hypothesis, the realities of the state's regulatory environment, energy efficiency players, and recent installations must be taken into account. In Vermont, despite a lack of favorable regulatory policies, certain programs, utility energy objectives, and other factors help to encourage CHP development (1). Vermont is unique in its recent energy savings goals, aiming to save 261.7 GWh between 2006 and 2008; it handily beat these goals. Efficiency Vermont, the state's "efficiency utility," which has its own set of savings goals, provides technical assistance for CHP developers. Additionally, the state subscribes to strong renewable energy goals through its Sustainably Priced Energy Enterprise Development (SPEED) program, and seven of the state's 10 CHP projects over the past five years are fired by biomass (including wood), an eligible renewable technology. Finally, net metering is available for systems less than 250 kW, which applies to three of the 10 systems.

DISCUSSION

Based on the above analysis of available data, it is clear that both financial incentives and favorable regulatory policies on the state level can play a role in encouraging CHP implementation. Many states that maintain favorable regulatory policies also offer CHP incentives, which together strongly promote installations. However, while financial incentives are certainly useful drivers of development, our analysis suggests that incentives are not necessarily sufficient to help push CHP toward its full potential.

As displayed in Figure 1, there are examples of states with both favorable and unfavorable regulatory policies, states with strong and weak financial incentives, and intersects of both. The states with both favorable regulatory policies and strong financial incentives exhibit strong numbers of CHP system installations, as well as new capacity. States with both unfavorable regulatory policies and weak or no financial incentives typically exhibit weak numbers for both capacity and installation, with the exceptions of a few states—such as Nebraska, Montana, North Dakota, Iowa, and Arizona—show weak numbers for both new installations and capacity. The exceptions, as discussed above, have implemented too few systems—and too large systems, as will be discussed further—to be able to defend an argument that regulatory policies and financial incentives do not play an important role in CHP development.

The most notable cells to examine in Figure 1 are the cells for states with 1) unfavorable regulatory policies and strong incentives and 2) favorable regulatory policies and weak incentives. An examination of these states can yield important insights about which state actions matter to CHP implementation.

Good Regulations, Bad Incentives

While there is a great deal of overlap between states with favorable regulatory environments and states with relatively strong incentives[4] for CHP, some states exhibit the former but not the latter. These states include Indiana, Maine, Massachusetts, and Texas. Texas and Massachusetts exemplify and strongly defend the hypothesis of this paper; they have had no financial incentives for CHP, but have still seen impressive new installation numbers in the case of Massachusetts and new capacity figures in the case of Texas. In contrast, Maine has installed only two systems over the past five years totaling 4.5 MW and Indiana has installed eight systems totaling 2.2 MW. While Indiana and Maine do not contradict the thesis that good policies are more important than financial incentives, it also does not directly support this thesis, either. Further work is needed to understand if what other factors are at play in these states that led to this unexpected result.

[4] Incentives vary widely from state to state. The states that are generally considered to have "relatively strong financial incentives" here are states that have demonstrated a dedication to CHP through either new incentives each year, long-lasting incentives, or renewed incentives over the past three years; as well as states that have offered incentives that ACEEE has deemed fairly accessible and fairly substantial.

Bad Regulations, Good Incentives

States that maintain unfavorable regulatory policies but relatively strong financial incentives for CHP include Alabama, Alaska, Idaho, Michigan, and Mississippi. Florida, North Carolina, and Vermont can also apply to this category, but due to the aberrance of these three states as discussed at length above, we can discount them from consideration as potential rejections of our hypothesis. All the other states in this category installed three or fewer new CHP facilities over the past five years. Additionally, these states' total CHP capacity installed over the past three years—with the exception of Alabama—fell below 4 MW. For these reasons, these states should also not be considered as potential rejections to the hypothesis. In Alabama, three new systems were installed over the past five years, totaling 47 MW of capacity. However, two of the three systems in Alabama—which account for 99% of the state's new capacity—were qualifying facilities under PURPA, enabling them to circumvent regulatory barriers at the state level.

Other Factors

Size Matters. As mentioned briefly above, the size of a CHP system is a key factor in the success of its implementation. Typically, systems over 20 MW in size serve loads at large industrial facilities and are owned by companies with the time, financial resources, and staff to overcome key regulatory obstacles. Additionally, state-level interconnection standards often do not apply to large CHP systems, as they are left subject to federal interconnection standards at the transmission level. Because developers of large systems are typically better equipped to overcome regulatory and utility barriers than developers of smaller systems, financial incentives prove to have a much greater impact on small systems, often helping to determine whether a small system will even be installed. This factor likely played a role in the implementation figure from various states, notably those where we see weak regulatory policies, a few large installations, and few or no small installations, such as Nebraska, Alabama, and Missouri.

Facilitation by State Players. Over the past decade, many states have established programs and in some cases entire organizations to provide technical assistance for energy consumers looking to implement efficiency measures. Some state entities, such as Efficiency Vermont, can assist businesses in determining where the obstacles are to CHP implementation and working around them. Project facilitation can help reduce uncertainty and consequently project costs. Such assistance is much more beneficial for small projects for which the cost of addressing barriers is a large share of a total project cost. Federally funded technical assistance centers for CHP, known as Clean Energy Application Centers, can also provide valuable assistance, though their impact cannot be analyzed as a state-sanctioned initiative. While state programs offering technical assistance specifically for CHP development are rare, they can serve to increase the number of small CHP installations in their state, and very well may have played a role in some of the installations that occurred in states with poor regulatory environment, such as Vermont.

Incentivization through Renewables. Some CHP systems can receive incentives that are apportioned for renewable energy projects. While some states accept CHP systems with any fuel source to be able to count toward state energy savings or renewable energy mandates or goals, others give precedence to strictly renewable energy projects. Still, renewable-fired CHP, predominantly biomass, is often eligible for satisfying certain renewable energy goals, as well as receiving other renewable-centric financial incentives. Renewable projects tend to be smaller and treated more favorably at the state level than strictly energy efficiency projects. This factor could have promoted the development of smaller, biomass-fired systems in several states.

Extending the CHP Experience to Other Energy Efficiency Projects

The experience with the relative impacts of incentives and regulatory barriers on CHP installation can provide some important insights into other energy efficiency opportunities. In particular, the CHP experience is most applicable to other capital-intensive projects such as boiler and chiller plant projects and district energy systems. These types of projects involve complex engineering challenges and can run afoul of many regulatory hurdles that may significantly increase transaction costs. A 1999 International Energy Agency (10) discussion paper suggested that increased project transaction costs can have a stifling effect on energy efficiency project implementation. Thus policy efforts that focus on facilitating the hurdling of regulatory and market barriers may be an attractive option, particularly in the current fiscal environment, in which government provision of significant financial incentives may be problematic.

CONCLUSION

While financial incentives for CHP are beneficial, based on our analysis, it is not clear that they are sufficient to create a healthy market for CHP development in the states where they are offered. On the other hand, there are substantial indications that removing regulatory and market barriers can significantly improve the potential for CHP implementation.

System capacity certainly plays a role in determining whether financial incentives or regulatory barriers are more important to encourage development. Incentives seem to be more beneficial for smaller systems, as they represent a great proportion of total project costs. Regulatory barriers are more important for large systems, as burdensome utility rates, interconnection standards, and state emissions regulations are much more challenging issues for large systems that can greatly reduce or preclude demand for utility services and can introduce a new “major” emissions source subject to stringent regulations.

These findings can be extended to other capital-intensive, energy-efficient systems. While a myriad of financial incentives exist for energy-efficient measures and systems, states would also be wise to closely examine hidden market and regulatory barriers that increase transaction costs and discourage implementation of these energy efficiency opportunities.

REFERENCES

1. Cinadr, Matt (Efficiency Vermont). 2010. Personal communication. February.

2. [DSIRE] Database of State Incentives for Renewables and Efficiency. 2010. Web site accessed March 2. http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US02F&re=1&ee=1.

3. Eldridge, Maggie, Michael Bill Prindle, Dan York, and Steve Nadel. 2007. The State Energy Efficiency Scorecard for 2006. June. ACEEE-E075. Washington, D.C.: American Council for an Energy-Efficient Economy.

4. Eldridge, Maggie, Max Neubauer, Dan York, Shruti Vaidyanathan, Anna Chittum, and Steven Nadel. 2008. The 2008 State Energy Efficiency Scorecard. October. ACEEE-E086. Washington, D.C.: American Council for an Energy-Efficient Economy.

5. Eldridge, Maggie, Michael Sciortino, Laura Furrey, Seth Nowak, Shruti Vaidyanathan, Max Neubauer, Nate Kaufman, Anna Chittum, and Sarah Black. 2009. The 2009 State Energy Efficiency Scorecard. October. ACEEE-E097. Washington, D.C.: American Council for an Energy-Efficient Economy.

6. Elliott, R. Neal and Mark Spurr. 1999. Combined Heat and Power: Capturing Wasted Energy. ACEEE-IE983. Washington, D.C.: American Council for an Energy-Efficient Economy.

7. [ICF] ICF International. 2010. Combined Heat and Power Installation Database. Arlington, VA.

8. McAllister, Keith (Clean Energy Applications Program Manager, North Carolina State University). 2010. Personal communication. March.

9. [ORNL] Oak Ridge National Laboratory. 2008. Combined Heat and Power: Effective Energy Solutions for a Sustainable Future. Oak Ridge, TN: United States Department of Energy.

10. Ostertag, Katrin. 1997. Transaction Costs of Raising Energy Efficiency. Presented at the IEA International Workshop on Technologies to Reduce Greenhouse Gas Emissions. May. Washington, D.C.: Fraunhofer Institute for Systems and Innovation Research.

11. Spurr, Mark. 1998. District Energy Systems Integrated with Combined Heat and Power: Analysis of Environmental and Economic Benefits. Report to the U.S. Environmental Protection Agency. March. Minneapolis, Minn.: International District Energy Association.

FEDERAL SUPPORT FOR ENERGY EFFICIENCY IN U.S. INDUSTRY: COLLABORATIVELY ADDRESSING ENERGY MANAGEMENT IN SMALL- AND MEDIUM-SIZED MANUFACTURERS (SMMs)

JEFFREY HARRIS
VICE PRESIDENT, PROGRAMS

PAUL BOSTROM
INDUSTRIAL PROGRAM ASSOCIATE

ROBERT BRUCE LUNG
INDUSTRIAL PROGRAM MANAGER

ALLIANCE TO SAVE ENERGY
WASHINGTON, DC

ABSTRACT

The U.S. industrial sector consumes about one-third of energy in the United States each year. Improving energy efficiency in an industrial environment may come with a host of benefits to the facility owner, including a reduction in annual energy expenses, lower maintenance costs, increased productivity, and improved profitability; but sector-wide improvements in industrial energy efficiency represent even greater advancements to a collective federal agenda relating to the economy, energy, and the environment. Multiple federal agencies—U.S. Department of Energy, U.S. Environmental Protection Agency, U.S. Department of Commerce, U.S. Department of Labor and the U.S. Small Business Administration—have taken a keen interest in industrial energy efficiency due to its clear links to the creation and retention of quality jobs, U.S. economic competitiveness, domestic energy security and global climate change.

This paper explores successful industrial energy efficiency programs established by various federal agencies, as well as emerging collaborative initiatives designed to enhance energy efficiency across U.S. small- and medium-sized manufacturers (SMMs). Authors investigate which of these programs have experienced traction and success among SMMs, as well as the best methods to engage SMMs at the local level. Additionally, this paper identifies existing barriers hindering energy efficiency within SMMs and discusses interagency opportunities to expand the reach and efficacy of federal energy-efficiency resources.

INTRODUCTION

Over the past three decades, federal agencies have been active in identifying opportunities to support U.S. industry across widespread sustainability initiatives[1], including energy efficiency; although recently, amidst rising energy costs and a troubled economy, energy has become of universal interest. Today, federal agencies are pursuing collaborative arrangements more aggressively, leveraging interagency resources to reach a greater number of U.S. manufacturers. According to the U.S. Census Bureau, SMMs[2] account for 70 percent of—or approximately 10.2 million—manufacturing jobs (23) within the United States and represent nearly 99 percent of all American manufacturing plants (23). SMMs are a vital component of the U.S. economy and will require federal support to successfully and effectively transition to a carbon-constrained economic environment. However, due to a number of barriers including high transaction costs, highly variable production, geographic dispersion, and the sheer number of facilities, small- and medium-sized manufacturers remain the among most difficult subsets to impact. For these reasons, federal programs targeting SMMs must rely on highly coordinated and flexible models to achieve the myriad of benefits an energy efficient manufacturing base can provide.

THE IMPORTANCE OF HEALTHY SMALL- AND MEDIUM-SIZED MANUFACTURERS (SMMs)

SMMs constitute a major portion of the U.S. manufacturing base, and therefore help to drive industrial operations on a global scale. The fiscal health and productivity of American SMMs are critical to both the domestic and world economies, and provide a multitude of benefits to national interest and international commerce. To demonstrate the criticality of healthy SMMs as a significant contributor to the U.S. economy, we explore the various ways manufacturers—including SMMs—stimulate U.S. prosperity.

Innovation. Small manufacturing firms play a central role in the developing innovative, new technologies emerging from the private sector. Many small manufacturing operations spin off from universities, research organizations, or larger parent companies to commercialize a single technology or a specialized suite of technologies. Small company size often fosters a focused, autonomous R&D setting and is more conducive to the financial liability of a risky commercialization endeavor. For these reasons, SMMs

[1] For the purpose of this paper, sustainability initiatives refer to all federal programs linked to air pollution, water pollution and product lifecycle.

[2] Authors have elected to use the U.S. Department of Commerce (DOC) definition of a small- or medium-sized manufacturer throughout this paper. SMMs are considered manufacturers with less than 500 employees.

have historically been a driver of breakthrough technology innovation. In fact, small manufacturing firms (<500 employees) produce 13 to 14 time more patents per employee than their large counterparts (15).

Agility. Production agility is a critical factor within a broader industrial supply chain. Small manufacturing shops using relatively simple production processes and small batch size enjoy the ability to alter production nimbly according to customer demand. Small manufacturers may also benefit from production agility by quickly mobilizing around specific R&D breakthroughs. This accelerated path to market is critical for SMMs to compete with larger competitors in end-use markets and to satisfy demands as a leading supplier to large manufacturers.

Quality Jobs. Manufacturing jobs often require a specialized skill-set, and therefore demand a wage premium over other economic sectors of employment. According to the U.S. Bureau of Labor Statistics, manufacturing employees earn 21 percent more on a weekly basis than the average private sector employee (23).

U.S. Competitiveness. Global trade is another critical element of economic health, attracting foreign currency to the U.S. economy. In 2008, American manufacturers exported over $86 billion worth of goods per month with an annual aggregate of nearly $1.04 trillion (16). In fact, in 2008 manufactured goods represented 57 percent of total U.S. exports. However, as of fiscal year (FY) 2000, the largest 1 percent of trading firms (employing an average of 8,000 employees) manufactured approximately 81 percent of American exports (15). This implies that small manufacturers accounted for well below 19 percent of U.S. manufactured exports. In an increasingly globalized economy, this statistic represents a tremendous opportunity to strengthen the reach of SMMs into global markets.

Meanwhile, although greater international opportunities exist for SMMs, many are becoming increasingly globalized. According to the National Association of Manufacturers (NAM), the share of SMMs reporting that exports represent greater than or equal to 25 percent of their total sales, has increased from 3.8 percent in 2001 to 12.8 percent in 2008 (16).

Attracting Foreign Investment. Commissioning a U.S. facility provides foreign manufacturing firms access to American markets, convenience to American suppliers, and proximity to American-educated intellectual capital. Alternatively, U.S.-based facilities owned by foreign firms provide jobs to American workers, taxes to American localities, and inject operating capital into the American economy. "Insourcing"—that is, direct foreign investment in the U.S. manufacturing sector—grew from $153 billion in 1990 to $519 billion in 2004 (15). As a result of accelerated insourcing, about 1 in 12 American manufacturing workers are now employed by a foreign-owned firm (16).

Economic Health. Manufacturing is tied to U.S. economic health in a number of ways, not the least of which is its contribution to domestic GDP. In 2008, manufacturing GDP accounted for 11.5 percent of the total U.S. GDP (16), valued at $1.63 trillion (36). Today, U.S. manufacturing continues to represent a significant portion of global manufacturing, however other sectors of the American economy have well outpaced the growth of the manufacturing sector. For example, in 1980 value-added manufacturing represented 20 percent of U.S. GDP as compared to today's 11.5 percent. Over the same period, China's share of global [value-added] manufacturing has grown from less than 2 percent to over 14 percent (16). This rapid rate of growth in Chinese manufacturing characterizes the threat of emerging economies as manufacturing competitors. India and Brazil represent similar competitors.

Indirect Job Creation and the Multiplier Effect. Manufacturing is intricately linked to the U.S. economy through direct investment, employment, and the production of manufactured goods; although manufacturing also provides a critical indirect link to other U.S. service sectors, agricultural subsectors, and others. According to the National Association of Manufacturers, in 2009 manufacturing directly employed 11.8 million workers in factories and plants across the country. Additionally, manufacturing also indirectly supported an estimated 6.8 million service jobs which depend on a healthy manufacturing base. These services include accounting, legal consulting, wholesaling, transportation, agriculture, finance, insurance, and real estate services, among others (16).

Manufacturing also has the greatest multiplier effect on GDP of sectors in the U.S. economy. According the U.S. Bureau of Economic Analysis, every dollar in output of manufactured products supports an additional $1.40 in output from other sectors of the economy. For context, as manufacturing production ramps up in a single subsector, there is a heightened demand for financial services to capitalize the excess production, logistics consultation to help boost productivity, transportation to distribute product, and so on. By comparison, wholesale and retail trade sectors generate low multipliers—only $0.55 and $0.58 respectively—relative to U.S. manufacturing (16).

ENERGY MANAGEMENT IN A SMALL MANUFACTURING ENVIRONMENT

For many SMMs, energy expenses are often treated as an overhead cost, or simply a cost of doing business (10). Indeed absolute energy consumption among SMMs is typically dwarfed by the energy costs incurred by larger industrial counterparts, and may have a tendency to be overlooked. Furthermore, SMMs often lack the time, money, and expertise required to track and analyze energy consumption trends, not to mention emerging technologies and pending energy-related regulation. Another common obstacle to energy efficiency projects in a small manufacturing environment—and one especially pertinent over the past 18 months—is access to capital. After efficiency projects have been identified, convincing banks and commercial lenders [of an attractive return on investment and a "reasonable" payback period] can be a challenge, as few lenders have the expertise to adequately evaluate energy efficiency projects. For SMMs, this process of searching for a viable source of capital may exceed the time and resources available to the prospective project. As was astutely cited in a 2003 National Institute of Standards and Technology (NIST) report, "Many SMM owners [are consumed with] work *in* the business rather than *on* the business (12)." This universal dilemma can have significant impacts on small manufacturers' productivity, competitiveness and profitability.

THE ROLE OF FEDERAL GOVERNMENT IN SUPPORTING ENERGY EFFICIENCY IN SMMs

Increasing energy efficiency among SMMs represents a major opportunity to revitalize the American manufacturing sector's role in the global economy, reduce environmental impacts of U.S. industry and advance a secure, reliable domestic energy regime. Because of the systematic societal benefits of energy efficiency in manufacturing facilities, many federal initiatives have been commissioned to promote energy efficiency among SMMs. However, due to the diverse landscape of manufacturing sector—both geographically and operationally—SMMs can be difficult to reach. SMMs are often run on tight production schedules with rigid budgets and find it difficult to engage in intensive programs that may be disruptive to production operations. SMMs also tend to be highly variable in production processes, which may require federal offerings to be customized on a case by case basis. "One size fits all" energy resources are unsuitable for all manufacturers, but especially for small facilities. Therefore, federal agencies tasked with advancing energy efficiency in small manufacturing plants must strike a balance between developing universal, cross-cutting resources that can be effective across industry, and devising initiatives that are highly customized, providing personal assistance and facility-specific recommendations.

Despite a number of valuable energy efficiency programs, resources and incentives available to SMMs, federal initiatives are often unintentionally competing among each other for the time and attention of small manufacturers. SMMs may not understand the differences in federal programs offered by various agencies, and the perception of federal assistance can appear disparate and disjointed. Effective interagency collaboration is one critical factor in productively engaging with small manufacturers, demonstrating the value of federal resources and achieving the highest possible return on federal investment.

SELECTED FEDERAL ENERGY EFFICIENCY INITIATIVES SUPPORTING SMMs

A number of federal programs touch small manufacturers, whether directly targeting SMMs or indirectly including SMMs among other small businesses. The following federal programs provide professional and technical assistance to SMMs, including resources related to energy efficiency.

U.S. Department of Energy, Industrial Assessment Centers. Industrial Assessment Centers (IACs) are network of satellite manufacturing technical assistance centers that are housed within 26 participating universities across the nation. This program, funded by the U.S. Department of Energy's (DOE) Industrial Technologies Program (ITP), matches teams of IAC energy consultants with surrounding small- and medium-sized manufacturers (SMMs) to examine and evaluate energy use within participating manufacturing facilities. IAC teams, comprised of both engineering students and university faculty, typically conduct a company survey followed by a full-day energy assessment, which inform a thorough facility analysis with energy efficiency recommendations and associated payback periods. IACs also have access to a suite of DOE energy tools and software including system assessment tools for motor-driven systems, steam systems, process heating and combined heat and power (CHP) systems. To date, over 14,000 (24) assessments have been conducted by IACs with each assessment yielding an average of $55,000 worth of energy saving recommendations and additional productivity recommendations (25). Furthermore, IACs provide participating students with targeted training on energy management in an industrial facility. In fact, of the 2,500 IAC program alumni since 1977, 56 percent of students have gone on to pursue energy-related careers (7).

Despite the successes of the IAC program over its 33 year history in both identifying energy efficiency opportunities and training a next generation of industrial energy experts, many SMMs remain unaware of the low-cost service offerings of the IACs. IACs have experienced rigid budget limitations over the majority of the past decade which has constrained IAC operations and program growth. For context, in fiscal year 2009 the total IAC program budget was capped at approximately $4 million, relative to funding levels in fiscal year 2001 which totaled $8.3 million (2).

The U.S. Department of Energy (DOE) has also devised other robust programs to advance energy efficiency in the industrial sector. Save Energy Now (SEN) is a national partnership initiative that aims to reduce U.S. industrial energy intensity by 25 percent or more over ten years. Companies formally participating in Save Energy Now, known as Save Energy Now LEADER companies, sign a voluntary pledge to reduce their energy intensity by 25 percent over 10 years and receive access to software tools, low-cost assessments, technical materials and training sessions as well as customized technical assistance via a secure online portal (28).

Superior Energy Performance (SEP) is another DOE program that promotes industrial energy efficiency through a lens of continuous improvement. SEP provides a standardized framework for industrial companies to implement energy management throughout their facilities. SEP includes a voluntary, industry-designed plant certification standard that provides a globally-accepted methodology for validating energy intensity reductions and energy management practices in industrial plants. A central element of Superior Energy Performance is implementation of the ISO 50001 energy management standard, with additional requirements to achieve and document energy intensity improvements over a 3-year period. The program will also contribute toward reaching the Save Energy Now goal of reducing industrial energy intensity by 25 percent in 10 years (27).

U.S. Department of Commerce, National Institute of Standards and Technology (DOC-NIST) Hollings Manufacturing Extension Partnerships (MEPs). The Manufacturing Extension Partnership (MEP) program provides a valuable suite of business services targeting small- and medium-sized manufacturers. Core MEP offerings include productivity consulting, employee training, facilitation of technology transfer, and perhaps most notably, no- or low-cost access to technical specialists to conduct system assessments, feasibility studies, and project engineering.

The MEP program was originally born out of the Omnibus Trade and Competitiveness Act of 1988 when the U.S. Department of Commerce (DOC) was directed to establish Manufacturing Technology Centers through its National Institute of Standards and Technology (NIST). At the commencement of the program, 7 centers were initially housed within qualified non-profit organizations and relied on a minimum of 50 percent of operational funding from the participating organization (12). Today, the MEP program has evolved to 59 principal centers located in every state and Puerto Rico, although services may also be delivered through public and private affiliates comprised of 1600 specialists in 400+ locations nationwide (8). Affiliates include technical experts from private consulting firms, administrators in state energy offices, engineers from partnering universities, and representatives of relevant trade associations. The MEP program has evolved over two decades to boast the broadest network of technical resources for small domestic manufacturers.

Over 21 years of service delivery, the program funding model has also evolved. Currently, the MEP program is supported by a one-third funding contribution from NIST and a two-thirds funding match from a mix of state-level funds, non-profit contributions, university donations and modest service delivery fees (8).

The intent of the MEP program is to enhance the productivity and competitiveness of small- and medium-sized manufacturers by providing training, assessments, consultation and additional resources. Specifically, MEP services delivers programs in lean manufacturing, providing facility assessments and trainings; energy and environmental services to reduce waste streams and enhance productivity; training and implementation support for international ISO standards 9000 and 14000 (related quality control and environmental management, respectively); supply chain management; technology assessments and project support to promote technology transfer to SMMs; and other productivity-centric offerings related to project financing and navigating state and federal regulation. Energy efficiency is not core to the mission of the MEP program, although excessive energy use is addressed as a waste stream within the lean framework

MEPs have a rich history of effective collaboration with other partners at the federal level, state level, and within professional and trade associations; although historically, these relationships have been forged on an individual MEP center basis. In other words, local MEPs have developed and managed their own relationships at the local level based on the most valuable resources available in the immediate area; although recently, NIST has been active in promoting interagency collaboration in the delivery of federal resources. The MEP program is actively engaged in a number of joint initiatives with partnering federal agencies including the U.S. Department of Labor, Environmental Protection Agency, National Science Foundation, and the U.S. Department of Energy, among others; however, many of these partnerships are not explicitly intended to bolster the delivery of energy efficiency-specific resources (9).

U.S. Environmental Protection Agency, Green Suppliers Network. The Green Suppliers Network (GSN) began in late 2003 as an initiative developed and funded by the Environmental Protection Agency (EPA) and deployed through the MEP network using existing technical expertise and resource delivery (4). GSN is a voluntary program that works with large manufacturers to engage their supply chain—consisting largely of SMMs—to leverage lean production techniques to 'green' operations and boost productivity. In turn, GSN partners with SMMs to conduct low-cost 'lean and clean' assessments in participating facilities, and provide detailed recommendations to facility owners regarding limiting operational waste streams, minimizing environmental impacts, maximizing productivity and enhancing profitability. Energy efficiency is addressed in the GSN lean and clean assessments, as excessive energy use is treated as an energy waste stream. To date, GSN has completed 100 facility reviews yielding over $53 million in cost-saving, lean recommendations (3). GSNs efforts in greening the manufacturing supply chain are widely recognized among large manufacturers and retailers, as pollution prevention and energy efficiency initiatives among SMMs have been endorsed by an independent third party (GSN). These efforts are typically validated by SMM customers when GSN partners are elevated to a 'preferred supplier' status.

ADDITIONAL FEDERAL SUPPORT

In addition to dedicated manufacturing resources and personnel available under the aforementioned programs, other federal agencies also administer grant and loan programs for which SMMs may be eligible. Many of these programs have experienced elevated levels of funding through the American Recovery and Reinvestment Act (ARRA) of 2009, and although the intent and focus of each program may vary, all could help to advance energy efficiency in a small manufacturing environment.

U.S. Department of Agriculture (USDA) Energy Programs.

The U.S. Department of Agriculture, charged with federal oversight and support of American agricultural operations, has a broad interest in energy. U.S. agriculture is a major energy end-user requiring large amounts of electricity and primary fuels to power daily operations—often times in rural or remote locations, making issues of reliability especially pertinent—but agricultural producers also hold an interest in biomass as a feedstock for manufactured biofuels. Currently, USDA programs are in place to promote reliable, affordable energy delivery to rural customers; promote agricultural feed stocks for the production of biofuels; deploy renewable energy systems; as well as general energy efficiency programs to advance competitiveness of U.S. farmers, stimulate job creation, and limit environmental impacts. Despite a variety of USDA initiatives that in some way include energy, energy efficiency resources and funding are most prevalent under the USDA's Rural Development Program.

The Rural Development Program has been tasked with a wide-ranging objective "to increase economic opportunity and improve the quality of life for all rural Americans." (22) Given the broad scope of the task order, the Rural Development Program is granted the authority to deliver a diversity of resources and services to rural Americans—households, farmers and businesses—including some earmarked for energy efficiency.

It is important to note that for the purposes of the Rural Development Program, USDA has defined 'rural' as a community of less than 50,000 people (21). In fact, using data collected in the most recent decennial census (CY 2000), the USDA has classified 97.5 percent of U.S. land as 'rural' according to eligibility requirements (13). Therefore, most small- and medium-sized manufacturers located outside urban centers remain eligible for funding and resources offered under the USDA Rural Development Program. Of these, three initiatives are considered most valuable to American SMMs:

Rural Energy for America Program (REAP). REAP, authorized under the 2008 Farm Bill, offers both agricultural producers and rural small businesses—including manufacturers—both loan guarantees and federal grants in support of renewable energy or energy efficiency projects. Energy audits and feasibility studies are also eligible for funding under this program. Energy efficiency grants under this program range in size from $1,500 to $250,000 and cannot exceed 25 percent of the total project costs. Energy efficiency loans range from $5,000 to $25 million, and may not exceed 75 percent of total project costs. Awards are allocated on a competitive basis (20).

Business and Industry (B&I) Guaranteed Loan Program. The B&I Guaranteed Loan Program is USDA initiative to bolster rural American's access to private capital. Under this program, USDA provides a federal loan guarantee to private lenders for loan proposals that meet the following criteria:

- Provide employment;
- Improve the economic or environmental climate;
- Promote the conservation, development, and use of water for aquaculture; OR
- Reduce reliance on nonrenewable energy resources by encouraging the development of renewable energy systems and energy efficiency improvements.

Small- and medium-sized manufacturers may use B&I guaranteed loans for facility improvements, facility expansion, equipment upgrades, pollution control and abatement, or projects related to biomass fuel production.

Loan guarantees under this initiative cover 80 percent of the capital advance for loans less than $5 million, 70 percent for loans between $5 million and $10 million, and 60 percent for all loans over $10 million. As with most loan guarantees, terms of the loan—including interest, fees, and collateral—are negotiated between the lender and borrower (19).

Rural Business Enterprise Grant Program (RBEG). The RBEG program is another USDA initiative intended to spur economic development in rural regions of the United States. RBEG funds may be used for the development of land, construction, renovation, new machinery, equipment upgrades, training/ technical assistance, and establishing a revolving loan fund, among other uses. Rural SMMs are eligible for funds through the RBEG program, although funds must travel through a municipality or qualifying non-profit as an intermediary. Projects are not required to include any elements of energy efficiency, although energy efficiency projects and training would be eligible for grant awards provided there is a clear link to economic development (21). RBEG program funding levels vary annually according to the USDA budget, although via the American Recovery and Reinvestment Act (ARRA) of 2009, RBEG has been authorized an aggregate $20 million over fiscal years 2009 and 2010. The average award under the RBEG program is approximately $99,000 (18).

U.S. Small Business Administration (SBA). The U.S. Small Business Administration provides federal support to America's small private enterprises, with the intention of strengthening regional and national economies and enhancing U.S. competitiveness. Among many other initiatives, the SBA oversees the Small Business Develop Center (SBDC) program, consisting of 63 lead SBDCs located in every state as well as in Guam, Puerto Rice, Samoa, and the U.S. Virgin Islands. The SBDC also employs a network model to disseminate program offerings through an additional 1100 service locations (35). Historically, SBDCs have provided management assistance to business owners, but as of late 2009, program offerings will also include energy audits to promote facility energy efficiency, as well as specific technical support to businesses engaged in the development of energy efficient and clean energy technologies. These offerings are available to all types of small commercial businesses, including small manufacturers. SBDC engagement in energy efficiency and clean energy is a direct result of the Energy Independence and Security Act (EISA) of 2007 (33 & 34).

Certified Development Company (CDC)/504 Loan Program. The 504 Loan Program, administered through the SBA, offers small businesses—including manufacturers—access to long-term, fixed-rate financing in support of the acquisition of fixed assets including land, real estate or equipment. The 504 Loan program has been in operation for over 25 years, although recently in early 2009, modifications to the program have included energy efficiency and renewable energy projects as special considerations for project financing (14). Today, small manufacturers may use this program as a vehicle to finance facility retrofits or equipment modernization initiatives. Loans for 'green projects' are capped at $9 million and require 10 percent equity from the borrower. The remaining 90 percent is structured with 40 percent obtained from a 'Certified Development Company' (community-based economic development organizations) and the 50 percent balance from a commercial lender. The SBA provides a 100 percent loan guarantees for the CDC portion of the loan (32).

U.S. Department of Labor (DOL); High Growth Training Grants. The U.S. Department of Labor promotes the welfare of American workers, job seekers, and retirees. In light of severe job loss throughout the recent recession, the DOL plays in integral role in stimulating job creation throughout all sectors of the U.S. economy. With an influx of funds under ARRA, DOL's Employment and Training Administration (ETA) has dedicated $500 million in competitive grants for worker training in "high growth and emerging industries" (30). Core industries under this designation include health care, biotech, energy efficiency and renewable energy, among others. These ETA grants are designed to provide job training to workers displaced throughout the recent recession in an effort to reemploy the American labor force and provide specialized skills to advance developing markets. To date, DOL has allocated approximately $440 million in grants to promote "green jobs training," including energy efficiency. Additionally, DOL has invested another $190 million in State Energy Sector Partnership (SESP) and Training grants. SESP grants are awarded at the state level and are also intended to promote job training and strategic planning targeting energy efficiency and renewable energy industries. Of the $190 in SESP grants, $25 million are earmarked for training displaced workers of the auto industry, to provide the necessary skills to transition to careers in energy-related manufacturing (31).

REACHING SMMs: IDENTIFYING PROGRAMMATIC BEST PRACTICES AMONG FEDERAL OFFERINGS

Federal initiatives have been configured in various ways to effectively facilitate resource and service delivery. After conducting interviews with representatives of SMMs, technical experts, federal program administrators and IAC specialists, we have identified the following programmatic elements as best practices.

Explore Local Utilities' Offerings. With demand outpacing supply, rising costs, and mounting environmental concerns, electric utilities face a number of challenges in securing and delivering affordable, reliable energy. Energy efficiency and demand-side management (DSM) programs are among the most constructive, cost-effective ways for utilities to address these challenges. Because industrial customers are typically large power users, they are important contributors to a utility's energy efficiency goals and peak load reduction strategies. Utility programs targeting industrial customers often include energy audits, financial incentives, low-interest financing, and operations and maintenance training. Many power companies also offer financial incentives or discounts to industrial customers who participate in load shedding or shifting programs.

Some utilities are also subject to energy efficiency resource standard (EERS) requirements (1), requiring measurable reductions in electricity end use. To capture energy efficiency opportunities across a given portfolio, utilities may provide incentives, rebates or project support to their industrial customers.

Utilize Municipalities, State Energy Office and Other State Agencies. Various public resources and personnel are available at the state and local level as local governments have a vested in promoting a healthy, efficient industrial base. Municipalities may offer financial incentives, fast-tracked permitting, or tax breaks to attract or retain local industrial companies. Municipalities have a strong interest in fostering a vibrant industrial sector due to their contributions to the local tax base as well as the synergies between energy efficiency, local job creation and economic competitiveness. Additionally, industrial energy efficiency projects are often evaluated favorably because they demonstrate significant, measureable energy efficiency gains.

Municipalities, including state and local governments, have experienced unprecedented access to federal funds via Energy Efficiency and Conservation Block Grants (EECBG) under the American Recovery and Reinvestment Act (ARRA) of 2009. The EECBG program apportions federal monies to state, local, and tribal grantees, and is intended to reduce fossil fuel emissions, reduce energy consumption, improve energy efficiency, and create/retain jobs. This program, created under ARRA, is capitalized with a total of $3.2 billion (28).

State Energy Offices may also offer a broad-based suite of services to industrial customers. Energy project grants, feasibility studies, training and R&D financing are all examples of resources available to promote energy efficiency across a given state's industrial portfolio. Of particular note, many State Energy Programs (SEPs) have also experienced a major increase in operating budgets due to the federal economic stimulus. Under ARRA, State Energy Programs were appropriated an aggregate $3.1 billion which has since been allocated through State Energy Program Formula Grants by the U.S. Department of Energy (26).

Similarly, other state agencies may have specific grant and loan programs intended to promote pollution prevention, job creation, or commerce. Developing a persuasive case that links energy efficiency to these types of end goals may qualify a SMM for access to grants, loan guarantees, or capital via revolving loan funds. Cultivating state-level relationships with representatives of the Department of Commerce, the Small Business Association and the Department of Agriculture, among others, may provide inroads for present or future funding opportunities.

Leverage Existing Relationships with SMMs. Getting to know an SMM client is the first step of a successful energy efficiency project. Understanding budget cycles, relationships with local banks, equipment replacement schedules and distinctive manufacturing processes are the types of details that will help to inform the best project-specific decisions on a case by case basis. Similarly, identifying deficiencies in existing energy management, equipment selection and equipment maintenance schedules are also examples of opportunities to for outside intervention.

From a federal perspective, cultivating these relationships with individual manufacturers poses a major challenge. Whenever possible, developing a team to include local technical consultants, MEP centers/associates, universities or utilities leverages preexisting relationships that may help to streamline the delivery of energy assessments and technical resources. Similarly, these collaborative teams help to navigate the complexities of the localized environment—state and local regulation, industrial energy fee structures, access to capital, etc.—from the perspective of a small manufacturer.

Include Local Investors. Often times SMMs may have a longstanding relationship with a local bank. Relationships with investors who take the time to understand the manufacturer, their operations, and the future direction of the company are invaluable. Including a trusted banker in the out-brief of a facility energy assessment or a energy efficiency project proposal helps to validate the associated productivity gains, energy savings, implementation costs and payback periods. An independent third party perspective can be integral in securing project financing for an energy efficiency project, as many small banks lack the expertise to adequately evaluate these types of loan proposals on their own accord. Including a local bank in an energy assessment out-brief may also provide an opportunity to cultivate relationships between a banker and an SBA loan officer, which could lead to opportunities in securing a federal loan guarantee. Loan guarantee programs help to minimize risk exposure for small banks and increase the likelihood of a loan approval for an ambitious energy efficiency project.

Keep SMMs Abreast of Regulatory and Policy Developments. Most SMMs lack the capacity to track regulation, policy and incentives that are introduced at the local, state and federal level. Local or national trade associations may help SMMs with navigating the world of regulation, although these resources are not locally available to many SMMs. SMMs, like all manufacturers, benefit from understanding the regulatory environment, as lead time for required action helps to temper the impacts of drastic change. Understanding the intricacies of impending policy and regulation also enable SMMs to choose the best and simplest compliance path on a facility-specific basis.

Promote Technology Transfer Among SMMs. Many SMMs operate without dedicated energy personnel that may be tasked with evaluating the potential of emerging technologies. Federal and state programs may assist SMMs by developing and maintaining a comprehensive database of both cross-cutting and industry-specific technologies, providing brief descriptions of the capabilities and deficits of each, and their potential to impact facility energy use based on direct energy consumption or by displacing a suite of legacy machines.

Enable Information Exchange Among SMMs. Small manufacturers occupying a specific geographical region may share common opportunities and challenges related to energy procurement, regulation and incentives, among others. Similarly, specific manufacturing subsectors may have a rich density in particular regions of the U.S., and therefore may experience additional shared challenges such as project engineering. Whereas large manufacturers may be less inclined to convene around mutual challenges due to issues of competitiveness, small manufacturers have historically been more open to problem solving on a 'pre-competitive basis'. Facilitating information exchange among industrial peers can be invaluable in addressing challenges related to energy and pollution prevention. Additionally, regular communication can be a productive tool in establishing industry-specific best practices.

Industry Energy Efficiency and Pollution Prevention Roundtable (E2P2) for Southwest Pennsylvania is a strong example of information exchange among SMMs. This program convenes local SMMs, as well as representatives from Penn State's Pennsylvania Technical Assistance Program (PennTAP) and Pennsylvania's Department of Environmental Protection (DEP), to share best practices related to energy efficiency and pollution prevention. This initiative provides an open forum for small manufacturers to engage energy experts and government officials on topics of energy and environment. Participants also organize facility tours of their respective plants and share project engineering challenges and resources.

Involve Owners/Executives Directly in Decision Making Where Possible. Strengths and skills of operations personnel and company executives tend to be complementary in a manufacturing environment and input from both parties is likely necessary in effective decision making. Operations personnel and plant management are likely more fluent in the technical requirements of proposed equipment and process changes, while executives may be more familiar with the capital constraints and financing opportunities related to energy projects. Working with a client team, including representatives from every level of the decision making process can streamline proposed energy efficiency projects and help to close the gap between energy efficiency recommendations and project implementation.

Leverage a Broad Network of Service Delivery Professionals. Among the most difficult aspects of supporting SMMs is reaching them. It is estimated that there are over 350, 000 small- and medium-sized manufacturing facilities in the United States, widely dispersed geographically (12). Any successful federal initiative requires a robust delivery strategy to get resources into the hands and facilities of small manufacturers. Today, NIST's MEP program boasts the largest and broadest network of manufacturing service delivery professionals housed in both MEP centers and within associated organizations. The MEP network offers a well established conduit for federal energy resources, boasting nearly 400 satellite centers occupying every state in the union and Puerto Rico. Further, centers are staffed by workforce of nearly 1600 technical experts, all of whom could be trained using energy-specific software and assessment tools (8).

Develop a Comprehensive Service Offering. Energy-related needs vary widely among small manufacturing facilities, therefore offering individual tools and resources under a myriad of federal programs is perceived by SMMs as overwhelming and overlapping. Bundling 'lean-', pollution prevention-, and energy efficiency-related services provides a single delivery mechanism for mutually beneficial resources. Additional programmatic layers may include links to feasibility studies, engineering resources, measurement & verification (M&V) services and project financing. This model also streamlines program administration associated with the service suite.

SUCCESSFUL FEDERAL COLLABORATION REACHING AMERICAN SMMs

Interagency collaboration at the federal level is valuable in coordinating resources and the delivery of services efficiently and effectively. Formal collaborative agreements—often initiated through an executive order, specific legislation, or outlined in a memorandum of understanding (MOU)—may also establish funding channels and financial commitments between participating agencies which can be a vital component of successful initiatives. Interagency collaboration may provide value in leveraging existing professional networks, relationships and infrastructure to minimize overlap of federal initiatives and the time, money and energy required to develop programs independently.

Over the past decade a number of collaborative models have been employed at the federal level intended to more effectively support small manufacturers. The following are two active initiatives that have demonstrated promise and yielded quantifiable energy efficiency gains as a direct result of successful collaboration.

E3 (Energy, Environment, Economy) Partnership. The E3 program is an emerging collaborative model supporting American SMMs through the coordination of technical assistance at the local level with tools and training from the federal level. The E3 program is intended to align energy efficiency, pollution prevention and lean manufacturing concepts with enhancing manufacturing productivity, job creation and profitability. E3 has been successful in engaging multiple stakeholders at the federal level, spearheaded by the U.S. Environmental Protection Agency (EPA), the U.S. Department of Energy (DOE), and the U.S. Department of Commerce's National Institute of Standards and Technology (DOC-NIST), and garnering formal interest from the Small Business Administration (SBA) and the U.S. Department of Labor (DOL) (11).

As an outgrowth of the Green Suppliers Network, E3 was proposed to better coordinate the delivery of technical resources for manufacturers, aligning federal offerings from various agencies to be complimentary rather than competing. Over the course of two successful pilots—San Antonio, Texas and Columbus, Ohio—E3 has offered participating organizations a thorough technical assessment, implementation support for subsequent projects, and staff training related to continuous improvement. Technical assessments incorporated elements of lean and clean manufacturing, a comprehensive energy assessment and a baseline greenhouse gas inventory. All technical assessments were concluded with clear, concise recommendations to be evaluated by the client team. E3 has also successfully engaged local stakeholders including municipal governments, small business development centers and utilities to identify applicable rebate programs, tax incentives, loan guarantees and other financing opportunities including access to Energy Efficiency and Conservation Block Grants (EECBG). Combining the talents and relationships of local technical service providers with the resources, tools and trainings of federal agencies, the E3 model has shown exceptional promise in closing the gap between the identification of energy efficiency opportunities and implementation of energy efficient solutions.

San Antonio E3 Pilot Project. In San Antonio, the E3 pilot convened local and federal stakeholders in support of six manufacturing facilities: Southern Folger, Munters, Danbury (AirCool Motors), San Antonio Aerospace, UEMC and Pratt & Whitney. Facilities were invited to join the pilot based on a review conducted by the local utility, CPS Energy, of energy consumption habits by local industrial rate-payers. Technical assessments, each conducted over three to four days, were performed by technical experts from the Texas Manufacturing Assistance Center (TMAC), an affiliate of the Manufacturing Extension Partnership program. Technical experts relied on lean manufacturing auditing protocols provided largely through the existing MEP network in addition to the EPA's Green Suppliers Network. When evaluating energy consumption, technical specialists worked with DOE-developed system assessment software tools, including the Quick Plant Energy Profiler (Quick PEP), as is typically used in IAC energy assessments. Audits were conducted with participation from client teams to ensure an understanding of each subsequent recommendation as well as to provide training and experience with DOE assessment tools. Client participation is an important element of the technical assessment as it provides interactive training to plant managers throughout the assessment, but also helps to develop a clear picture of the comprehensive energy efficiency potential within the plant.

The role of CPS Energy as the local utility was also integral to the success of the San Antonio pilot. CPS has worked hard to expand its energy efficiency offerings to the industrial sector over the past half decade. CPS initially covered 50 percent of the cost associated with the technical assessment, with the balance to be paid by the client. After energy efficiency recommendations were developed in a detailed TMAC report, CPS chose recommendations that were considered high-impact and offered to cover the balance of the assessment cost pending the implementation of these selected projects. Additionally, clients were eligible for conventional rebates offered under CPS' commercial/industrial energy efficiency program. Having received an 'investment grade' out-briefing report, clients could also explore financing options with the local small business development center as well as local banks. Independent energy assessments can be a major step toward securing a line of credit for a prospective energy efficiency project as proposed improvements have been identified and endorsed by third-party energy experts. Banks and commercial lenders without in-house energy expertise often rely on third party specialists to validate energy projects when assessing the proposal for risk.

Further support was offered by City of San Antonio's Office of Environmental Policy, which helped to convene local stake holders and cultivate a relationship between CPS Energy and TMAC. Additional funding was also secured through the Texas State Energy Conservation Office (SECO) via an Energy Efficiency and Conservation Block Grant (EECBG) which will be used to conduct additional technical assessments at other local manufacturing facilities. Project participation from state and municipal government can enrich the collaborative process, foster relationships with government officials, leverage funding from various sources of capital and provide additional credibility through the eyes of commercial lenders.

As a testament to the effectiveness of the technical assessment, at the Southern Folger facility—a manufacturer of detention equipment—TMAC specialists identified energy efficiency opportunities totaling $85,000 annually. Specifically, energy efficiency recommendations yielded 159,000 kWh of electricity savings and 36,900 therms natural gas savings annually, in addition to a reduced monthly electric demand of 48 kW (11). Southern Folger has begun to implement selected energy efficiency recommendations.

Interagency Network of Enterprise Assistance Providers (INEAP). The INEAP initiative began in 2005 and was the product of a simple meeting between a representative of the Small Business Administration's (SBA) Small Business Develop Center (SBDC) program and a counterpart from the National Institute of Standards and Technology's (NIST) Manufacturing Extension Partnership (MEP) program. The meeting was intended to discuss the details and offerings of their respective initiatives and to identify programmatic overlaps. After a mutually beneficial meeting, it was decided that the two organizations would forge a partnership to promote effective federal support of small American enterprises and establish a collaborative framework whereby other relevant federal agencies could participate (5).

Today, INEAP is in its fifth year and boasts participation from over 40 federally funded assistance and extension programs under 12 federal departments (6). Meetings of member organizations are held once monthly to explore synergies and are conventionally centered on themes related to economic recovery, technology transfer assistance with a focus on energy efficiency and pollution prevention, business management assistance, export assistance, workforce training, finance assistance and disaster preparedness.

To date, INEAP activities have supported a number of efforts with direct implications on energy efficiency in SMMs. Specifically, INEAP was an inspiration to language featured in the Energy Independence and Security Act (EISA) of 2007 including a provision establishing the SBA 'Energy Efficiency Clean Technology Assistance Program' to be deployed through participating SBDCs. This program is intended to assist business owners with the development of clean energy technology through the vehicle of small private enterprises. Similarly, INEAP helped to encourage another EISA provision establishing a SBA "Energy Audit and Energy Efficiency Program" also deployed through participating SBDCs. INEAP has also fostered strong working relationships between select MEP centers and SBDCs. Currently INEAP is focused on revitalizing fiscal health and commerce in areas of economic distress. Energy efficiency and clean energy will be key elements in the revival of these target regions.

CONCLUSION

2010 marks a phase of rebuilding after two years of enduring a tumultuous economic climate. The U.S. economy has shed over 8 million jobs since May, 2008 (17), and small manufacturers—among other small enterprises—are in need of federal support now, perhaps more than ever. Simultaneously, federal agencies and extension programs are facing budget cuts and spending freezes in attempt to control government spending. These factors strengthen the case for federal coordination and collaboration, to stretch federal resources while providing robust and effective support to America's small manufacturers. Coupled with rising energy costs, the advancement of energy efficiency and equipment modernization represents a major opportunity with implications on job creation, manufacturing productivity, U.S. competitiveness, energy security and greenhouse gas emissions reductions. Energy efficiency among America's small manufacturers remains a common cornerstone in a collective federal agenda.

PRIMARY REFERENCES

A special thanks to those individuals who contributed their professional experience and expertise to help inform this study:

- Antonio Doss, U.S. Small Business Administration
- Bernie Linn, USDA Rural Development, Pennsylvania Office
- Bob Brennand, Grays Harbor Paper
- Carl Allsup, Texas Manufacturing Assistance Center (TMAC), Southwest Research Institute (SWRI)
- Dan Pitkin, U.S. Department of Commerce (DOC), National Institute of Standards and Technology (NIST)
- Jeff Pfeifer, MLP Steel
- Kristin Pierre, U.S. Environmental Protection Agency (EPA)
- Lou Dreher, Jergens, Inc.
- Raelyn Pearson, Washburn Iron Works
- Roger Price, Pennsylvania Technical Assistance Program (PennTAP), Pennsylvania State University
- Roland Mueller, Pacific Wood Preserving
- Sandy Glatt, U.S. Department of Energy (DOE)
- Scott Hutchins, U.S. Department of Energy (DOE)
- Sherrie Ford, Power Partners MasTec, LLC

SECONDARY REFERENCES

1) American Council for an Energy Efficiency Economy (ACEEE). 2009. "State Energy Efficiency Resource Standard (EERS) Activity; November, 2009." Retrieved January, 2010: http://www.swenergy.org/news/news/documents/file/ACEEE%20State%20EE%20Standards%20Summary%20Nov-2009.pdf.
2) American Council for an Energy-Efficient Economy (ACEEE). 2010. "DOE Releases FY2011 Budget Request." ACEEE Industrial Energy Efficiency Blog. Retrieved February, 2010: http://aceee.org/labels/Industrial%20Assessment%20Centers.html
3) Green Suppliers Network. 2010. "Green Suppliers Network; Network Highlights." Retrieved January, 2010: https://www.greensuppliers.gov/gsn/home.gsn.
4) Green Suppliers Network. 2010. "Green Suppliers Network; The Basics." Retrieved January, 2010: https://www.greensuppliers.gov/gsn/page.gsn?id=fq_basics.
5) Interagency Network of Enterprise Assistance Providers (INEAP). 2009. "INEAP; An Innovative Network of Federal Assistance Providers Serving U.S. Businesses; About INEAP." Retrieved February, 2010: https://www.ineap.nist.gov/ineap/page.ineap?id=about.
6) Interagency Network of Enterprise Assistance Providers (INEAP). 2009. "INEAP; An Innovative Network of Federal Assistance Providers Serving U.S. Businesses; Program Profiles." Retrieved February, 2010: https://www.ineap.nist.gov/ineap/resources.ineap?type=pp.
7) Muller, Michael R. 2008. "Critical Workforce Needs in Energy." Rutgers University. Presented to U.S. Senate Task Force on Manufacturing. Retrieved January, 2010: http://www.aceee.org/industry/iac.htm

8) National Institute of Standards and Technology. 2010. "Manufacturing Extension Partnership; About MEP." Retrieved January, 2010: http://www.mep.nist.gov/about-mep/index.htm.
9) National Institute of Standards and Technology. 2010. "Manufacturing Extension Partnership; Partners; Federal Agencies." Retrieved January, 2010: http://www.mep.nist.gov/partners/federal-agencies.htm.
10) Payne, Christopher T. 2006. "Energy Consumption Behavior in the Commercial Sector: An Ethnographic Analysis of Utility Bill Information and Customer Comprehension in the Workplace." University of Delaware. Pg 120.
11) Pierre, Kristin, et al. 2009. "Supporting Manufacturing Leadership Through Sustainability; E3: Economy, Energy and Environment." E3 Partnership. Retrieved December, 2009: http://www.epa.gov/greensuppliers/e3.html.
12) Reeder, Frank, et al. 2003. "The National Institute of Standards and Technology's Manufacturing Extension Partnership Program; Report 1 Re-examining the Core Premise of the MEP Program." National Academy of Public Administration. Pgs 8-10. Retrieved December, 2009: http://www.napawash.org/Pubs/NIST0903.pdf.
13) Reynnells, Lousie. 2008. "USDA; What is Rural?" USDA National Agriculture Library. Retrieved December, 2009: http://www.nal.usda.gov/ric/ricpubs/what_is_rural.shtml.
14) Small Business Development Center National Information Clearinghouse. 2009. "SBA Goes Green with Loans for Small Businesses." University of Texas—San Antonio. Retrieved January, 2010: http://sbdcnet.org/sbdcs-in-the-news/sba-goes-green-with-loans-for-small-businesses.php.
15) StratEdge, Inc. 2008. "Offshoring and U.S. Small Manufacturers.; An Office of Advocacy Working Paper." U.S. Office of Advocacy. Retrieved December, 2009: http://www.sba.gov/advo/research/rs336tot.pdf.
16) The Manufacturing Institute. 2009. "The Facts About Modern Manufacturing. 8th Edition." National Association of Manufacturers (NAM). Pgs 3-20.
17) U. S. Bureau of Labor Statistics (BLS). 2010. "Current Employment Statistics Highlights January 2010." Bureau of Labor Statistics. Retrieved February, 2010: http://www.bls.gov/web/ceshighlights.pdf.
18) U.S Department of Agriculture (USDA). 2009. "Rural Business Enterprise Grant Program Applications." USDA Rural Business-Cooperative Service (RBS). Catalog of Federal Domestic Assistance Number: 10.783. Retrieved December, 2009: www.rurdev.usda.gov/rbs/RBEG%20Notice.doc.
19) U.S. Department of Agriculture (USDA). 2009. "Business and Industry Guaranteed Loans (B&I)." USDA Rural Development Program. Retrieved December, 2009: http://www.rurdev.usda.gov/rbs/busp/b&i_gar.htm.
20) U.S. Department of Agriculture (USDA). 2009. "Rural Energy for America Program Guaranteed Loan Program (REAP Loan)." USDA Rural Development Program. Retrieved December, 2009: http://www.rurdev.usda.gov/rbs/busp/9006loan.htm.
21) U.S. Department of Agriculture (USDA). 2009. "USDA Rural Business Enterprise Grants (RBEG) Program." USDA Rural Development Program. Retrieved December, 2009: http://www.rurdev.usda.gov/rbs/busp/rbeg.htm.
22) U.S. Department of Agriculture (USDA). 2009. "USDA Rural Development; About Out Programs." Rural Development Program. Retrieved December, 2009: http://www.rurdev.usda.gov/rd/aboutrd.html.
23) U.S. Department of Commerce (DOC). 2007. "Making a Difference for America's Manufacturers." National Institute of Standards and Technology (NIST) Manufacturing Extension Partnership (MEP). Retrieved December, 2009: http://www.mep.nist.gov/impacts/making-a-difference.pdf.
24) U.S. Department of Energy (DOE). 2007. "Industrial Assessment Centers Database." Industrial Technologies Program. Retrieved January, 2010: http://iac.rutgers.edu/database/.
25) U.S. Department of Energy (DOE). 2007. "Industrial Technologies Program; Best Practices; Industrial Assessment Centers (IACs)." Retrieved January, 2010: http://www1.eere.energy.gov/industry/bestpractices/iacs.html
26) U.S. Department of Energy (DOE). 2009. "Financial Assistance Funding Opportunity Announcement (FOA); State Energy Program Formula Grants; American Recovery and Reinvesment Act (ARRA)." National Energy Technology Laboratory. FON: DE-FOA-0000052. Retrieved February, 2010: http://apps1.eere.energy.gov/wip/pdfs/sep_arra_foa.pdf.
27) U.S. Department of Energy (DOE). 2009. "Superior Energy Performance Program Plan." Industrial Technologies Program.
28) U.S. Department of Energy (DOE). 2010. "Energy Efficiency and Conservation Block Grant Program; About the Program." Office of Energy Efficiency and Renewable Energy. Retrieved January, 2010: http://www.eecbg.energy.gov/about/default.html
29) U.S. Department of Energy (DOE). 2010. "Guide for Save Energy Now LEADER Companies; Taking a Bold Pledge to Reduce the Nation's Energy Carbon Footprint." Industrial Technologies Program.

30) U.S. Department of Labor (DOL). 2009. "DOL Information Related to the American Recovery and Reinvestment Act (ARRA) of 2009." Retrieved February, 2010: http://www.dol.gov/recovery/implement.htm.
31) U.S. Department of Labor (DOL). 2010. "State Energy Sector Partnership Grants Video & Audio." Retrieved February, 2010: http://www.dol.gov/dol/media/webcast/grants3.htm.
32) U.S. Small Business Administration (SBA). 2010. "CDC/504 Loan Program." Small Business Administration Program Office. Retrieved January, 2010: http://www.sba.gov/financialassistance/borrowers/guaranteed/CDC504lp/index.html.
33) U.S. Small Business Administration (SBA). 2010. "Program Announcement; Small Business Energy Efficiency Clean Technology Assistance Program [Formerly Small Business Sustainability Initiative (SBSI)]" Office of Small Business Development Centers. Program Announcement OSBDC-2010-05. Retrieved February, 2010: http://www.sba.gov/idc/groups/public/documents/sba_program_office/2010_energ_eff_clean_tech_prog.pdf.
34) U.S. Small Business Administration (SBA). 2010. "Program Announcement; Small Business Energy Audit and Energy Efficiency Program [Formerly Small Business Sustainability Initiative (SBSI)]." Office of Small Business Development Centers. Program Announcement OSBDC-2010-06. Retrieved February, 2010: http://www.sba.gov/idc/groups/public/documents/sba_program_office/final_energy_audit_effi_assist.pdf.
35) U.S. Small Business Administration (SBA). 2010. "The Office of Small Business Development Centers; About Us." US SBA Office of Small Business Development Centers. Retrieved January, 2010: http://www.sba.gov/aboutsba/sbaprograms/sbdc/aboutus/index.html.
36) World Bank. 2009. "Gross Domestic Product 2008." Retrieved February, 2010: http://siteresources.worldbank.org/DATASTATISTICS/Resources/GDP.pdf.