Energy Data Modeling and Analysis for Improved Energy Management Planning and Performance

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ABSTRACT

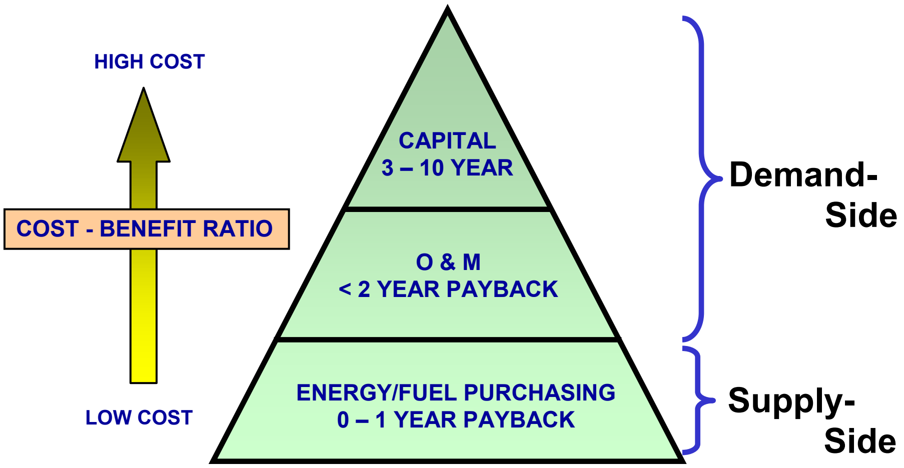
Organizations that adopt the American National Standards Institute's Management System for Energy, ANSI/MSE 2000 the national management standard for energy, are required to develop an energy profile and conduct regular energy assessments of facilities, systems and equipment. The energy profile includes utility tracking, identification of significant energy uses, and development of key performance indicators (i.e. normalization). In addition, the standard necessitates that a means of connecting energy usage to facility operating levels and types of operation (i.e. modeling) be developed as appropriate. The purpose of the energy profile is to reveal trends, anomalies, price signals, and energy and cost allocations that can provide insight into the impact of energy on the cost of operations. A case study in a clay processing plant is presented showing how proper data normalization, modeling, and analysis of energy information combined with an energy assessment will lead to strategic, systematic management of energy and continual improvement instead of a series of random point solutions. The lessons learned in this facility can be successfully applied to other energy intensive process operations.

Introduction

As energy costs rise, increased emphasis is placed upon managers to control energy operating costs. Effectively managing energy costs requires organizations to have an intimate understanding of the factors influencing energy use and cost. Unfortunately, most organizations grasp of energy is limited to charting the monthly expenses and developing an annual budget. As more facilities elect to proactively manage energy, detailed analysis and modeling of energy usage will be required to formulate an effective energy management strategy. This is especially true if an organization wants to optimize their energy management efforts to achieve the lowest cost to benefit ratio for this continuous improvement effort. At Georgia Tech's Economic Development Institute, the priority pyramid in Figure 1 illustrates an attitude to energy management that is built into the ANSI/MSE 2000 standard. (Brown, 2000) By first looking for opportunities to optimize the supply-side with current operations and maintenance practices, energy management costs can be minimized while still making significant reductions. Capital projects can lead to substantial energy reductions but sometimes entail lengthier payback periods. ANSI/MSE 2000 has been successfully applied in energy intensive manufacturing operations and other, non-energy intensive organizations that want to actively control their environmental impacts from energy use.

The process of energy data management starts on the facility level with utility and production data and drills down through the process or system level to individual equipment where energy usage is disaggregated to yield an energy balance. The objective of energy data management is to create an accurate picture of energy utilization and costs on the facility level and then break this down to the end use so that an accurate representation of system efficiency can be determined. Only when this information is developed can realistic goals and targets be developed as prescribed in ANSI/MSE 2000.

FIGURE 1



Move up the opportunity hierarchy

Case Study

An energy assessment was conducted at a large clay processing plant as part of formulating a strategic energy plan. This manufacturing process involves several energy intensive steps to produce clay of the proper purity, particle size and moisture content. Energy usage was analyzed at the facility using a utility tracking and modeling software package. The steps involved in preparing the analysis to be used as the basis of their strategic plan are discussed below.

Tracking of Utility Data

With the advent of electronic utility meters and the reduced cost of sub metering, more and more energy and production data is available to industry. In many cases, these data can be overwhelming and are typically not utilized to strategic advantage. At a macro level, utility data must be tracked, analyzed, and normalized to reveal trends, anomalies, and performance of the manufacturing enterprise. The data and information to be collected should be time series data and include an analysis of component costs for each account (energy, demand, fuel cost, transportation, penalties, and sales tax), rate schedules, production, and financial information. Graphical presentation of utility data is required and should be presented in as many useful ways as possible. Table 1, below, summarizes the annual utility expenses for this clay processing operation which includes three facilities: mining, main processing, and calcining.

A graphical representation comparing the total energy usage and costs at all three facilities for multiyear data is shown in FIGURE 2. Both Table 1 and FIGURE 2 reveal important information that leads an energy manager toward further investigation. This information is summarized below in Table 2 as “red flags” from which information on potential energy saving opportunities can be gleaned.

FIGURE 3 shows a sample graph available in the Energy Profiler^{GT} utility tracking software. Graphs that reveal various characteristics about a utility account can be generated, but the selected graph compares the facility monthly energy expenses over a 2 year period. The 2003 data are represented by the blue line and 2004 by a red line. Obviously, seasonal variations and some anomalies exist. These "red flags" were explained due to changes in production levels and ambient weather conditions.

Table 1: Energy Summary, 2004

	Electricity				Fossil Fuel		
Facility	Annual Use (kWh)	Annual Cost	Unit Cost ($/kWh)		Annual Use (MMBtu)	Annual Cost	Unit Cost ($/MMBtu)
			$/kWh	$/MMBtu			
Main(1)	70,750,000	$2,555,000	$0.0361	$10.58	1,324,500	$9,393,500	$7.092
Mine(2)	44,221,874	$1,656,300	$0.0375	$10.99	19,829	$122,600	$6.183
Calcine(3)	14,206,600	$538,800	$0.0379	$11.11	211,640	$1,514,300	$7.155
TOTALS	129,178,474	$4,750,100			1,555,969	$11,030,400	

NOTES: (1) Main facility: 1 large electricity account (RTPHA - Georgia Power)
1 small electricity account (block rate - co-op)
1 large natural gas account (firm and interruptible, transportation)
Minor fuel uses - #2 fuel oil (back up), gasoline (vehicle)
(2) Mine: 1large electricity account (RTPHAAL – Georgia Power)
9 small electricity accounts (block rate - co-op)
1 large natural gas account (interruptible – muni)
Minor fuel uses - #2 fuel oil (back up), gasoline (vehicle)
(3) Calcine: 1 large electricity account (FPA – Georgia Power)
5 small electricity accounts (block rate – muni)
1 large natural gas account (interruptible – transportation)
Minor fuel uses – propane (backup)

Table 2: Information Revealed from Red Flags in Energy Summary Table

Red Flag	Information
Large energy costs	**Energy costs of interest to management**
Fossil fuel consumption is large	➢ **Typically means greater savings potential** ➢ **CHP opportunities may be possible**
Unit electricity costs are low	**Constrains electricity opportunities**
Fuel cost spread is narrow	**Constrains fuel switching opportunities**
Main processing facility consumes > 75% of total energy cost	**Focus on systems & equipment at main facility**
Fuel costs significantly lower at one facility	**Supply advantages at mine need to be investigated**
Sophisticated electricity rates	➢ **Investigate rate optimization** ➢ **Interval data needs to be investigated** ➢ **Supply-side sophistication in organization**
Multiple meters	**Investigate meter account aggregation**
Firm natural gas accounts	**Investigate lowering firm costs with interruptible purchase**
Multiple fossil fuel use	**Investigate fuel switching**

FIGURE 2: ENERGY USAGE AND UNIT COST COMPARISON OF MINING OPERATION FACILITIES

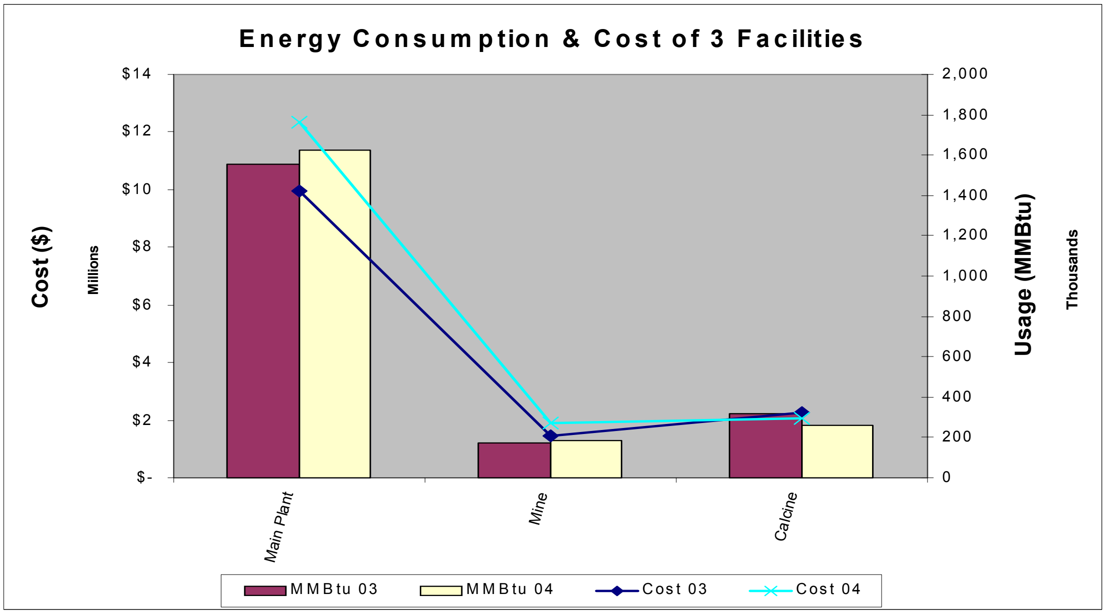
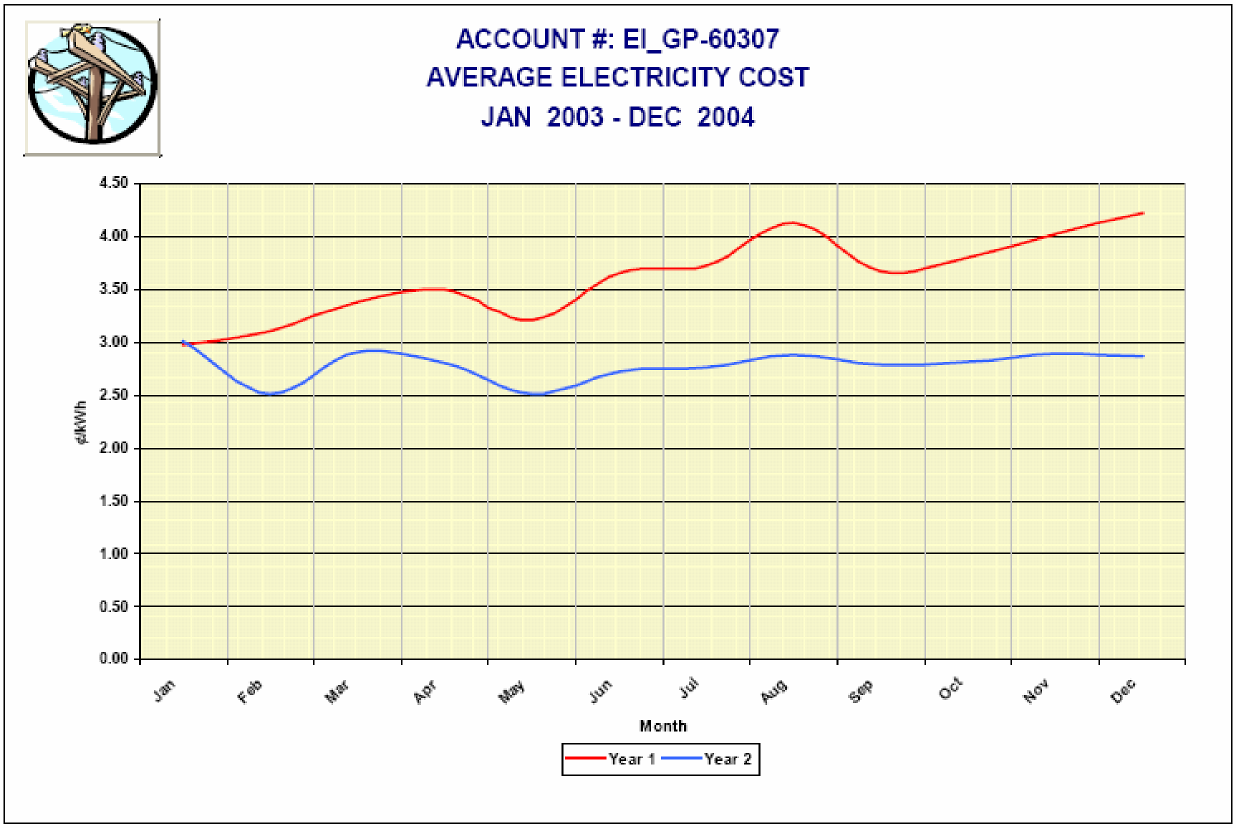


FIGURE 3: GRAPH OF UTILITY ACCOUNT INFORMATION FOR MAIN PLANT



Key Performance Indicators

While accurate understanding of utility data is crucial for effective energy management, the next step where energy and organizational output are tied together to form key performance indicators (KPI) is equally important. Properly defined, a KPI can be used to provide insight into operational efficiency as well as show the impact of reduced energy usage on organizational value and competitiveness.(Mahoney, 2002) KPIs normalize energy data to provide a tool that allows valuable comparisons over time despite production and operational variations.

The KPI used will vary depending on the business sector (i.e. commercial, industrial or institutional) and metrics commonly used by the organization. A KPI to describe efficiency is usually based on input divided by output, for example Btu/widget in an industrial plant and Btu/square foot for a commercial or institutional site. Since efficiency is actually calculated from output over input, this KPI is actually the inverse of efficiency, but it effectively conveys a beginning measure for efficiency improvement. The desired goal is to reduce the Btu/unit measure to the lowest value possible. For a manufacturing enterprise, several KPIs may be needed if multiple products with significant process differences are produced.

FIGURE 4 shows graphs of the monthly KPI during 2003 for the entire facility with calcining (4a) and without calcining (4b). On the same graph is a line for total energy use for each month. The indicator selected for this operation is energy use per unit output presented in millions of Btu per ton produced. Comparing the lines for monthly energy use and KPI in MMBtu/ton helps to verify the chosen KPI as a good normalization tool. Without conducting a statistical analysis, the correlation appears to be very good. However, the KPI can be improved by considering process dynamics. The vast majority of clay slurry is dried till it is 99.5% solid. A small fraction of this “bone-dry” product is then put in a calciner that uses a significant amount of fossil fuel energy to heat the clay and change the molecular structure. If the energy used in calcining is removed from the total energy usage and the KPI recalculated as presented in FIGURE 4b, similar results are found.

The KPI correlation without calcining appears better than that for the entire facility except for a couple of months; January, and November when calcining production was abnormally low. This observation does have a logical explanation in that manufacturing processes are optimized for a set output and when they operate below this level serious inefficiencies develop because some input is required just to idle the process even when no useful product is generated. This observation should lead to further investigation to understand why the process is less efficient at lower production levels and hopefully improved efficiencies at off-production levels.

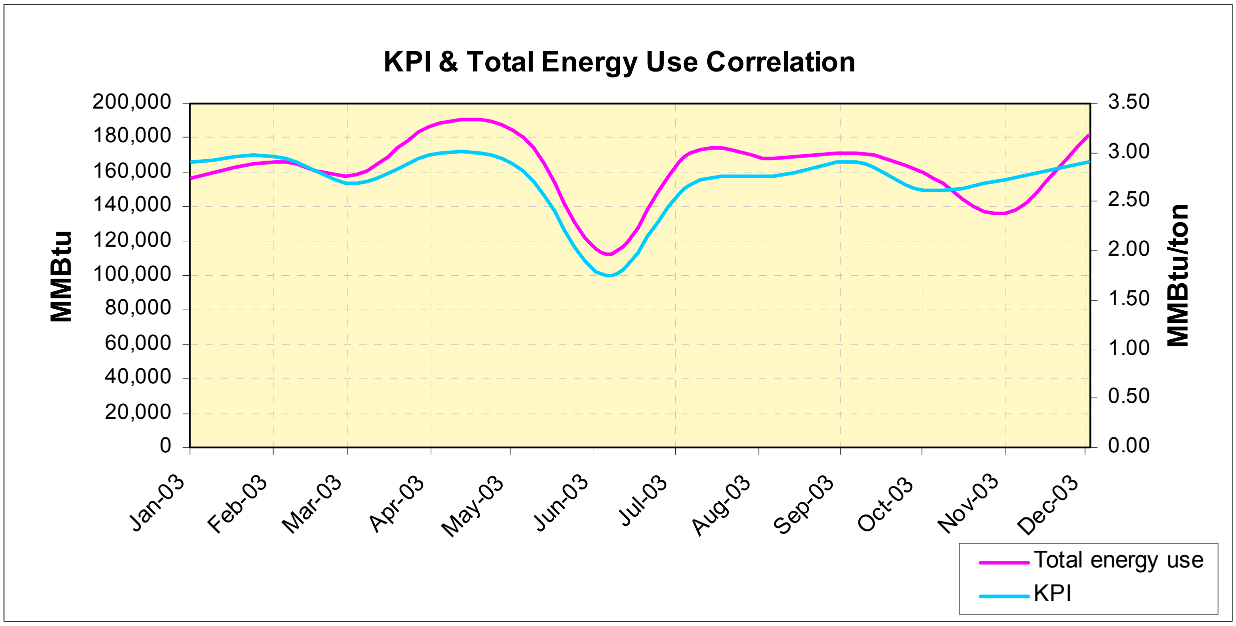
The KPI graph also shows significant variation in 2003. In June, unusual process efficiencies were achieved. Upon further investigation, it was determined that production levels were the highest of the year and the spray dryers, the largest on-site energy users, burned #2 fuel oil for the majority of the month. The spray dryers did achieve increased efficiencies by burning #2, but this is not a viable fuel option for the entire year because of emission restrictions.

Another useful KPI is the cost per unit of output. The Btu/unit of output indicator can give a false idea of process economy if the efficiency is high, causing Btu/widget to be low, but the unit energy cost is high. This translates into an efficient operation that is too costly to operate. By examining both the energy and cost KPI, both efficiency and economy can be optimized.

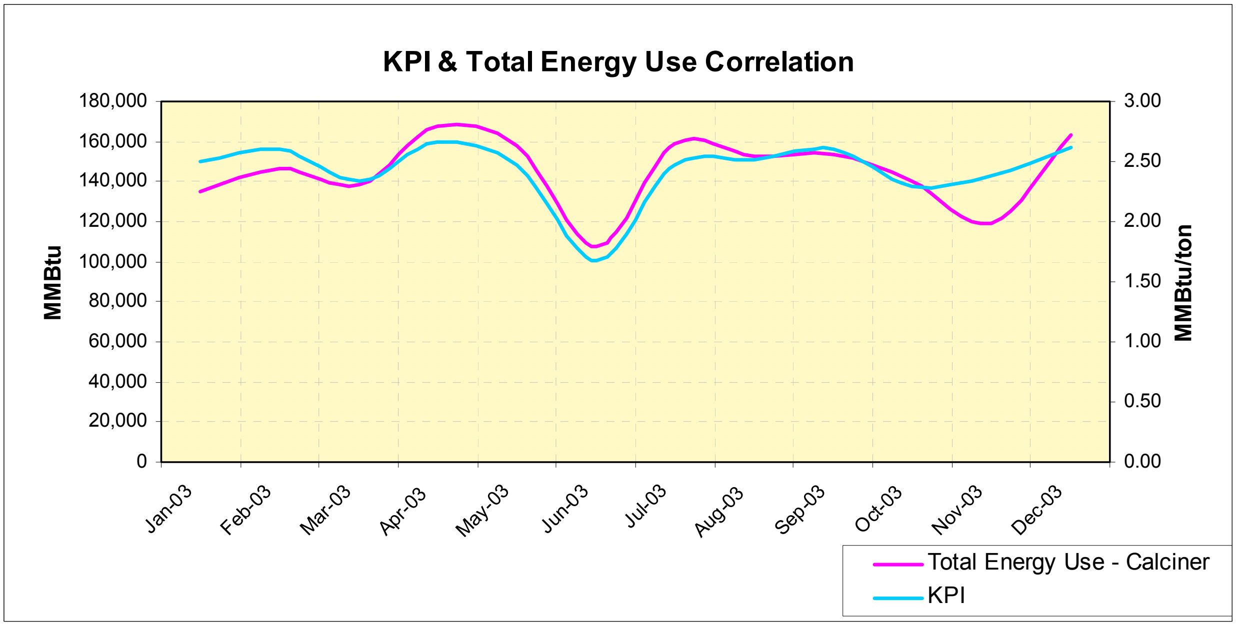
Calculation of two separate KPIs to measure energy and cost efficiency can be achieved by combining the measures together in a single indicator. For example if we calculate the energy cost per dollar of added value, the energy cost and production efficiency, as measured in dollar value added, are both included. For example, the calculated energy cost for December, 2004 is \$22/ton. If the raw material is purchased for \$20/ton and sold for \$100/ton, the value added is \$80/ton. The energy cost per dollar of added value is \$22/\$80 or 0.275.

FIGURE 4: CORRELATION BETWEEN KPI AND TOTAL ENERGY USE

4a. with Calcining



4b: without Calcining



Energy Balance

A process model and resulting energy balance are used to segregate energy by end use process.(ANSI, 2000) While utility tracking and KPIs provide insight into overall energy efficiency and cost at a facility, a strategic approach to energy saving opportunities can not proceed without knowing where the bundle of energy that enters the facility fence line eventually ends up. Targeting systems and setting goals for energy reduction can not be done effectively without these tools.

The process map is a basic tool which provides an overall picture of the inputs and outputs to the manufacturing process and ties energy use to material flows and production activity. It also identifies the systems and equipment that are the largest energy users and require the most attention, both for efficiency improvements and operational controls. The process mapping also provides insight into how energy input and efficiency varies with manufacturing output. The process map will incorporate both energy and material balance information and include all process support systems and secondary utilities.

In FIGURE 5, the energy balance generated from the process model is shown for the main processing facility. The bar chart segregates energy use according to the main process steps: spray drying, vacuum filtration, steam system, make down, polyglos, magnetic separation, and pumping. Drying of the clay slurry is by far the most energy intensive part of the process, requiring over 90% of the energy usage. Drying requires several steps: vacuum filtration, evaporation (which consumes all of the steam), and spray drying. Therefore, drying systems are a priority target and require further investigation. Thus, the energy balance was effective in directing the focus of the assessment efforts to the most costly operation.

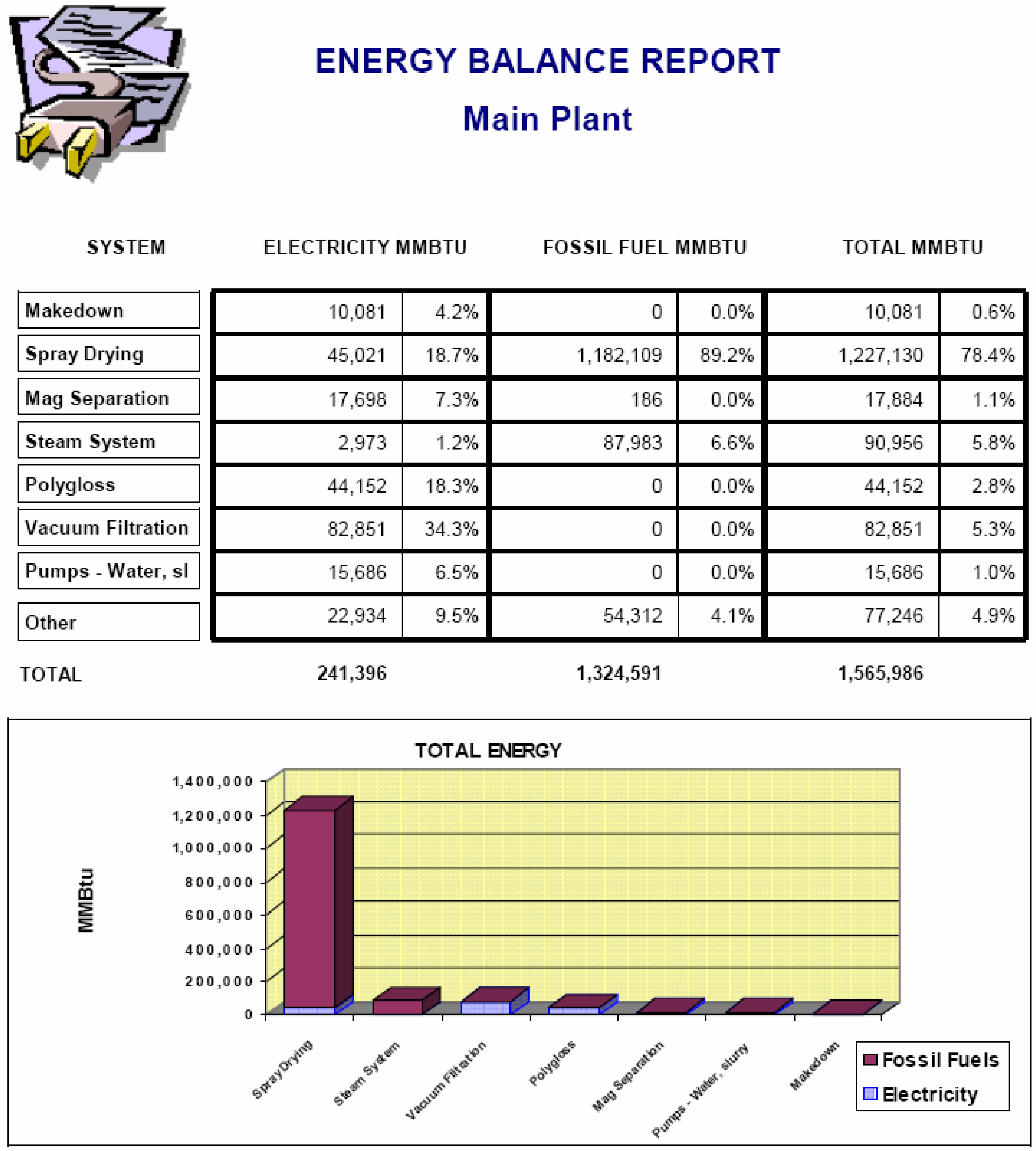
Use of benchmarks to evaluate process steps and systems is another useful tool. For the drying processes, the current drying efficiencies were calculated and benchmarked. FIGURE 6 shows the energy use per lb of water evaporated and the benchmark associated with that drying process. If the drying processes could be optimized by increasing the amount of water removed mechanically, over 20% energy savings could be achieved. Thus, the magnitude of the energy savings achievable at the plant is known and can help to shape an overall savings goal for the plant.

Energy Assessment

Using the utility information, equipment list, energy balance and analysis of plant data conducted, an accurate picture of energy cost and flows was developed for the facility. Using this information, the assessment team was ready to assemble a comprehensive list of energy saving opportunities (ESOs). Prioritization of ESOs and development of an implementation plan is a major element of the overall energy management plan at the facility.

When identifying ESOs for a facility, a strategic energy plan demands a structured approach. Instead of concentrating on the easiest, most obvious improvements such as more efficient lighting, a strategic plan requires paying attention to the largest users. In the ANSI/MSE 2000 management system standard, these items are referred to as “significant uses.”(ANSI, 2000) Significant uses at the clay processing operation include spray drying, vacuum filtration, evaporation, compressed air for particle sizing, and pumping water and magnetic separation.

FIGURE 5: MAIN PLANT ENERGY BALANCE



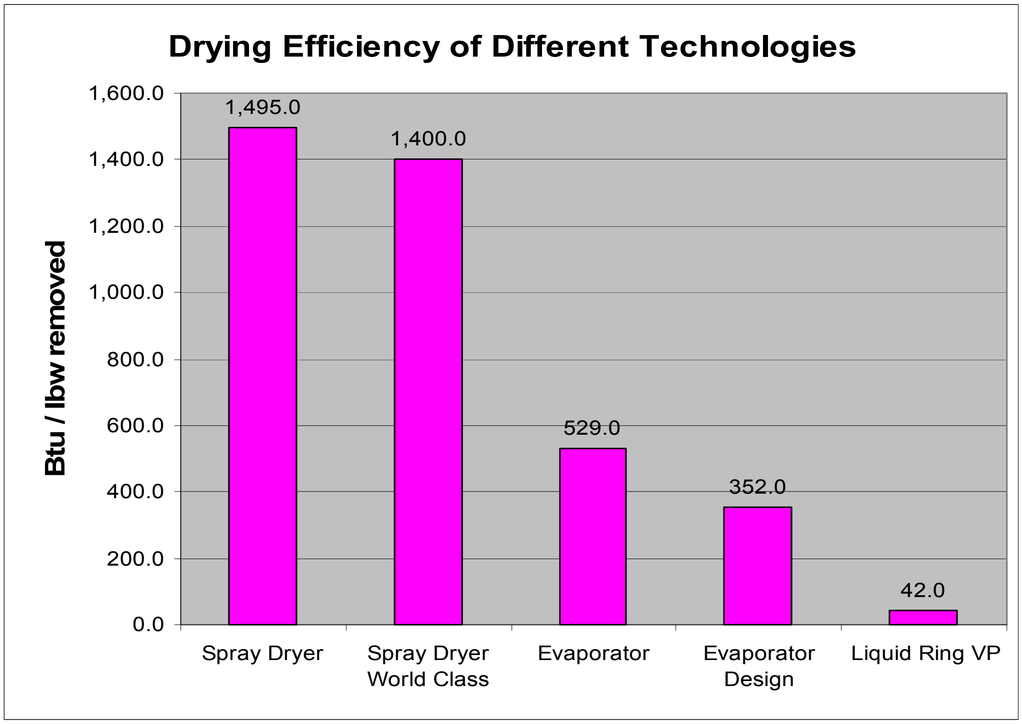
ENERGY BALANCE REPORT

Main Plant

SYSTEM	ELECTRICITY MMBTU		FOSSIL FUEL MMBTU		TOTAL MMBTU	
Makedown	10,081	4.2%	0	0.0%	10,081	0.6%
Spray Drying	45,021	18.7%	1,182,109	89.2%	1,227,130	78.4%
Mag Separation	17,698	7.3%	186	0.0%	17,884	1.1%
Steam System	2,973	1.2%	87,983	6.6%	90,956	5.8%
Polygloss	44,152	18.3%	0	0.0%	44,152	2.8%
Vacuum Filtration	82,851	34.3%	0	0.0%	82,851	5.3%
Pumps - Water, sl	15,686	6.5%	0	0.0%	15,686	1.0%
Other	22,934	9.5%	54,312	4.1%	77,246	4.9%
TOTAL	241,396		1,324,591		1,565,986	

The strategy followed in identifying potential opportunities once the significant uses are known is based on the priority pyramid identified in FIGURE 1.(Brown, 2000) Start by looking for improved energy purchasing opportunities. Purchasing measures usually have good cost saving potential with no capital expenditures and low risk even though no energy is saved. Next examining existing equipment, look for savings opportunities from improved equipment maintenance or operating procedures. Operation and maintenance (O&M) measures also have low risk and yield some energy and cost savings. Lastly, after the first two types of opportunities have been exhausted, begin to look for equipment replacement, retrofit and upgrade opportunities. This type of measure will involve significant capital expense, and thus incur some amount of project risk even though the potential savings may be large.

FIGURE 6: ENERGY EFFICIENCY OF DIFFERENT DRYING TECHNOLOGIES



Energy Saving Opportunities

During the energy data analysis and site assessment, a total of 23 red flags with associated saving opportunities were identified. The total included eight purchasing, nine operation and maintenance, and six capital measures. Plant energy savings included in the opportunity list were motor drives, compressed air, and product drying. The search for red flags and opportunities considered all of the significant energy use areas identified during the data analysis, thermal drying, vacuum filtration, evaporation, compressed air, and motor drives.

The first list of opportunities is purchasing, Table 3. At a plant that consumed over $16 million of energy in 2004, one might find some cost saving potential through improved purchasing practices. Small savings were found on the electrical side, but the big savings are on the natural gas side. Opportunities include eliminating firm gas usage and nomination penalties, greater utilization of existing cogeneration system and by-passing the municipal gas distribution company. Identification of potential energy purchasing measures is partially revealed during the utility data modeling and analysis. Items such as nomination penalties, LDC charges, firm gas premiums and electrical demand costs are determined during this process. The estimated cost savings from purchasing improvements is $1,332,400.

Table 4 was prepared to present the nine O&M measures identified. Although the savings from changes in operating or maintenance procedures is usually small, the risk associated with their implementation is limited. Of the O&M measures identified, a total of six are maintenance and three are operational. Only four of the measures have estimated savings that exceed $46,000. The number of O&M opportunities associated with each affected energy system is: 3 motor drive, 3 drying, 2 compressed air and 1 steam system. The largest measure, addition of flocculent to vacuum filtration feed to increase moisture removal rate, involves an additive that has experimentally been shown to enhance the removal of moisture during filtration. The savings are large because if water is removed by filtration mechanically, the thermal energy required for evaporation is eliminated. The estimated energy cost savings from improved plant operation and maintenance $1,921,000.

Finally, Table 5 presents the six opportunities identified requiring a significant capital expenditure. As was the case with O&M measures, most of the savings involves changes to the drying operation. The drying process consumes the greatest amount of energy and offers the greatest prospect for savings. The expected savings from capital measures is $3,066,000. The energy savings identified for the facility are not additive because several of the ESOs are dependent. For example, the savings attributed to membrane separation is partially captured by the O&M opportunity of flocculent addition. If both flocculent addition and membrane filtration are implemented, the savings from membrane filtration will be reduced by approximately half.

Table 3: Red Flags and Possible Opportunities-Purchasing

No.	Red Flag Description	Possible Opportunities	Category	Potential Savings (est.)		Simple Payback (est.)	System
				electric	NG		
1	Multiple electric meters (16)	Aggregate Accounts: Install Master Meter / Rewire accounts / Utility agree to combine accounts	Purchasing	$4,400		1-2 years	purchasing
2	Electric accounts with 0 kWh	Investigate accounts & eliminate ones no longer needed	Purchasing	$2,000		<1 year	purchasing
3	High CBL-Mine	Lower CBL on Mine Account	Purchasing	$71,000		0.1 years	purchasing
4	High LDC gas cost	By-pass LDC with direct connection to Interstate pipeline	Purchasing		$650,000	2 years	purchasing
5	Natural Gas Penalties	Improve gas nominating process	Purchasing		$9,000	0.1 years	purchasing
6	Underutilized CHP	Increase CHP utilization	Purchasing	$100,000		Requires improved turb. maintenance	purchasing
7	Firm Gas Usage	Fully interruptible at Main Plant; Adjust #3 spray dryer to burn oil	purchasing		$410,000	3 mos. But could exceed 1 year if larger oil tank needed	purchasing
8	Firm Gas Usage	Lower firm gas amount to just supply SD #3	purchasing		$86,000	0.1 years	purchasing

Table 4: Red Flags and Possible O&M Opportunities

No.	Red Flag Description	Possible Opportunities	Category	Potential Savings (est.)		Simple Payback (est.)	System
				electric	NG		
9	Standard V-belts on motor drives	Cogged V-belts or HTD belts	O&M	$24,000		1 year	motor drives
10	Standard Petroleum-Based Lubrication	Use Synthetic Lubrication on Gear Drives	O&M	$4,000		< 1 year	motor drives
11	Audible Air Leaks	Survey, tag and repair air leaks- adjust compressor controls to respond to reduced demand	O&M	$30,000		0.5 year	Compressed Air
12	High set-point for air pressure	Reduce compressed air pressure- this needs to be approached carefully	O&M	$30,000		Immediate	Compressed Air
13	Low solids on Vacuum Filter Discharge	Add flocculent to vacuum filter slip	O&M		$1,600,000	No investment but incr. operating cost	Drying
14	Loose Control of Burner Excess Air	Install oxygen trim on boilers and calciner	O&M		$64,000	1 year	steam system
15	Low Vacuum in #2 Spray Dryer	Fix leaks in #2 Spray Dryer	O&M		$113,000	0.5 years	Drying
16	Outlet Dampers on Fans (e.g. Calcine Pt.)	Downsize Motors/Install adjustable sheaves	O&M	$46,000		< 1 year	Motor Drives
19	High steam use for evaporator	clean plate & frame HX	O&M		$10,000	> 1 year	Drying

Table 5: Red Flags and Possible Capital Opportunities

No.	Red Flag Description	Possible Opportunities	Category	Potential Savings (est.)		Simple Payback (est.)	System
				electric	NG		
17	Outlet Dampers on Fans (e.g. Calcine Pt.)	Replace with ASD (Adjustable Speed Drive) Motor	capital	$46,000		2-3 years	Motor Drives
18	Standard pressure-switch control on multiple air compressors	Add automatic sequencer on compressors	capital	$30,000		2 years	Compressed Air
20	Moisture removal by Evaporation in Spray Dryers	Investigate membrane separation to increase moisture removal prior to drying	capital		$3,200,000	4 years	Drying
21	Moisture removal by Evaporation in Spray Dryers	Use additional evaporators to remove water from product before spray drying	capital		$1,200,000	1-2 years	Drying
22	High Compressed Air Usage in Baghouses (typically also involves repairs)	Add metered air storage tanks for shakers	capital	$25,000		1-2 years	Compressed Air
23	Motor Purchasing Policy Encourages Rewinding	Track motor rewinds and limit to 1/motor	capital	$165,000		4-5 years	Motor Drives

Results

A Georgia clay processing facility has investigated the benefits of developing a strategic energy plan and using extensive energy data modeling and analysis to guide energy management efforts. Using the Energy Profiler^{GT} software program to assist with data management, modeling and analysis proved an invaluable asset to improved energy management at the facility. Relying on established procedures to help in the data analysis and identification of potential energy saving opportunities allowed the organization to discover more than $5 million of potential energy cost savings. This represents over 30% of the facility's energy cost. The plant is currently prioritizing the opportunities identified, and the corporate engineering staff is instituting a companywide strategic energy plan. As might be expected, the low-cost purchasing and O&M opportunities are being pursued at first. Energy procurement is a corporate function and is being managed from headquarters. The company is in the process of or has implemented the following ESOs:

- Eliminate zero usage electricity accounts,
- Procure more interruptible natural gas supply,
- By-pass LDC,
- Install cogged v-belts,
- Utilize synthetic lubricants,
- Survey, tag, and fix air leaks,
- Add flocculent to slurry before vacuum filtration.

Drying remains a high priority for investigation. Plant personnel have sub-metered the spray dryers, the boiler, and the vacuum filters with the hope of identifying trends, catching inefficiencies, and developing tighter operational controls. Advances in drying technology are of interest to top management and will be investigated further in the near future.

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