Project Process Mapping: Evaluation, Selection, Implementation, and Assessment of Energy Cost Reduction Opportunities in Manufacturing

By

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B.S. Mechanical Engineering, MIT, 2006

Submitted to the MIT Sloan School of Management and the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the Degrees of

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Abstract

Company X uses large amounts of electricity in its manufacturing operations. Electricity prices at selected plants in the company's Region 1 territory rose by over 350% between 2000 and 2011, in part due to increasing reliance on high-cost fossil fuels. A focus on reducing these costs has identified numerous energy-saving projects in recent years, but with mixed implementation and performance results between the different plants in the region. Consequently, there is both a need to reduce exposure to high electricity prices and an opportunity to better share best-use practices between plants. This paper has two focuses: identifying and quantifying energy cost-reduction opportunities, and mapping the value-streams for the decision-making and implementation process for energy savings projects. From this Value Stream Map, recommendations are made for a new process that can be standardized and rolled out to other sites in the region.

During the first phase of the project, data gathered from utility bills, power meters, and production records are used to identify the best opportunities for energy reduction within the plants. Using this technique, 7 GWh/year of potential energy cost savings are identified via reduced downtime, lighting motion detectors, high-efficiency lighting, and negotiable changes to energy contracts. For the benchmarking phase, the historical record of identified energy projects is compared with the number of projects actually implemented. An observational study of the local LEAN team from one plant is combined with interviews of engineers, managers, and financial analysts to build a process map of both the current and former processes for energy project identification, evaluation, and implementation. The results show a reduction in process steps and a step-change increase in the number of energy projects implemented. A key feature of the new approach is the creation of a dedicated energy team within the existing LEAN program. It is believed that emulating this integration of energy and LEAN at other sites will yield cost reductions as well. To follow up this work, a pilot study modeling this program at another site is recommended before further expansion to the rest of the region.

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1 Introduction

According to a 2009 report from the Aberdeen Group, many business leaders say that sustainability initiatives are a 'must-have' business imperative for companies [1], and energy price trends show why: from 1988-1999, energy prices were relatively stable with a slight decrease in cost over the decade. From 2000-2010, however, energy prices (with the exception of natural gas) increased by 50-150% and were highly variable:

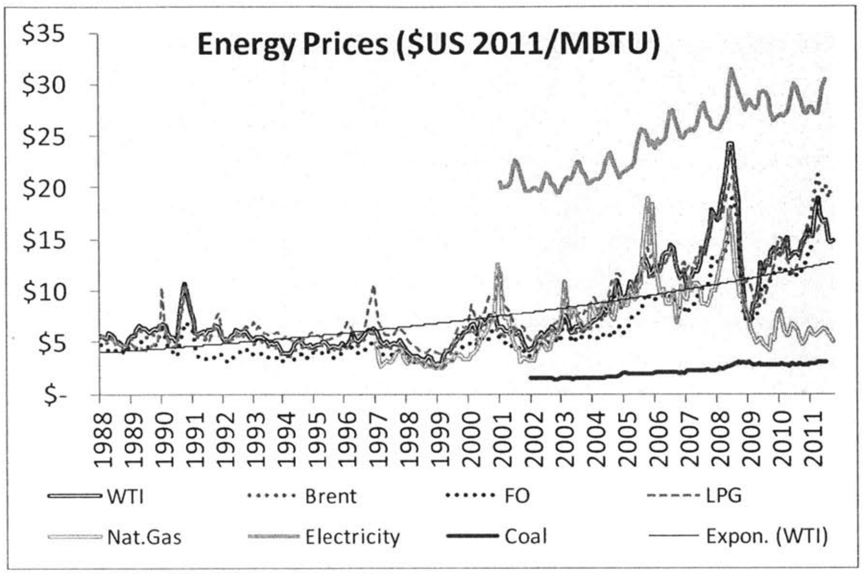


Figure 1-1. U.S. and World Energy Prices 1988-2011, normalized to 2011 dollars. While all prices rose in the long term, oil, oil derivatives, and natural gas saw the largest variability [2, 3, 4, 5, 6, 7, 8]

Notes: All prices from U.S. Energy Information Administration; WTI = West Texas Intermediate, Cushing OK; Brent = Europe Brent spot; Natural gas = Henry Hub Gulf Cost spot; FO = US residual fuel oil retail; LPG = US propane wholesale/retail refiner; Electricity = US average industrial electricity price; Coal = U.S. average industrial coal price

Furthermore, long-term energy price projections from the US Energy Information Administration (EIA) call for prices to continue rising in the future [9], posing a problem for consumers and businesses alike. The fact that energy is a cost embedded in virtually all products and services means that when energy prices go up, profit margins drop – unless cost increases can be passed on to the customer. When sales price cannot be increased, firms must become more energy-efficient or risk losing market share.

At the same time, an increasingly eco-conscious public pressures companies to create robust sustainability initiatives. For example, a 2007 survey by BBMG showed that given a product of equal quality and price, 90% of Americans prefer to buy from companies that manufacture energy-efficient products and 87% are more likely to buy from companies that commit to environmentally-friendly business practices [10]. Investors are jumping onto the sustainability bandwagon as well, as evidenced by the rapid growth of socially-responsible mutual funds in recent years [11]. With sentiments like these, it's no wonder that many companies are trying to institutionalize sustainability in their organizations.

Much of the time, sustainability programs are manifest in the form of energy reduction efforts because of the benefit to the corporate bottom line. One challenge that companies face is the fact that any effort spent reducing energy consumption usually means giving up time and resources that would otherwise be spent on the 'core' business. Finding the budget for sustainability initiatives and demonstrating quantified business value for these projects remains a challenge for many companies [1]. While significant past work has been completed around reducing energy consumption within specific manufacturing facilities,[1] much less has been done around the institutionalization of that work across facilities and through the broader organization.

1.1 Problem Statement

The problem addressed in this work is whether a systematic approach to energy cost reduction can be developed at the organizational level. This work is undertaken in the context of energy costs and reduction efforts in several of Company X's manufacturing facilities within a particular geographic division of the company, referred to throughout this paper as Region 1.

1.2 Thesis Overview

The structure of this thesis is as follows: we first provide a background for work already done in the field of sustainability and energy cost reduction in manufacturing; next, we describe Company X, its business and sustainability efforts, and lay out the methodology used to complete the study. In Chapter 3, we compare trends across four company plants to see what insights can be gleaned from the historical cost and consumption data. Chapter 4 examines current energy-reduction efforts at the company and takes a deeper dive at one plant via a traditional energy audit. With these results in mind, we next study the project management process for identifying and implementing energy-savings projects via a benchmarking case study from one of the plants. Chapter six discusses the results, proposes a framework for implementing an energy reduction program at the organization level, and suggests research topics for the future. Finally, we conclude with a brief summary and discussion of the lessons learned.

[1] See, for example, Norelli or Espindle.

2 Background & Methodology

2.1 Energy Management Programs and Previous Work

Technology-Focused Energy Savings

Much of the development for energy management programs in the U.S. started in the late 1970's in response to the global energy crisis of 1973. The early work focused on efficient operating practices for commercial and industrial equipment, formalized the procedures for energy auditing, and promoted development of technologies that were more energy-efficient. The Association of Energy Engineers (AEE) was created in 1977, and they developed a handbook for facility engineers on how to manage energy from a technology-centric perspective [11]. Once energy prices dropped, however, industry focus on reducing energy consumption waned in the 1980's and early 1990's, and little work was done in improving energy efficiency.

In the late 1990's and early 2000's, energy cost reduction re-emerged as a focus area due to increasing energy prices and the growing pressure for sustainable business practices. Again, much of the work done during that time and even today is highly technology-focused, and solutions and frameworks are highly technology-specific. For example, a 2010 journal article discussed the techniques and benefits of variable-speed drive for motors, waste heat recovery for flue gas economizers, high-efficiency motors, and leak detection and prevention in compressed air systems, all of which have been discussed thoroughly in previous literature [12].

Energy-Management as a Framework

More recent work, led by industry groups and the U.S. government, has focused on the development of systematic frameworks by which organizations can continuously improve their energy management practices. The Department of Energy's (DOE) Industrial Technologies Program, the Environmental Protection Agency (EPA) and the ENERGY STAR program all have made efforts at providing frameworks for corporate energy management programs for the industrial sector.

EPA developed a Lean-Energy toolkit, which seeks to integrate energy reduction into a traditional Lean manufacturing framework. They suggest conducting plant walk-throughs and energy audits, examining energy use with Value Stream Mapping, using Six Sigma techniques for eliminating energy waste, and conducting energy Kaizen events as ways to reduce energy consumption [12].

ENERGYSTAR developed assessment guidelines which apply to energy management and continuous improvement. They develop a somewhat more explicit framework than EPA via a step-by-step process for achieving superior energy management. The seven steps outlined in this framework are [13]:

1. Make a commitment
2. Assess performance
3. Set goals
4. Create action plan
5. Implement action plan

6. Evaluate progress
7. Recognize achievements

This process is meant to be an ongoing path of continuous improvement, and is represented schematically in Figure 2-1 below:

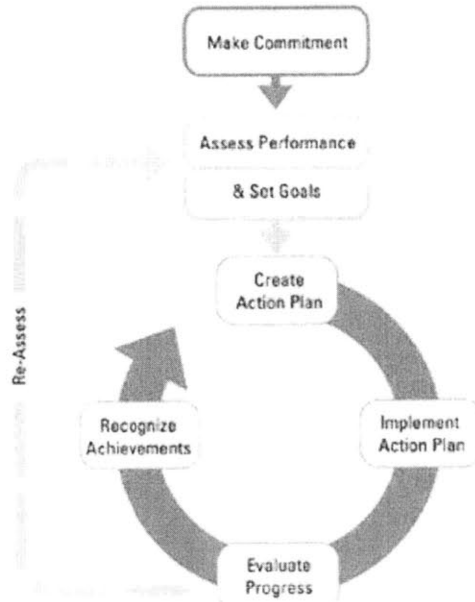


Figure 2-1. ENERGYSTAR framework for superior energy management Source: ENERGYSTAR

Much like the bulk of literature, resources developed in the early 2000's at the DOE's Industrial Technologies Program (ITP) focused primarily on technologies such as boilers and steam systems, compressed air systems, motors, fans and pumps, process heating, and material handling. The work done there was technology-focused and revolved around equipment upgrades or maintenance activities to allow for more efficient operation [13]. More recently, however, ITP combined with the U.S. Council for Energy-Efficient Manufacturing to develop the Superior Energy Performance (SEP) program to certify the performance and maturity of a company's energy management program. The SEP certifies compliance with the new ISO energy management standard, ISO 50001, which was published in June 2011. ISO 50001 follows a Plan-Do-Check-Act process for continuous improvement.

Energy Management In Practice

Work examining the implementation of energy management frameworks into specific manufacturing cells has been completed previously. Espindle found that both the measurement of energy-usage of individual equipment and real-time operator feedback improved energy efficiency. In this work, he found that use of the Design, Measure, Analyze, Improve, Control (DMAIC) tool from Six Sigma increased the energy efficiency of a manufacturing area by about 10% [17]. This corroborates the results reported by companies in the Aberdeen survey which saw energy cost reductions of 6-10% [1].

2.2 Company X and Region 1 Operations

Company X is a consumer products company with operations in 36 countries. Headquartered in USA, the company has approximately 60,000 employees and had net sales of over $20 billion in 2011. They make many consumer and personal products commonly used in the home and own many of the best-known consumer brands. Region 1 is one of the company's regional divisions and consists of 15 production locations and employs more than 18,000 people [18].

2.3 Energy & Sustainability at Company X

Company X has a well-established sustainability organization that has been recognized worldwide for excellence in sustainability efforts. In 2009 and 2010, the company was named one of the U.S. EPA's Energy Star Partners of the Year [19]. Company X develops sustainability plans in congruence with its periodic business planning cycles. The program focuses on the impact of its operations to both people and the planet. Highlights from the most recent sustainability plan includes the following goals [18]:

PEOPLE:
- Zero workplace fatalities
- Socially focused programs in all communities
- 100 percent compliance to the company's social standards for contract manufacturers and top-tier suppliers

PLANET:
- 25 percent reduction in water use and maintain quality of discharge
- 100 percent certified fiber
- 5 percent absolute reduction in greenhouse gas emissions
- Zero manufacturing waste to landfill

PRODUCTS:
- 250 million new consumers touched
- 25 percent of 2015 net sales from environmentally innovative products
- 20 percent reduction in packaging environmental impact

The goals around reducing water use and greenhouse gas emissions most directly relate to the subject of this paper. However, these are only several components of a broader cost-reduction effort throughout the organization.

Due in part to cost pressures in product categories where the company has traditionally been strong, the executive team has rolled out a number of cost-reduction efforts in recent years which include the following programs:

- *Global Energy Services Team (GEST) & Energy Audit:* GEST consists of subject-matter experts located at the Region 1 headquarters who are tasked with providing technical support and assistance to make each plant's operations more energy efficient. Part of this responsibility includes a whole-site energy audit, performed annually or tri-annually at each plant. One of the outputs of this audit is a report which recommends equipment upgrades and project opportunities to save energy within the plant. Operational changes are often recommended also, especially in the areas of compressed air and boiler systems. The energy services team also establishes energy efficiency performance metrics and reporting requirements.

- *Energy-Efficiency Metrics and Targets:* Another focus area of the GEST team involves setting efficiency targets and monitoring the current performance metrics for each plant. Targets are set as part of the five-year business plan cycle, and are established by the GEST team after taking into account the size, process type, equipment, and age of each plant. Metrics are monitored on a monthly basis and examine energy production efficiency in the form of energy use per unit production. Each year, the plants are ranked and underperforming sites are earmarked as focus areas for the GEST team. The team utilizes a data entry system on the corporate intranet to facilitate monthly reporting from the plants.

- *Cost-Reduction Database:* Company X has implemented a continuous improvement initiative focusing strictly on cost reduction opportunities. Reduction targets are set by top management and process owners at the regional, group, country, and site level are responsible to meet the savings targets. The object of the program is to gather cost-saving ideas from people at all levels of the organization, but especially from front-line production workers. Both electronic and paper-based systems exist for people to submit their ideas. Once submitted, the process owners review the ideas and assign them to local subject-matter experts for full evaluation. These experts then evaluate the ideas for feasibility and establish performance projections and expected cash flows.

  For example, an equipment operator may notice that changing a machine setup could reduce the amount of waste at his step of the process. He writes this idea on a submission form and drops it in a box on the factory floor. The site process owner collects the box at the end of the day and reviews the submissions. Since this idea pertains to a piece of manufacturing equipment, the process owner forwards the suggestion to the manufacturing engineer responsible for the area. The manufacturing engineer then assesses the feasibility of making the change, perhaps consulting with production engineers or area managers. If it is feasible, the engineer then builds an estimate for the implementation cost as well as the cash flows resulting from expected energy savings. If the result is attractive, the change will likely be implemented. While the program does not focus exclusively on energy costs, many projects do result in energy savings.

- *LEAN:* Company X has been expanding the use of LEAN principles and techniques in its plants worldwide over the last several years. The company's version of LEAN, like many others, is more than just a cost-reduction methodology; it seeks to achieve operational perfection through continuous improvement. One of the major focuses of LEAN is to eliminate waste from the process, which often entails a reduction of energy use as well. In Region 1, LEAN implementation has occurred in several plants through months-long efforts known as LEAN "waves". These waves bring together cross-functional teams (e.g. engineers, operators, supply-chain analysts, planners, HR specialists, etc.) from within a site and pair them with experienced LEAN practitioners from other sites to create a transformation within specific operating areas. The efforts utilize many traditional LEAN tools, such as standard operating procedures, visual systems, 5s, root cause analyses, and kaizen events. Company X has an internal framework for evaluating the level of LEAN maturity of a plant across six different dimensions, and regional management and LEAN practitioners visit the site at various stages of the process to evaluate the success of the implementation.

2.4 Hypothesis

Many organizations examine energy efficiency projects as part of cost-reduction initiatives. Most often, decision-making in such efforts is governed by the same guidelines and financial requirements as any other project. It is hypothesized that applying lean principles to the management of energy projects can yield greater savings results than traditional project management techniques.

2.5 Project Methodology

This project examines the energy consumption and cost trends for four facilities within Region 1. Key characteristics for these facilities are shown in Table 2-1 below.

Table 2-1. Key characteristics of the plants examined in this study.

	Products	**Fuels**
Plant A1	Home care	Electricity, natural gas
Plant B1	Personal Care	Electricity
Plant B2	Personal Care	Electricity
Plant A2	Home care	Electricity, fuel oil, LPG

For the remainder of this paper, the different plants are referred to primarily by the abbreviations of A1, A2, B1, and B2 as shown in the table.

As part of this study, three primary activities were completed:

1. Assess current energy use and analyze historical trends to identify cost-reduction opportunities
2. Recommend technology upgrades, process modifications, or generation projects to reduce cost
3. Perform comparative study of energy-savings project processes and recommend a process for rollout throughout Region 1

In order to complete these tasks, a significant data analysis effort was undertaken. The general methodology listed below was followed for each of the plants:

1. Create historical trends
    a. Gather past data and create a chronological database (energy bills, internal corporate and site-specific databases)
2. Assess current uses

a. Develop a list of all plant equipment
b. Assign "typical" power draw to each based on historic equipment measurements (where possible)
c. Use plant production (scheduled hours, uptime, % yield) to estimate actual energy use
d. Chart consumption and costs by equipment type, end-use, etc.

3. Recommend energy-savings opportunities
    a. Use output from (1) and (2) to identify big users and "quick hits"
4. Develop a process map for current energy-savings project identification, evaluation, implementation, and review process (Plant A2 only)
    a. Conduct interviews to understand process
    b. Obtain relevant data (capital budgeting vs. expense budgeting rules)
    c. Create map of current process - identify delays and pain points
    d. Develop new process map

3 Energy Use Trends in Region 1

One of the traditional energy management tools is the facility energy audit. The goal of an audit is to assess the current state of energy consumption and to recommend operational and equipment improvements to increase energy efficiency in the facility. In order to do this, the first step in any audit is to gather historical cost and consumption data. This chapter examines such data for the four plants studied. First, energy costs are contextualized by comparison to the other primary operating cost inputs; then, the trends in energy cost, consumption, and price are examined for each of the four plants.

3.1 Product Cost Contribution

Production of Company X's products requires significant energy. Raw materials must be processed extensively through both mechanical and chemical transformation processes. Steam is required in a number of process steps. Large heating loads demand hot air heated from steam or combustion gases and electricity is required to move the product, drive conveyors, and to monitor equipment. Approximately half the energy used is consumed for product processing and heating loads [14]. The large amount of energy required makes it a high percentage of overall operating costs in a Type-A production facility. For example, at Plant A2, energy costs comprised 27% of the total production costs in 2011. The remaining dominant product costs are shown in Figure 3-1 below.

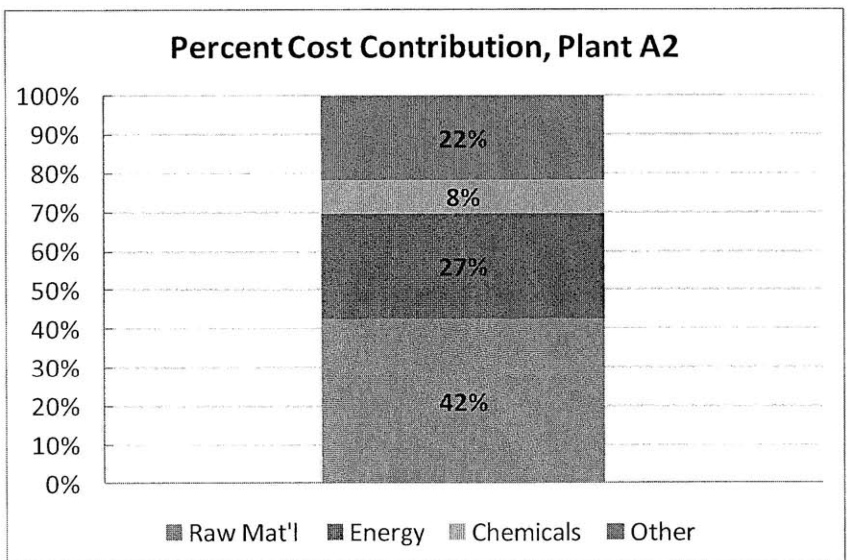


Figure 3-1. Energy makes up nearly 30% of production costs for A2

Energy has not always been such a large portion of production costs, however. As seen in the introductory chapter, energy prices worldwide rose considerably in the last decade, and Company X's industry was not immune.

3.2 Cost Trends and Drivers

Rising energy costs are one of the primary motivations for this study. A look at absolute costs and the change in costs over time show three important things:

1. Total energy costs are rapidly increasing at all sites studied
2. Energy cost increases are driven much more by price than by consumption
3. Energy costs vary significantly between plants (i.e. order of magnitude difference)

These important points can be observed from the energy cost, price, and consumption history. For example. Figure 3-2 below shows that the average increase in total energy costs since 2004 was over 500% for the four plants studied here, and the individual plant cost increases ranged from 350-800%:

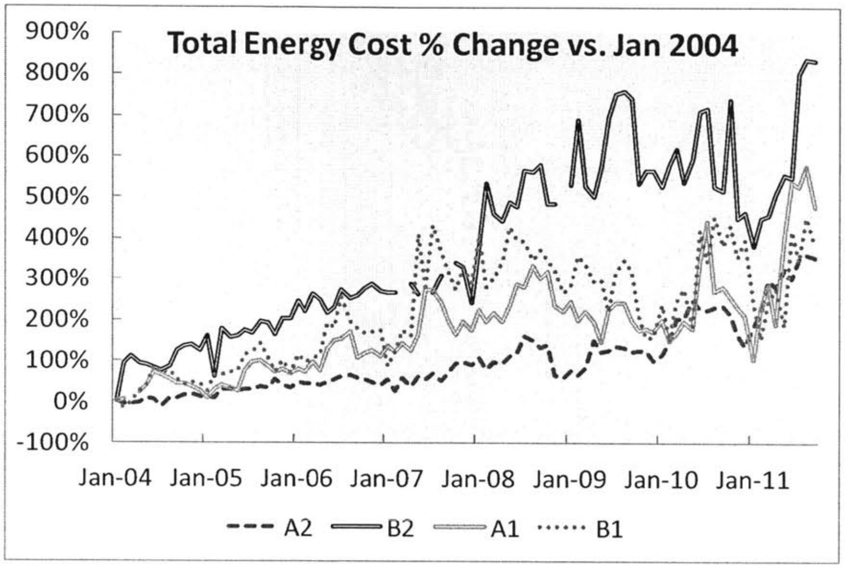


Figure 3-2. Average plant energy costs have increased over five-fold since 1994

The drivers of these changes in cost are primarily changes in price, as seen in Figure 3-3 below for each of the four plants:

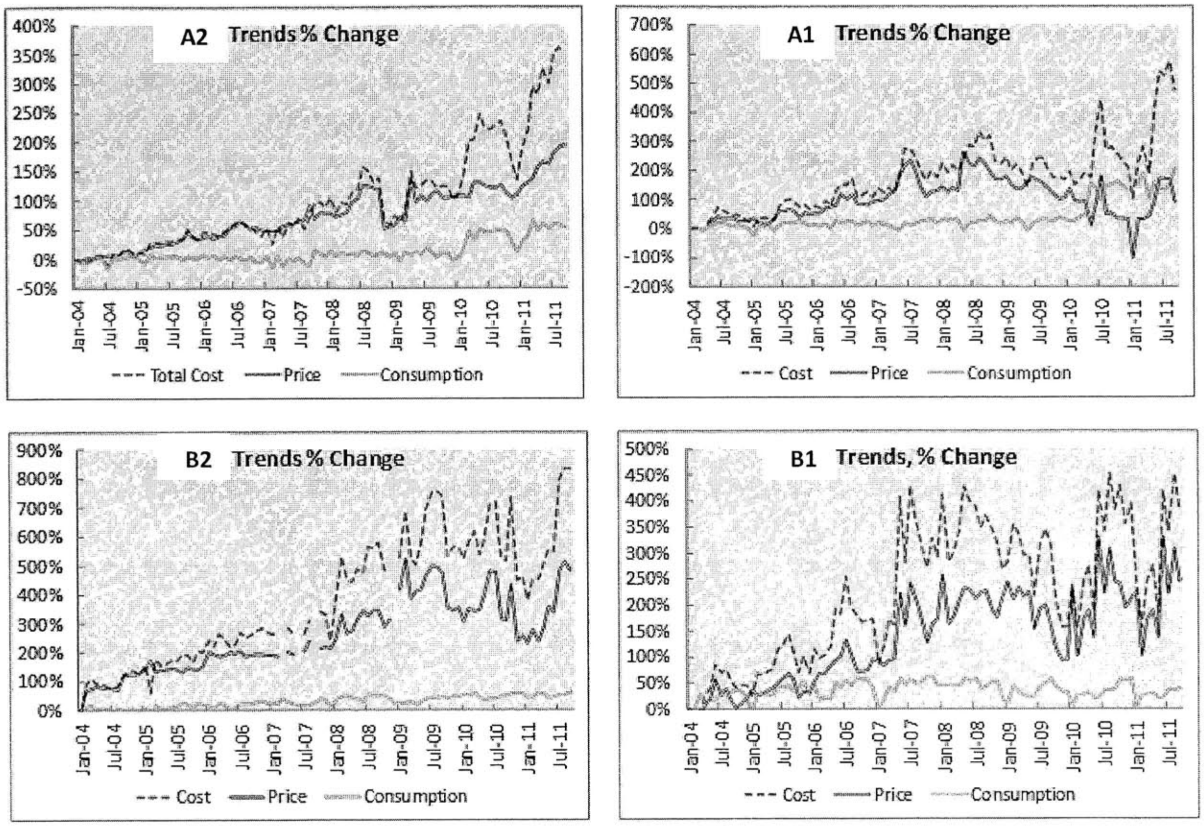


Figure 3-3. Changes in energy prices are the primary driver for changes in total energy cost

Lastly, energy costs vary significantly between plants. For example, costs at Plant A2 are a full order of magnitude greater than the other three plants, as Figure 3-4 shows.

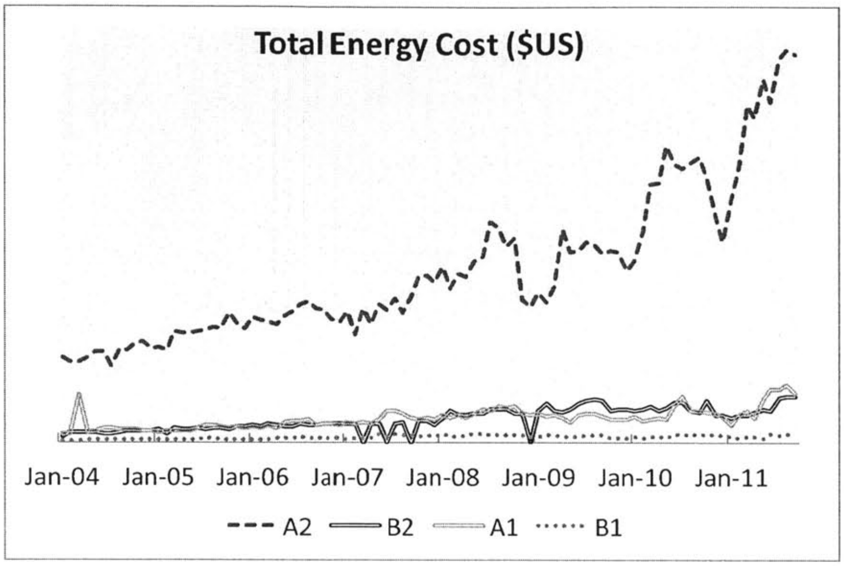


Figure 3-4. Total energy costs in each of the four plants on an absolute basis. Plant A2 dwarfs the other. Note: actual dollar values have been removed to protect proprietary data

Given that total energy costs in one plant can be so much larger than in the others, it would be reasonable to focus energy-reduction efforts on a small number of high-consumption plants. Similarly, any actions that can be taken to reduce or stabilize energy prices will result in greater value than just reducing energy consumption. To get a better view into the root of these cost increases, the next sections focus on average price paid and consumption by fuel type for each plant.

3.3 Consumption Trends in Relation to Cost

Like costs, the trends in energy consumption show several important things as well. There are two points to note:

1. Drastic differences in energy consumption between plants drives the cost differences observed
2. Purchased electricity accounts for too much cost in relation to its consumption

Point 1 is evidenced by Figure 3-5 below, where A2 shows total energy consumption of 4-10 times larger than the other plants.

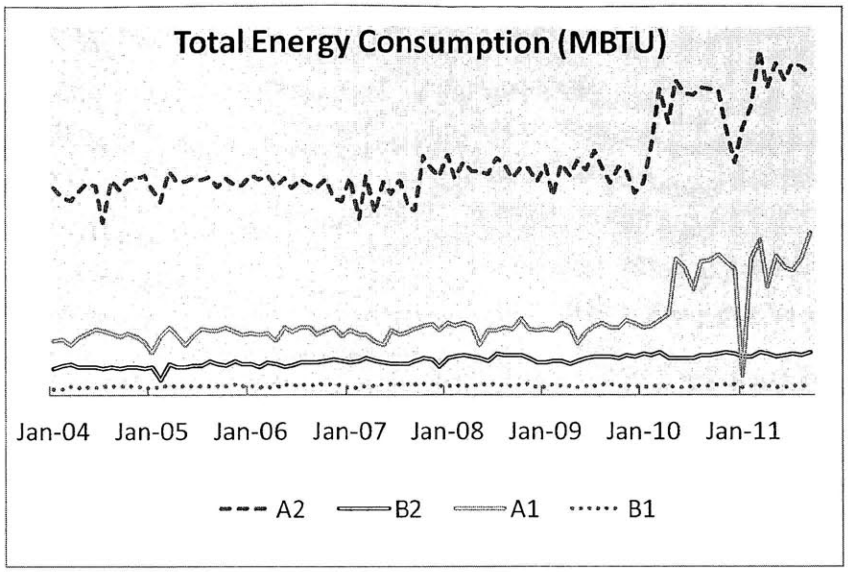


Figure 3-5. Total energy consumption for each of the four plants on an absolute basis. Consumption is significantly larger for A-type plants than for B-type plants. Note: actual values have been removed to protect proprietary data

The next set of charts lead to the second point. Figure 3-6 and Figure 3-7 show that electricity makes up nearly 100% of the energy cost for the B-type plants:

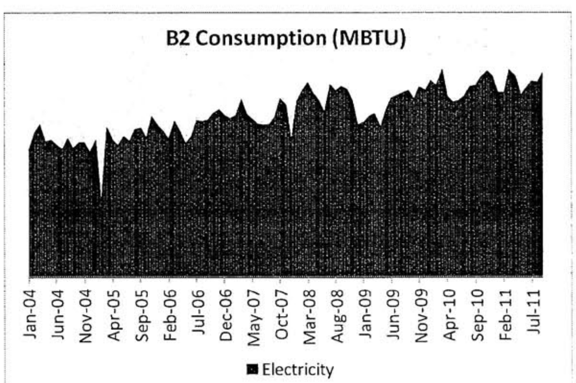


Figure 3-6. B2 has steadily-rising but relatively stable electricity consumption

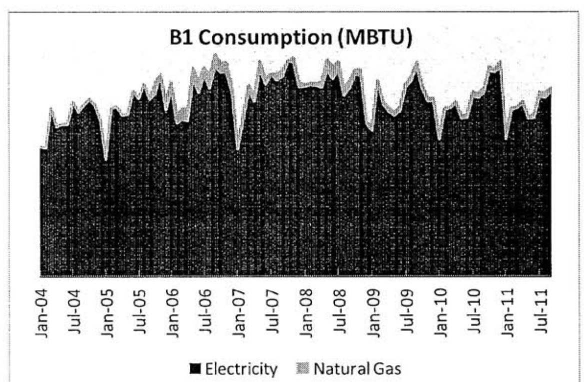


Figure 3-7. B1 electricity consumption has a flat or even declining lont-term trend

In the A-type plants, electricity makes up only 30-40% of the total energy consumption, yet accounts for 50-60% of total energy cost, as indicated by Figure 3-8 through Figure 3-11.

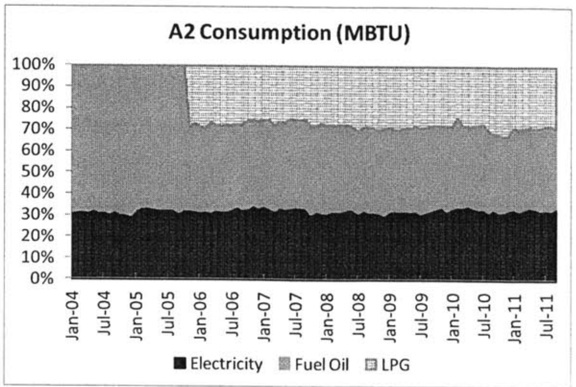


Figure 3-8. Electricity has remained constant at about 30% of total energy consumption at A2

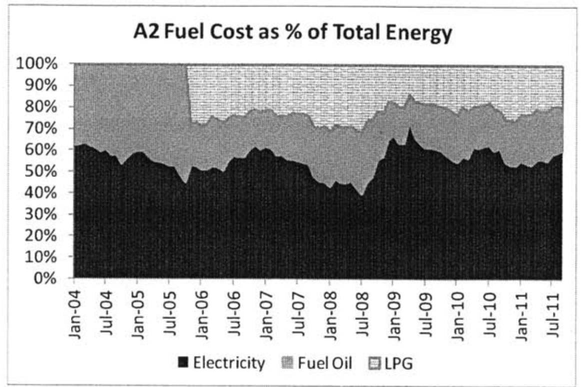


Figure 3-9. Electricity has averaged around 60% of total energy costs at A2 since 2004

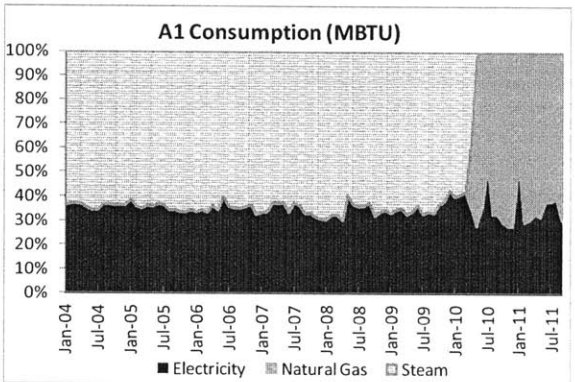


Figure 3-10. Electricity has remained constant between 30 and 40% of total energy consumption at B1, except during plant shutdowns

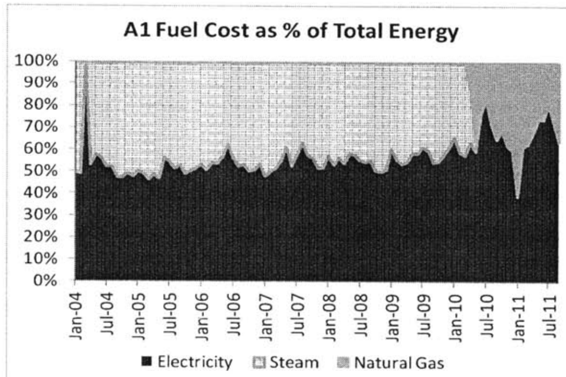


Figure 3-11. Electricity has grown from about 50% of total energy costs in 2004 to nearly 70% for much of 2011

Thus it is seen that while consumption drives the total energy cost differences between plants, it is fuel prices -- especially electricity prices -- that drive changes in energy costs over time. A closer look at energy prices in each of the plants can provide insight into opportunities for cost reduction.

3.4 Price

The four plants studied utilize energy in the form of electricity and heat. It is useful to compare the average prices paid for both of these energy types with benchmark prices from worldwide markets. Analysis of these price trends leads to two key insights for the company:

1. On-site combustion of natural gas is the lowest-cost source for meeting thermal energy needs.
2. Electricity prices are high across all plants, and are exorbitant at Plant A2

Figure 3-12 below compares the prices of fuels used for heating in the A-type plants with the benchmarks of the WTI crude spot market price and U.S. Henry Hub natural gas price.

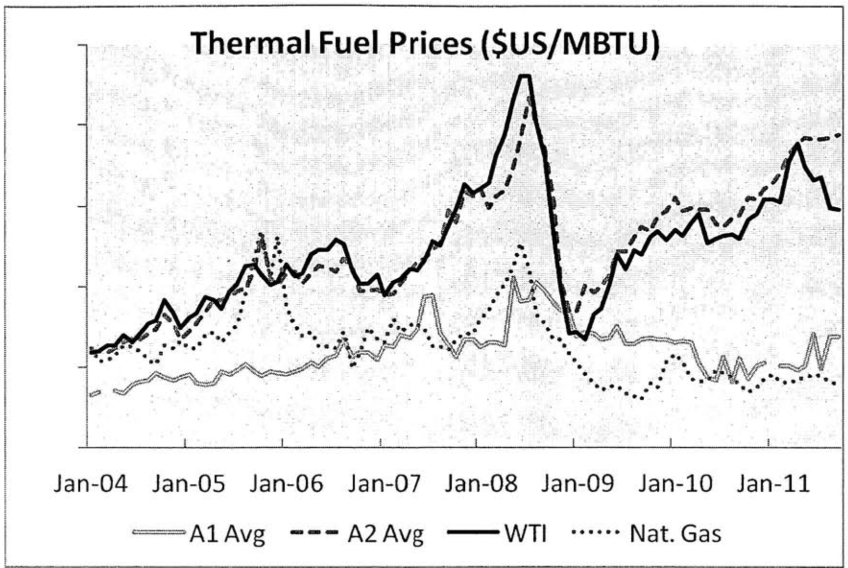


Figure 3-12. Thermal energy prices in A1 and A2 compared to benchmarks on an absolute scale. Actual values have been removed to protect proprietary data.

The figure above shows a strong link between the average fuel price at Plant A2 and WTI crude. This is to be expected because A2 uses LPG and fuel oil for heating, which are both derived from crude oil. Prices in Plant A1 show less of a link to either of the two benchmarks. The trend is somewhat proportional to WTI through about 2009, after which point it tracks more closely to natural gas. It should be noted that the plant switched from industrial steam purchased from a nearby manufacturing facility to natural gas in January 2010.

Below, Figure 3-13 compares the absolute electricity prices in each of the four plants with the average industrial electric price paid in the U.S. Three of the plants show a price history comparable to the U.S., with values increasing more rapidly in 2010 and 2011. Plant A2 shows prices at least three times greater than those in the U.S., and approximately twice those of the other plants. Because electricity markets are regional, it should be noted that A2 is located in a small country with few resources suitable for electricity generation. As a result, a large portion of the country's electricity is generated via imported liquid fuels, which, as seen above in Figure 3-12, are more costly per unit energy. The other three plants are all located within a single, larger country, which is more developed, has greater natural resources, and greater access to international markets. These geopolitical differences explain the drastic price differences observed.

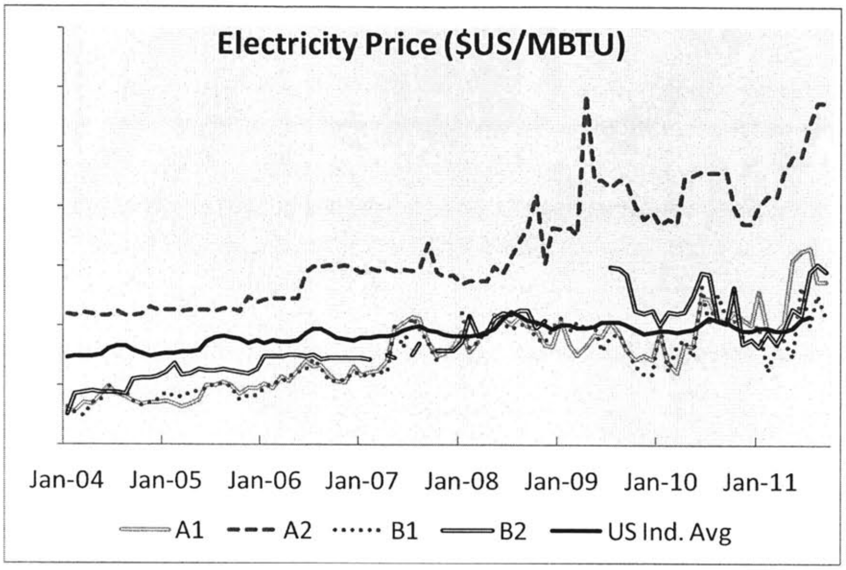


Figure 3-13. Electricity prices in the four plants compared to the U.S. industrial average on an absolute scale. Actual values have been removed to protect proprietary data.

The high electricity prices paid by A2 present a risk, especially because a large portion of the electricity is derived from imported fuels, which are subject to wide price fluctuations and supply disruptions. A2 (as well as A1) could benefit from the development of on-site cogeneration (or combined-heat-and-power) facilities, which are discussed in greater detail in the next chapter.

3.5 Region 1 Energy Trends Summary

This section examined historical energy cost, consumption, and price trends within four plants in the company's Region 1 territory. Analysis of these trends revealed that total energy costs are increasing rapidly. These increases are both significant (ranging from 350-800%) and pervasive within Region 1 (as observed at four separate plants in two different countries). Energy costs vary significantly between plants due to drastic differences in energy consumption (for example, an order of magnitude larger energy costs in A2 compared to the others). This fact suggests that cost reduction efforts should focus on the heavy users.

Additionally, it was seen that energy cost increases, while driven in part by rising consumption levels, are primarily due to rising energy prices across all fuels. Chief among these is electricity, which showed high prices in all plants, but was 2-3 times higher in Plant A2. As a result, purchased electricity made up a greater proportion of total cost (60%) than consumption (30%), making total energy costs disproportionately sensitive to electricity prices. Lastly, the data showed that on-site combustion of natural gas is the lowest-cost source for meeting thermal energy needs. The last two points, taken together, make a case for constructing natural gas-fired cogeneration capacity on-site.

4 Cogeneration and Combined Heat and Power

Traditional electrical generation systems rely on the use of large centralized power plants to serve a local or regional network of power transmission lines which carry energy to end consumers in towns and cities located some distance away from the generating stations. A typical plant in this system has the capacity to generate on the order of several hundred megawatts (MW) or even gigawatts (GW) of power. Depending on the fuel type and the specific design of the plant, it may have a conversion efficiency ranging from 30% (for an older coal-fired plant) to 60% or slightly better for a natural gas-fired combined-cycle plant.

Distributed generation (DG) facilities, in contrast, range from tens of kW or less for some residential systems to 300 MW or higher for large industrial systems. Table 4-1 below shows the breakdown of different DG systems by size and application type [15]. The energy needs for the four plants would put them in the Mid-Large range for system capacity.

Table 4-1. Types of Cogeneration Systems by Size

System Designation	Size Range	Application
Mega	50-100+ MWe	Very large industrial
Large	10s of MWe	Industrial and large commercial
Mid	10s of kWe – several MWe	Commercial and light industrial
Micro	< 60 kWe	Small commercial and residential

One form of distributed generation commonly implemented is cogeneration, or combined heat and power (CHP). It is defined as "the process of producing both electricity and usable thermal energy at high efficiency and near the point of use". Energy conversion efficiencies can reach as high as 80% or more in these systems because much less energy is lost as waste heat. Additionally, significantly lower electric line losses are encountered as these generators are typically located on-site or very nearby the point of consumption. Depending on the specific configuration, CHP systems can provide hot water, steam, chilled water, and space heating in addition to electricity [16]. Systems are characterized by their heat-to-power ratio, which is defined as:

$$HPR = \frac{Energy\ produced\ as\ heat}{Energy\ produced\ as\ electricity}$$

This ratio is important for deciding which CHP technology to install into a facility. In the case of A-type plants, the high heating and steam loads make a steam/electricity mix most desirable. From Figure 3-8 and Figure 3-10, it can be seen that the desired HPR for both A1 and A2 should be about 2.33 (i.e. heat and electricity are about 70% and 30% of total consumption respectively, and 7/3 = 2.33). That is, if CHP systems were installed in these plants, systems with an HPR near 2.33 would operate most efficiently. B-type plants, on the other hand, would likely do better with a hot water/electricity mix, where the hot water could be used to drive an absorption or adsorption cooling system to meet air conditioning needs. Such system supplies electricity, hot water, and air conditioning and is known as trigeneration.

4.1 CHP Technologies

Substantial literature can be found describing CHP technologies and comparing the performance and benefits of each. The most common technologies found in cogeneration systems vary depending on the total system capacity. Larger systems tend to use gas turbines (GTs) or reciprocating internal combustion engines (ICEs) coupled with a waste heat recovery boiler, or a steam boiler coupled with a steam turbine generator [15]. The latter systems are often found in industrial facilities where steam boilers already exist and have excess capacity or waste steam being vented to atmosphere. Although it may not be optimized for the needs of the plant, simply adding a steam turbine to the system requires the lowest up-front cost. The two other types of cogeneration technologies commonly used are Stirling engines (SEs) and fuel cells, though these are more frequently found in the micro and mid-size applications. A detailed description of each technology is outside the scope of this work; however, a basic comparison of the pros and cons for each technology follows below in Table 4-2 and detailed characteristics are laid out in Table 4-3 [17].

Table 4-2. Pros and cons of CHP technologies

CHP system	Advantages	Disadvantages	Available sizes
Gas turbine	High reliability. Low emissions. High grade heat available. No cooling required.	Require high pressure gas or in-house gas compressor. Poor efficiency at low loading. Output falls as ambient temperature rises.	500 kW to 250 MW
Microturbine	Small number of moving parts. Compact size and light weight. Low emissions. No cooling required.	High costs. Relatively low mechanical efficiency. Limited to lower temperature cogeneration applications.	30 kW to 250 kW
Spark ignition (SI) reciprocating engine	High power efficiency with part-load operational flexibility. Fast start-up. Relatively low investment cost. Can be used in island mode and have good load following capability. Can be overhauled on site with normal operators. Operate on low-pressure gas.	High maintenance costs. Limited to lower temperature cogeneration applications. Relatively high air emissions. Must be cooled even if recovered heat is not used. High levels of low frequency noise.	< 5 MW in DG applications
Compression ignition (CI) reciprocating engine (dual fuel pilot ignition)			High speed (1,200 RPM) ≤4MW Low speed (102-514 RPM) 4-75 MW
Steam turbine	High overall efficiency. Any type of fuel may be used. Ability to meet more than one site heat grade requirement. Long working life and high reliability. Power to heat ratio can be varied.	Slow start up. Low power to heat ratio.	50 kW to 250 MW
Fuel Cells	Low emissions and low noise. High efficiency over load range. Modular design.	High costs. Low durability and power density. Fuels requiring processing unless pure hydrogen is used.	5 kW to 2 MW

Table 4-3. Characteristics of Selected CHP Technologies

Technology	Steam Turbine[1]	Recip. Engine	Gas Turbine	Microturbine	Fuel Cell
Power efficiency (HHV)	15-38%	22-40%	22-36%	18-27%	30-63%
Overall efficiency (HHV)	80%	70-80%	70-75%	65-75%	55-80%
Effective electrical efficiency	75%	70-80%	50-70%	50-70%	55-80%
Typical capacity (MW_e)	0.5-250	0..01-5	0.5-250	0.03-0.25	0.005-2
Typical power to heat ratio	0.1-0.3	0.5-1	0.5-2	0.4-0.7	1-2
Part-load	ok	ok	poor	ok	good
CHP Installed costs ($/kW$_e$)	430-1,100	1,100-2,200	970-1,300 (5-40 MW)	2,400-3,000	5,000-6,500
O&M costs ($/kWh$_e$)	<0.005	0.009-0.022	0.004-0.011	0.012-0.025	0.032-0.038
Availability	near 100%	92-97%	90-98%	90-98%	>95%
Hours to overhauls	>50,000	25,000-50,000	25,000-50,000	20,000-40,000	32,000-64,000
Start-up time	1 hr - 1 day	10 sec	10 min - 1 hr	60 sec	3 hrs - 2 days
Fuel pressure (psig)	n/a	1-45	100-500 (compressor)	50-80 (compressor)	0.5-45
Fuels	all	natural gas, biogas, propane, landfill gas	natural gas, biogas, propane, oil	natural gas, biogas, propane, oil	hydrogen, natural gas, propane, methanol
Noise	high	high	moderate	moderate	low
Uses for thermal output	LP-HP steam	hot water, LP steam	heat, hot water, LP-HP steam	heat, hot water, LP steam	hot water, LP-HP steam
Power Density (kW/m^2)	>100	35-50	20-500	5-70	5-20
NO_x (lb/MMBtu) (not including SCR)	Gas 0.1-.2 Wood 0.2-.5 Coal 0.3-1.2	0.013 rich burn 3-way cat. 0.17 lean burn	0.036-0.05	0.015-0.036	0.0025-.0040
lb/MWh$_{TotalOutput}$ (not including SCR)	Gas 0.4-0.8 Wood 0.9-1.4 Coal 1.2-5.0.	0.06 rich burn 3-way cat. 0.8 lean burn	0.17-0.25	0.08-0.20	0.011-0.016

* Data are illustrative values for typically available systems; All costs are in 2007$

[1]For steam turbine, not entire boiler package

For the power and heating demands required in the four plants considered here, only the first three CHP technologies provide sufficient power generation capacity. To provide a better financial comparison, we assess the first three technologies for Plant A2 in the next section as an example.

4.2 Cogeneration Example

For this example, we estimate the total annual cost for three of the CHP technologies, which should be compared with the current cost of electricity at the plant. All assumptions and results are shown in Table 4-4 below. We walk through the calculation for the steam turbine here. First, for ease of calculation, we assume that the plants are fully loaded and supply their full capacity year-round, or 8,760 hours per year. This value is then adjusted down based on the "availability" factor in Table 4-3. For the steam turbine, we multiply 8,760 by a factor of 1 since the availability is near 100%. This yields actual operating hours of 8,760 per year. Next, we divide the maximum value for installed cost by the annual operating hours just calculated to estimate the installed cost per kWh. From Table 4-3, the CHP installed cost is $1,100 per kWe for the steam turbine, so dividing that by 8,760 yields a price of $0.126 per kWh. We then add the operating cost of $0.005/kWh from the table to find an annualized cost of

$0.131 per kWh. Note that these are amortized installed costs. The results of these calculations for the reciprocating engine and the gas turbine are shown in Table 4-4:

Table 4-4. Estimated amortized installed cost for select cogeneration systems

	Steam Turbine	Recip. Engine	Gas Turbine
Base hours	8760	8760	8760
Availability	1	0.92	0.9
Actual hours	8760	8059	7884
Installed Cost ($/kWe)	1100	2200	1300
Installed Cost ($/kWhe)	0.126	0.273	0.165
O&M Cost ($/kWh)	0.005	0.022	0.011
Total Annual Cost ($/kWh)	**0.131**	**0.295**	**0.176**

The actual cost for any system will be different from the values calculated here, depending on existing equipment, capacity, etc. It should be noted that the costs for the steam turbine do not include the cost of the entire boiler package. As mentioned previously, this is a reasonable assumption because many facilities already have boilers and would only incur the cost of the steam turbine. It should also be noted that the power-to-heat ratios listed in Table 4-3 are the inverse of the equation for heat-to-power ratio mentioned earlier. The value of this ratio will also affect the decision regarding the type of CHP system to implement. While the analysis shown here uses only back-of-the-envelope calculations, the resulting costs suggest that CHP systems could indeed be attractive for some plants, and a more detailed study is warranted. Ultimately, cogeneration systems can only alter the supply-side of the energy equation, but there are many ways to reduce cost and consumption from the demand side as well. Reducing energy demand is the subject for the remainder of this work.

5 Energy Cost Reduction Strategies

The second step of an energy audit is to better understand the breakdown of how energy is used in the facility. Ideally, one could gather second-by-second data for every single end-use over a number of years, but that level of granularity rarely exists. This chapter begins by looking at the audit completed by the author in one B-type facility. We first examine total energy consumption by end-use, then look at end-use over time and estimate potential energy savings through basic equipment upgrades and monitoring. We next track the results of Company X's energy reduction efforts within the four plants using historical records of key performance indicators (KPI's) for energy efficiency. This leads us to a discussion of the company's internal structures for monitoring energy efficiency within plants and the identification, evaluation, and implementation process of energy-savings projects within Region 1.

5.1 External Audit in Personal Care

In one B-type plant, significant prior effort has been made to track the energy consumption within different plant areas on a monthly basis. The author utilized this data to generate a breakdown of the end-use of energy consumption by equipment type. This chart is shown in Figure 5-1.

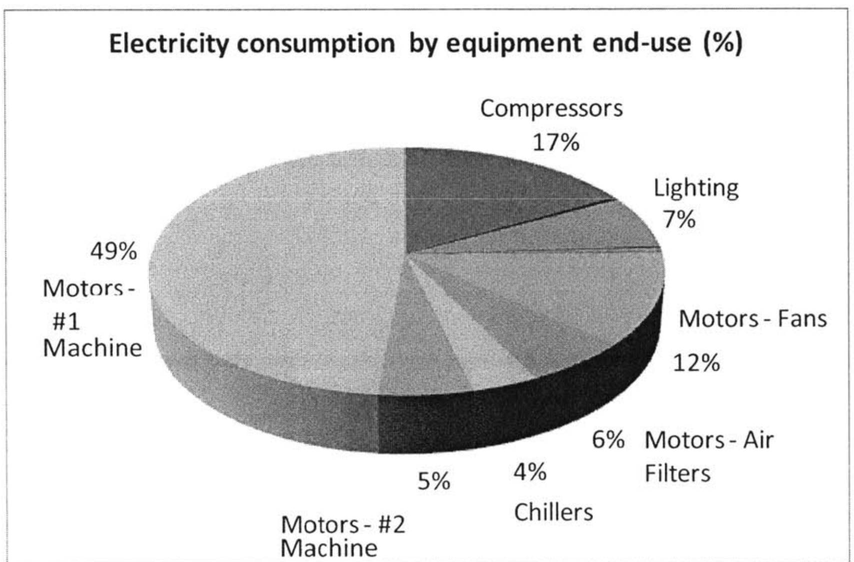


Figure 5-1. Energy consumption by end use in Plant B2

The majority of energy use comes from the #1 and #2 production machines - 54% in aggregate, most of which comes from motors which drive belts, conveyors, or fans. These machines run virtually 24 hours a day, seven days a week. There are two operating modes, one with and one without charge. The production machines are making product during the "with charge" phase and are running and consuming energy, but not producing product, during the "without charge" phase. The power consumption during the without-charge operating condition is about 66-75% of the max power drawn during actual production with-charge. Thus, if uptime can be increased or the machine can be fully turned off during downtime events, there is a substantial opportunity for energy savings. For instance, in 2009, these time periods represented nearly 17% of the total consumption for the year, and nothing was produced.

The second largest user of electricity is the compressors (17%). Internal best practices at the company demonstrate compressor consumption at 6% of total.

The 12% consumer is the fan motors. There likely are opportunities for savings here because the airflow for virtually all of the fans is controlled by dampers rather than direct motor control. Controlling via dampers puts an unnecessary pressure drop in the ductwork which reduces fan motor efficiency. Using variable frequency drive (VFD) fan motors could improve this situation.

Seven percent of the consumption is due to lights and other office equipment. There are definite energy saving possibilities here via higher efficiency equipment (such as LEDs for office space and plasma or induction lighting for high-bay applications) and through more efficient operations. For instance, it was noted that office lights are constantly turned on, even over nights and weekends when no one is occupying the space. The use of photocells or timers could cut this consumption immediately. A simple efficiency comparison between conventional fluorescent bulbs and LEDs implies that this plant could save 450 MWh of electricity over three years. Similarly, installation of photocell-lights could save 985 MWh over this same time period. Moreover, much of the lighting electricity consumption comes from high-bay lighting, such as in warehouse or production areas. Switching to more efficient high-bay lighting such as plasma or induction lighting could save nearly 4,000 MWh. While these modifications are relatively low-cost and low effort, the fact that lighting makes up only 7% of total consumption limits the savings here to between 4 and 5% of total.

Air filters accounted for 6% of the electricity consumption. Because of stringent product specifications, there may not be opportunities for improvement through operational changes. However, on-time maintenance or replacement of the filters can help reduce the pressure drop and therefore increase the operational efficiency of the blower motors which force air through these filters.

The last major energy user is the cooling system at 4%. This system consists of two chillers. There may not be great opportunities for savings here, since one chiller is brand new as of 2010 and the energy efficiency is very high. Unless the full cooling capacity is required, the more efficient chiller will be run instead of the older one. Thus, the efficiency gains achieved by replacing the older unit would apply to less than half of the 4% consumption. Upgrading the older chiller to a more efficient unit would realize some energy savings, but the savings likely would not justify the costs.

Given the energy use breakdown above, we can selectively target energy savings opportunities for both areas with 'low hanging fruit' and those with the largest percentage of energy consumption.

5.2 Internal Results

Company X has taken efforts to reduce energy consumption in most of its plants. Such efforts have ranged from items as simple as installation of lighting motion sensors to complex projects such as overhauls of production machines. However, the continuous increase in energy costs leads one to question whether the energy efficiency efforts are having the desired effect. One way to measure the progress made to date is to examine the energy efficiency of the company's plants. The internal metric used to measure energy efficiency at Company X is energy consumed per unit of production. In the case of A-type plants, this is denoted in terms of thousand British Thermal Units (MBTU) per bone dry metric ton (BDMT). For B-type plants, products do not lend themselves as well to being measured in terms of metric tons. Hence, these are measured on a per-standard unit basis (MBTU/SU). Figure 5-2 through Figure 5-5 below show the overall energy efficiency trends for each plant.

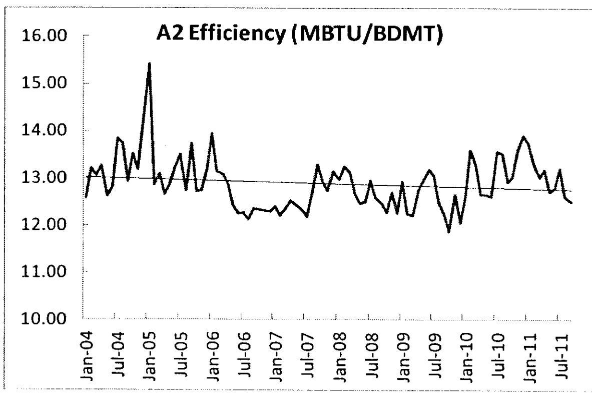


Figure 5-2. A2 has seen total plan efficiency improve slightly since 2004.

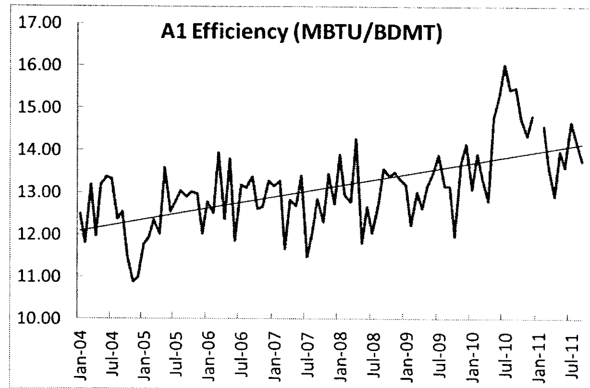


Figure 5-3. A1 plant overall efficiency declined primarily due to its performance between mid-2010 and late 2011.

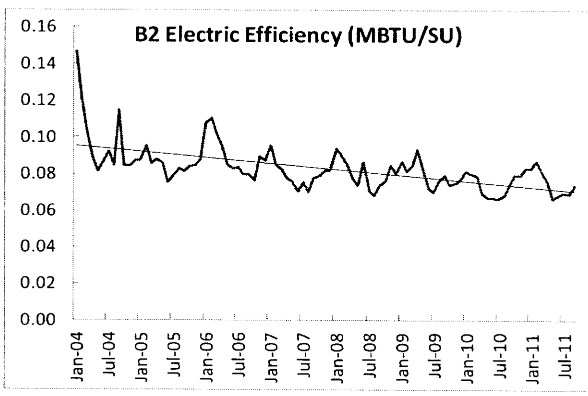


Figure 5-4. Energy efficiency has been increasing in B2 over the long term, although seasonality remains.

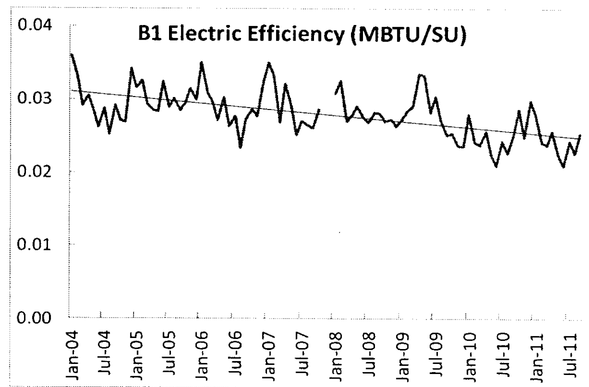


Figure 5-5. B1 energy efficiency has improved though it exhibits general seasonality as well.

From the graphs, we might infer that Type-B plants perform better than Type-A plants across the board. However, because efficiency at Type B plants is calculated based on Standard Units, it is not a constant-basis metric since the amount of material in a standard unit depends on the product SKU and the particular product design, which might change over time for the same SKU. That is to say, the declining trend observed in the graphs for B2 and B1 could be the result of several factors:

1. Improved energy-efficiency at the plant

2. Product SKU's with low material-weight and/or low processing complexity have become a larger percentage of total production
3. Product redesigns have resulted in less material and/or processing per unit

For these reasons also, we cannot judge based solely on these charts that B1, at about 0.025 MBTU/SU, operates more efficiency than B2, at 0.08 MBTU/SU. In fact, B2 primarily manufactures larger products than does B1, so we know for certain that the material processing required is different. For further discussion of the use of these efficiency metrics, refer to the appendix.

Given the discussion above, we will compare performance only between plants of the same type. In the chart that follows, we examine actual energy use efficiency in MBTU/BDMT and the resulting percentage deviation from the energy target previously set for each plant by the GEST team. These data are presented for all Type-A plants in Region 1 in 2010.

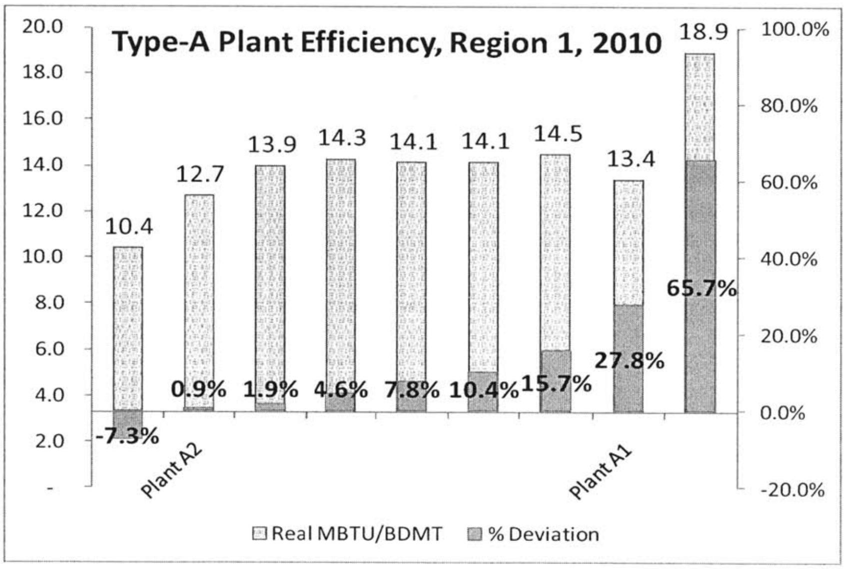


Figure 5-6. A2 plant had the second best efficiency indicator and the second lowest deviation from the target efficiency value in 2010

The plants toward the left-hand side of the chart are considered to be "better performing" in terms of energy efficiency because of their low deviation from the GEST team target. By this standard, Plant A2 is the second-best performing plant in the region. The hatched bars show the actual energy efficiency value in each of the plants. Here again, A2 outperforms all but one of the others. The results raise the question as to what is different between the plants on the left hand side and those on the right that leads to such a vast difference in deviations from the energy target.

The deviation from target consists of two components – the actual energy efficiency, in MBTU/BDMT, and the target efficiency. Targets are set by the GEST team individually for each plant, depending on the size, capacity, and equipment installed. For the purposes of this project, we assume that the energy efficiency target calculations treat each plant equally. That is, the methodology should not give an unfair advantage to some plants by setting a target value that is relatively "easier" to achieve, given the equipment installed. Under this assumption, the only variable that can be changed is the actual efficiency performance of the plants – namely, by reducing consumption or increasing production on a relative basis. Thus, we focus on the efficiency of the overall operation for the remainder of this report.

5.3 Region 1 Energy Projects

As described earlier, several systems exist within the organization for identifying, evaluating, and implementing energy projects. Between the GEST team site visits, energy audits, and cost-reduction ideas, a number of projects get recommended each year. However, anecdotal evidence suggests that many of these projects simply do not get implemented, or are implemented on much longer timescales and with lower frequency than the organization desires. A simple evaluation of the completion rate of energy projects at A2 provides some evidence to support this assertion. Figure 5-7 below shows the number of projects conceived and completed each year, along with the number at various stages of the evaluation, planning, and implementation process.

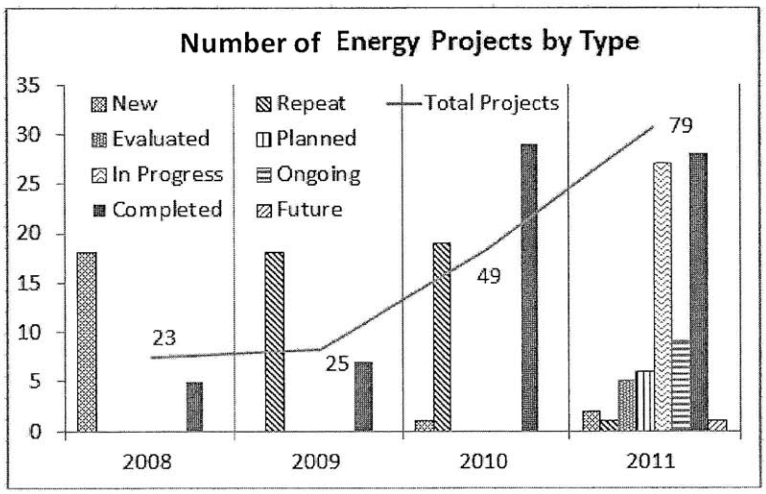


Figure 5-7. The number of projects undertaken as well as the total number of proposed projects increased dramatically in 2010 and 2011

Notes: All non-completed projects from 2008 are treated as new although many are likely to be repeat recommendations from prior years. Values for each year represent incremental changes from the previous year, not accumulated total.

In 2008 and 2009, very little action was taken toward the identification and implementation of energy projects, with only five completed projects in 2008 and seven in 2009. However, since the number of repeat projects in 2009 equals the number of new projects from 2008, we know that all seven of the projects implemented in 2009 were created in that year, perhaps suggesting an improved implementation process. In 2010 this trend continues as 29 new projects were created and completed within the same year. The following year, 2011, saw additional increases, with virtually the same number of completed projects and many more at various stages of implementation. If the 2008 and 2009 project completion rates at A2 were typical and representative of those at other plants, the question is, what did A2 begin doing (or stop doing) in 2010 that caused it to realize a step change in completion rates? Further, what result did these energy projects have on the plant efficiency metrics?

When posed with these questions, company management noted that LEAN manufacturing initiatives were started at A2 in 2010, and that perhaps there was a link between project completion and the start of the LEAN program. A2 site management also started an energy team within the LEAN structure in order to apply LEAN principles to the management of energy use at the plant. Thus, regional management recommended a case study of the A2 site in order to discover the causes for these results and to document and share the learnings from A2 with other sites around the world. The following sections discuss this case study in further detail.

6 Case Study: Plant A2

The purpose of the case study is to provide a "before" and "after" picture of the energy project process. The "before" snapshot captures the energy project identification, implementation, and review process prior to the creation of the LEAN Energy team. It is likely that the methodologies employed at A2 during this phase are different from other sites; however, many of the challenges faced are the same. The "after" picture describes the new methodology employed at A2 starting around June of 2011. To adequately characterize the nature of these efforts, the author conducted a number of interviews with on-site staff, reviewed internal project documentation, and made direct observations of the "after" scenario. The following two sections describe these processes.

6.1 Plant A2 Energy Project Process: "Before"

The project implementation process consists of six main tasks: identification, evaluation, decision-making, financing, implementation, and review. The key characteristics of these tasks are outlined in Table 6-1 below, which shows the key features of this project implementation methodology. However, sequencing of these activities is important as well, and is shown graphically in the "Before" snapshot figure following this section.

Table 6-1. Key phases of the energy project implementation process at A2: "before" state

	Stage	Description / Details / Sources	
1	Identification	-GEST site visits -Staff visits to other sites -Communications with other sites	-Cost-reduction database - other sites - internal
2	Evaluation	-Present case to Energy Committee -Support case using Excel template	-Compare & rank with all proposed A2 energy projects
3	Decision-Making	Expense: Area engineering chief, maintenance manager, and plant manager	Capital: Above plant-level management; depends on total cost
			Requirements: < 3 year payback, < 1 year preferred, none for safety projects Low capital outlay preferred; Must use WACC = 12.5-13% for A2
4	Financing	Miscellaneous (< $10K) and in-kind replacement (<$25K) from operations expense	Appropriations (> $25K) from regional projects budget
5	Implementation	Detailed evaluation and planning by engineering department; Purchasing acquires materials; Maintenance assists in planning physical installation; Quality Gate meetings aid in coordinating all stakeholders	
6	Review	A maintenance plan is developed; project champion or area manager assigns the task of monitoring project performance – performance is reported in cost-reduction database; capital project performance gets reported monthly to Region 1 executives	

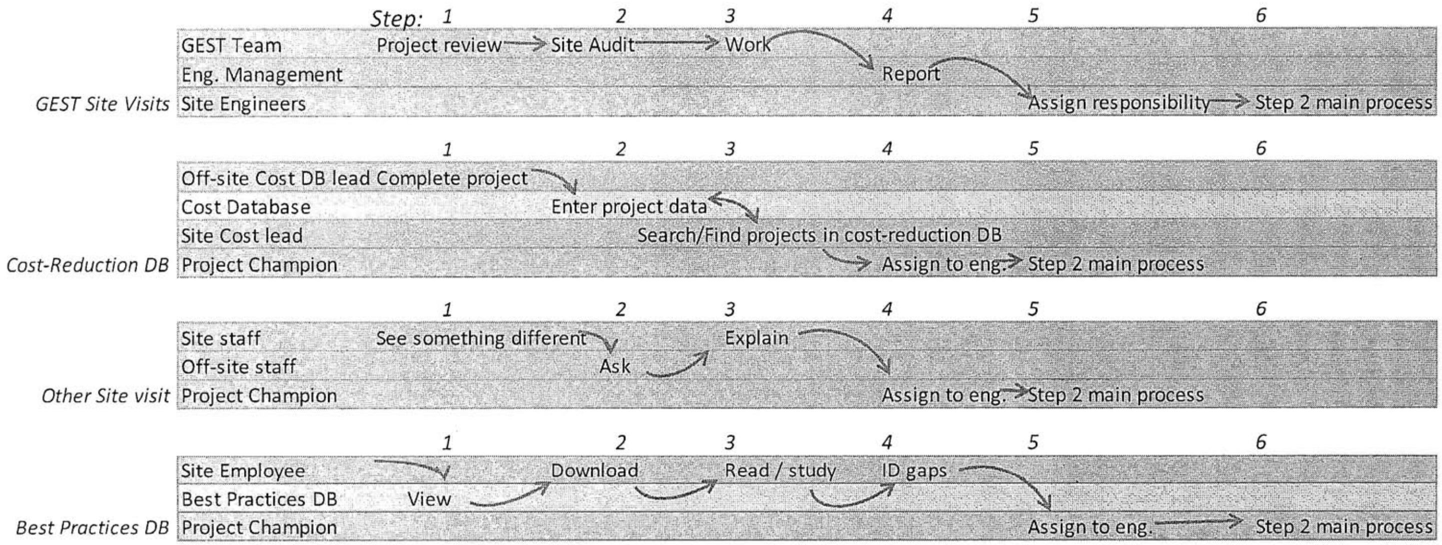
From approximately 2007 to 2011, A2 had a standing Energy Committee, which consisted of the plant manager, the maintenance and engineering manager, the production manager, and area engineering managers. The committee met once per week to view presentations of new project proposals and review status of ongoing projects, the majority of which were usually equipment upgrades. Under this process, a "project champion" - usually an engineer in the area where the project would be implemented - captured the idea (step 1) from one of the typical idea sources (shown in Idea Processes) and discussed it with the area manager. After this vetting, the project champion then made the initial evaluation with projected costs and energy savings and pitched the project to the Energy Committee. The committee then discussed the project and ranked it for priority compared to all other energy projects under consideration (steps 5 and 6). At this point, the committee sometimes requested additional verification from the engineering department.

Once approved (step 8), the project could go in one of two directions. If it fell under the category of miscellaneous new equipment under $10,000 or was a replacement-in-kind of existing equipment under $25,000 in cost, it was sent to the engineering department for implementation at the plant and charged under the expense budget. If the project required a larger capital investment, it was routed upward through the organization for further approval (steps 9-14). This additional approval typically added two to three weeks to the project implementation process. In the end, these projects were also routed to engineering for implementation.

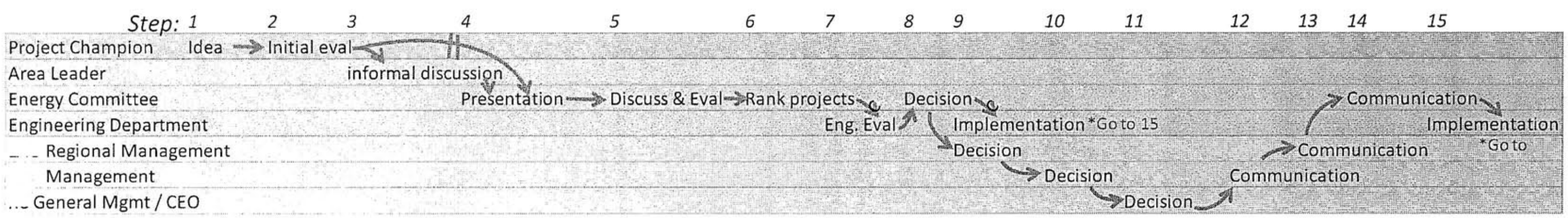
Once the project had been routed to engineering, someone from the department performed a more detailed assessment of the project, which typically included following a standardized Management Of Change (MOC) procedure (steps 15-16). The engineer responsible then specified the materials and equipment required and passed this spec to the purchasing department (step 17). Purchasing then solicited quotes from approved vendors in step 18 and reviewed the results with engineering to better understand the project needs (steps 19-20). This review generally resulted in purchase of the lowest-cost equipment which still met the safety and performance requirements of the project. Once the quotes were agreed upon, the Purchasing department negotiated with the vendors and bought the equipment (step 21). Engineering then worked with maintenance and operations personnel to schedule the optimal time for equipment installation in step 24 (typically during a planned maintenance outage). Once the equipment arrived, it was installed and started up according to the established schedule (steps 25-26). At some point later, a project review would be conducted with the appropriate stakeholders.

"Before" Snapshot of Energy Project Process at A2

Idea Generation Process for Energy Savings Projects



Project Evaluation Process



Project Implementation Process

Step:	15	16	17	18	19	20	21	22	23	24	25	26
Engineering Dept.	Detailed Eval	MOC				Quotes/Discuss			Equip. Delivery	Scheduling		
Purchasing Dept.		*See MOC	Equip. Specs		Quotes	Quotes/Discuss						
Vendors				Solicit Quotes			Purchase	Working				
Maintenance Dept.										Sched Installatio	Startup	
Operations Dept.										Scheduling		

Legend:

= Upper Management / Off-Site staff
= Site staff
= IT systems
= Site Management

Several problems plague this "Before" scenario, but there are three primary issues:

1. Multiple steps at each task stage;
2. Changeover of task and project ownership, and;
3. Resources are shared and not designated solely for energy projects

Under this system, approximately 50% of the projects created were completed from 2008-2010. This corresponds to about 50 projects completed out of 100 entering the system. Notably, a number of the 50 not completed were rolled over from year to year with no action, as evidenced in Figure 5-7.

The new energy project process that has been practiced since the installation of the LEAN Energy team in June of 2011 attempts to reduce or eliminate all three of these problems.

6.2 A2 Energy Project Process: "After"

In 2010, A2 began implementing its first wave of LEAN manufacturing within portions of the plant. In 2011, during the third LEAN wave, the Energy Committee was abandoned in favor of a LEAN Energy team consisting of mechanical, electrical, and process engineers, with management supervision from LEAN leaders. Whereas the Energy Committee had focused on equipment upgrades and the use of more energy-efficient technology, the LEAN Energy team shifted focus to measuring performance, meeting target metrics, and cultivating a culture of continuous improvement.

LEAN, as a management system, provides a framework for implementing change. Company X uses an adapted version of the LEAN framework that best suits its specific needs. The site's LEAN Energy team followed this framework, shown graphically and described below, throughout the four-month implementation period from June-September of 2011.

Figure 6-1. LEAN implementation framework utilized by the LEAN Energy team at A2

The six phases of LEAN transformation are described in further detail below:

<u>Preparation:</u>

1. *Analyze historical data*: The team gathered historical price, consumption, cost, and supply data with as detailed level of granularity as possible.
2. *Conduct Assessment Survey* - The team conducted a survey of approximately 50 personnel from different departments across the facility to determine the level of awareness and interest in energy-related plant issues.
3. *Raise Awareness:* The team, along with managers in plant, made signs, placards, and announcements to raise awareness in the facility about the team and its purpose.

<u>Diagnosis:</u>

1. *Project Brainstorming* – LEAN Energy team members brainstormed a list of potential projects, savings ideas, and assessment activities.

2. *Refine list & initiate buy-in* - The energy team reviewed and refined the list with department and area managers. Managers also brought up new ideas and suggested that operator training would be necessary.
3. *Analyze survey results:* Survey results confirmed that many employees believed that they did not know what was necessary to help reduce energy consumption in their operating areas, nor did operators know the energy targets for their areas.
4. *Defining measures and targets:* The team drew on historic performance data to establish energy efficiency targets (in MBTU/BDMT) for each production machine individually. They also installed flow meters, voltage monitoring, and other measurement devices to provide operators with actual consumption data in near-real-time. [Installing meters does not sound like a diagnosis step. It sounds like an implementation step.]

Planning:

1. *Plan, Schedule, Select, Assign:* The team planned the activities for the remainder of the four months. This included project selection, schedule-setting, and assignment of responsibilities.

Implementation:

1. *Visual Management Systems:* The LEAN Energy team labeled the new efficiency targets for each machine within the digital control system and on whiteboards in the control rooms, and established a system for bi-hourly reporting of actual consumption versus the efficiency target.
2. *Mindsets & Capabilities:* Training for 225 people was conducted to better explain the key factors affecting energy use in each step of the manufacturing process.
3. *Operational Systems:* The team implemented energy savings projects via equipment installations, upgrades, process changes and optimization. Some examples of projects include:
    a. Premium efficiency motors - installed higher efficiency motors in some applications. This project was previously identified but had not been implemented.
    b. Motor switching - by switching motors within the plant, the team was able to "right-size" equipment and save energy.
    c. Changing and standardizing procedures for startup of equipment – simultaneous startup of equipment after power outages lead to voltage and power spikes which exceeded A2's demand contract limit.
    d. Production shifting – the team found that some machines produced certain products more efficiently than other machines.
    e. Installation of vapor flow meters.
    f. Replacement and optimization of burners.

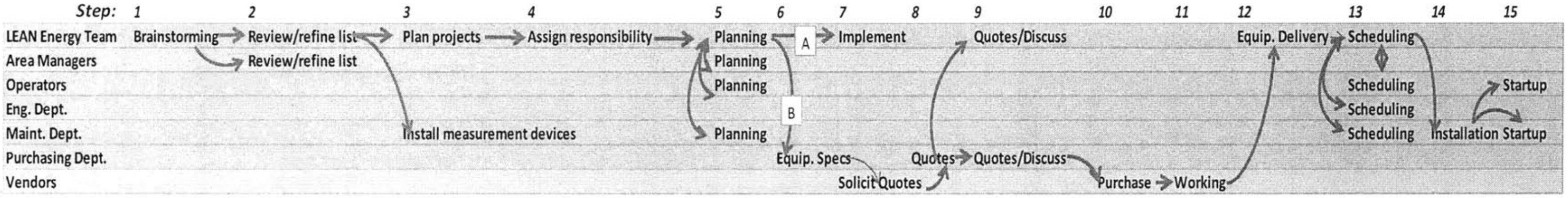
Keeping:

1. This stage focuses on sustaining the savings and results achieved during the previous stages. It is carried out by the operations staff rather than specific LEAN team members.

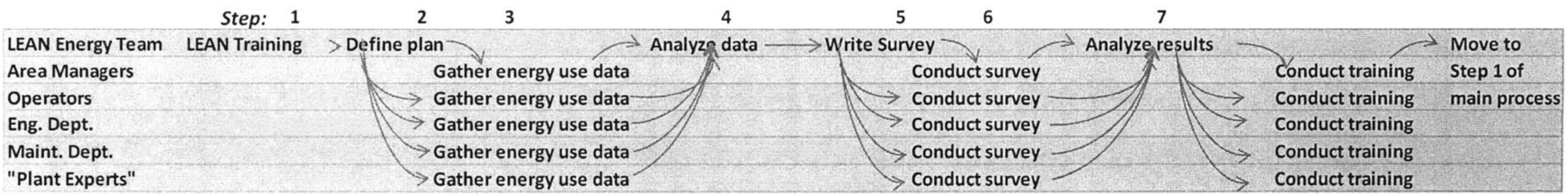
A visual representation of the timing and sequencing of the above framework is shown on the following page. This process is similar to that implemented by the Energy Committee, but with fewer steps. Additionally, rather than waiting for a project champion to be inspired with an energy-saving idea, the "After" methodology calls for the team to proactively brainstorm with the specific purpose of identifying energy-saving projects. The list created is then reviewed and refined with area managers to better assess feasibility (steps 2-3). For the LEAN Energy team, projects then go in one of two directions. If the project is part of a monitoring activity, the team then selects and installs measurement devices. This is essentially a one-time activity, however, because once in place, monitors should not need to be upgraded or replaced for some time. The remaining projects then go into the planning phase (step 3). The team starts the planning process jointly and then assigns responsibility for each project to a specific team member to complete the detailed work with the assistance of the appropriate personnel from asset management, operations, engineering, and maintenance (step 6). The output of this planning is the equipment specifications which get sent to purchasing to solicit quotes (steps 7-8). Once the quotes are back, purchasing reviews them with the original personnel from the LEAN Energy team (step 10) and buys the equipment (step 11). Once it arrives, the Energy team members work with operations, engineering, and maintenance to schedule and install the equipment (steps 13-14). Finally, the equipment is started up (step 15) and reviewed later during the final project reviews of the LEAN wave.

One key difference in the "After" scenario that is not captured in the process flow diagram is that the LEAN Energy team has focused thus far on projects that qualify as expense spending, whereas the Energy Committee generally deals with capital projects. During the latest LEAN wave, capital projects were handled by an informal engineering team. This group currently stands to deal with recommendations from the GEST team, and is not associated with LEAN in any way.

“After” Snapshot of Energy Project Process at Plant A2



Process used by LEAN team as part of LEAN activities prior to identification of savings opportunities



Legend:

= Upper Management / Off-Site staff
= Site staff
= IT systems
= Site Management

6.3 A2 "Before" vs. "After"

Some of the key differences between the "Before" and "After" processes are highlighted in the table below.

	"Before" – Energy Committee		"After" – LEAN Energy	
	# Steps	Task Leader	# Steps	Task Leader
Identification	6	Project Champion	1-2	Lean Energy
Evaluation	5-6	Energy Committee	1-2	Lean Energy
Decision-Making	1+	Plant Management	1	Lean Energy
Implementation	12	Project Champion	9	Lean Energy
Review	1	Variable	1	Lean Team
Project Type	Typically capital		Typically expense	
Staff Awareness	Low		High	
Management Support	Variable		High	

Table 6-1. Key differences between previous and current energy project processes

The table highlights the multiple steps required to complete each task in the "Before" state and showcases the continuous handoff of task leadership. In contrast, the "After" state simplifies the process with fewer steps and by placing ultimate responsibility for each stage with the LEAN Energy team. Furthermore, the LEAN Energy team is dedicated 100% of the time to work on energy projects, whereas the Project Champions from the "Before" scenario only worked on energy projects as a small component of their overall responsibilities. It should also be noted that the LEAN team focused on expense projects, eliminating the need for additional approval beyond the level of plant management. Management support for LEAN Energy projects is very high at A2, as LEAN is a strongly-supported program from the top down. This support also likely cleared the way for faster and simplified decision-making. Interviewees at A2 noted that, in the "Before" state, awareness among general plant personnel of any given project was typically very low, whereas in the "After" state, awareness is currently much higher because of the high visibility and importance of projects associated with LEAN.

What remains to be seen, however, is whether there will be any impact to the capital project process. Interviews with employees suggested that that process was overhauled as well, but in a much more informal way. When pressed for clarity, employees did not know the specifics of the workings of the new, informal process for implementing capital projects. Discussions with personnel in the finance department showed that the financial requirements for capital projects (shown in Table 6-1) remain the same as before the implementation of the new project process. These observations suggest that little has changed in the implementation procedure for capital projects, and the same problems that plagued all energy projects in the "Before" process will be likely continue to hinder capital projects going forward. Thus, a different revamped process for capital projects may be necessary.

7 Conclusion and Recommendations

7.1 Hypothesis Review

Earlier in this report, it was hypothesized that applying lean principles to the management of energy projects can yield greater savings results than traditional project management techniques. The methodology of conducting an energy audit, recommending areas for improvement and equipment upgrades, and leaving it to the site team to implement the solutions was discussed in general and tested specifically at one site within the Region 1 organization. This work was very similar to the current state of energy management at the company, with an outside team of energy specialists visiting a plant to conduct the energy audits and provide recommended technical improvements. An analysis of the energy project completion rate was taken as proxy for the energy savings results of this implementation strategy, and these results were compared with the energy projects implemented under an integrated LEAN program with a focus on energy as one component. The chart in Figure 28 shows a step-change in the number of projects completed at one site when moving to a LEAN-based approach. Fewer handoffs of project leadership and fewer process steps were seen as characteristic of a LEAN-based approach as well. Under these measures, the results do not refute the hypothesis.

The energy efficiency metrics of several plants were compared in Figures 23-26, and a direct comparison between two Type-A plants shows that the plant which adopted a LEAN-based approach improved energy efficiency slightly while the efficiency of the other plant declined for the same period. While these results are consistent with the hypothesis, it should be noted that two Type-B plants which did not implement a LEAN-based energy cost reduction program saw improving energy efficiency metrics as well. This result suggests that a more controlled study should be undertaken in the future.

7.2 Key Insights and Recommended Approach for Organization Rollout

The previous section identified that observational results are consistent with the stated hypothesis, although a more robust experiment should be undertaken to control for variable between plants. However, anecdotal evidence offers some insight into the key takeaways relevant for rollout of a LEAN-based energy management program to additional sites.

Monitoring & Metrics

1. Monitor energy consumption – It is said that one cannot change what is not measured. Real-time monitoring and feedback moves the effect on consumption temporally closer to its operational cause, which eases the diagnosis of problems. Energy consumption is a continuous process and weekly or monthly data collection misses the majority of the information.

2. Set energy efficiency KPI's and make them as granular as possible – Setting an energy consumption target per line or area is paramount to monitoring performance deviations relative to goals. LEAN techniques such as visual management can be used to show how an area is performing vs. the target. Deviations from target should be identified and corrected as soon as possible.

Strategic Design

1. Assign a project leader and hold them accountable – A project management process that has too many ownership handoffs leads to miscommunication and a lack of ownership.

2. Provide the necessary resources – Project leaders whose primary responsibilities lie elsewhere make for lousy project leaders. Dedicating personnel 100% to the project demonstrates management commitment and creates a consistent work environment.

Culture & Politics

1. Focus on and publicize quick wins – low or no-cost projects with lower potential savings are often faster to implement. Work on these first and publicize the results to build momentum.

2. Leverage LEAN – Instituting a new standalone initiative risks being viewed as management's newest 'flavor of the month' program. Rolling energy reduction into existing LEAN frameworks reinforces the importance and usefulness of LEAN to the organization

3. Support the effort – Management sets the tone and a new decree without demonstration of commitment from management undermines everything else.

One important point to note is that expense projects naturally can be implemented faster than capital projects and feedback is quicker. People are able to see results more quickly and close temporal juxtaposition helps to understand the relationship between effort and result. In contrast, this is generally not the case with capital projects. For this reason, capital projects may need a different structure in order to sustain them through their long process and connect the beginning to the end.

Proposed Rollout & Implementation

Dedicated teams in each of the plants may not be feasible due to staff levels. However, a central team which travels to the plants in order to implement projects likely will not have the support and buy-in necessary from the individual sites. Thus, a hybrid approach may be best. This could be similar to how LEAN has been implemented in some locations – i.e. with a local team to support the day-to-day but an outside team to initiate the change. Ultimately, handoff to the local team is required. The sustaining or "keeping" portion, as with LEAN, will be the most difficult. Part of the traveling team could include staff from LEAN Energy in A2. Integration into LEAN would be helpful for several reasons:

1. LEAN is already being implemented or will be implemented in every plant worldwide, per executive level decision. The infrastructure to support it is already in place
2. LEAN has visibility and upper management support, so add-on programs are more likely to succeed
3. LEAN focuses partly on eliminating waste – which is exactly what energy efficiency does. Eliminating waste almost invariably also reduces energy consumption because energy is embedded in everything. LEAN also helps participants to focus on systems thinking,

which aides in evaluating the energy savings opportunities, carbon reduction methodologies, and self-generation options.

The recommendations provided here are assembled based on the observed results from four plants within the region. However, benchmarking by looking to other companies and industries could provide additional insights and opportunities for innovation not considered here. The next section discusses possible areas for future work.

7.3 Suggestions for Further Research

The work described in this paper examined from a qualitative perspective the results of different energy project management processes within one organization. At their heart, these are operational practices. One area largely untouched by this study is the impact of differing financial practices. The financial rules used for evaluating projects can have significant impact in how they are implemented, or whether or not they are implemented at all. Many companies have found it difficult to financially justify energy reduction projects. As a result, they often do not even attempt to justify them and complete them anyway [1]. Others, such as the Dorsey Company, have taken a portfolio approach, where projects in individual regions are optimized for cost and environmental impact in order to meet the sustainability goals of the company. For instance, a solar installation that receives carbon credits in a region with high electricity prices can be used to offset a coal-fired facility elsewhere in a low-price electricity region. On balance, this portfolio of energy projects meets the company's targets for total cost and CO_2 emissions reductions [21]. Still other companies simply price carbon internally and add this to the traditional NPV or payback period calculation.

Another area that could be interesting to explore would be to test the impact of modified financial criteria to the number of energy savings projects implemented. This could be as simple as moving from, say, a two-year payback requirement to three years. Pricing the risk of future energy price increases or of supply disruptions into the financial assessment could reveal even better ways to evaluate energy projects. This is especially important for Company X because of the high relative impact of electricity compared to other energy types.

A more focused assessment of self-generation opportunities for every facility in the network could provide significant value as well. In A-type plants, the combined heat and power (CHP) opportunities abound because of the large heat loads. This fact, combined with the high electricity prices in many of Region 1's operating areas, presents potentially attractive CHP opportunities. Even just the installation of some electrical generating capacity, as opposed to meeting the full demand at any given plant, could cut out costs from peak load pricing.

Lastly, an assessment of the recommended actions listed above, once they have been implemented, would provide another opportunity for process improvements. Bringing the best practices to each of the other plants provides more opportunities for process innovations.

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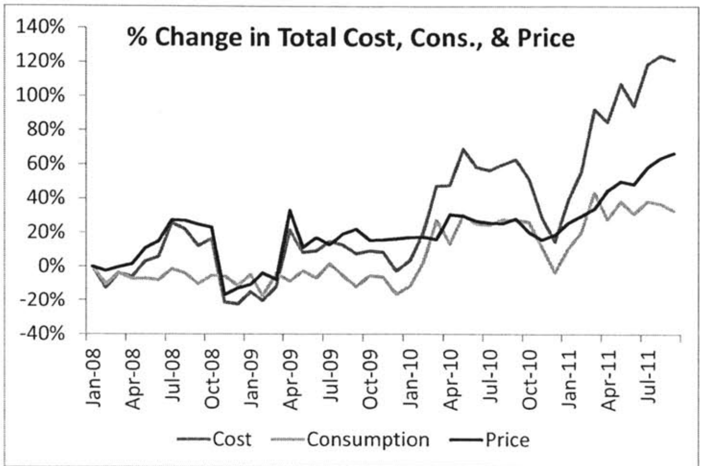
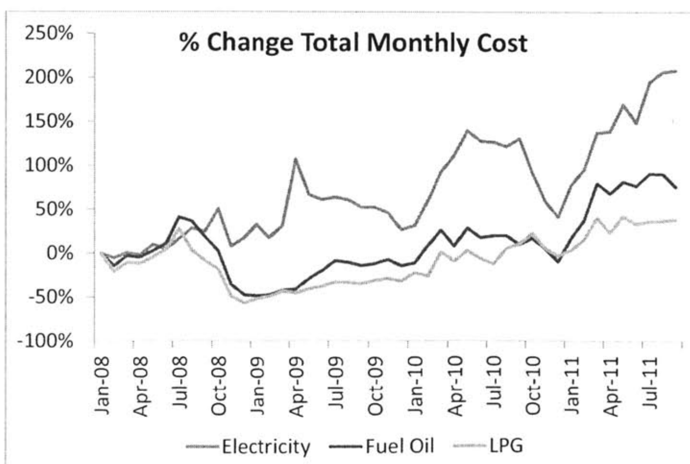
Appendix A: Energy Consumption in Plant A2

The A2 facility is one of Company X's largest in Region 1. This facility contains four A-type manufacturing machines. As such, both electricity and fossil fuels play a large role in the energy consumed at the plant. The plant operates several boilers which can be heated using either fuel oil or LPG. The third primary energy type consumed is electricity. In recent years, energy costs have been rising at the facility, causing some concern for cost control. The chart below highlights this increase.

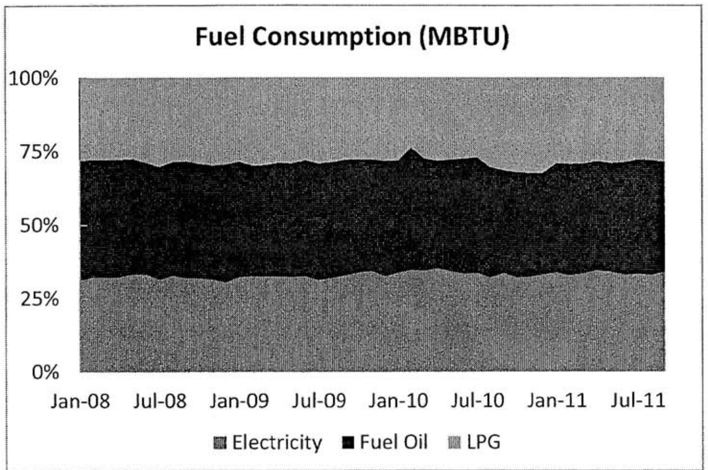


Here we see that we have rising total energy costs coinciding with both increasing consumption and increasing prices. Specifically, prices appear to drive the increase occurring near April 2009, whereas consumption increases drive the cost increase that occurs near January 2010. There is a drop in both consumption and cost near October 2010, while average prices remain mostly stable. Then, around January 2011, we see a sharp increase in costs again, which is driven at first by a combination of increasing prices and consumption, but is sustained through the remainder of the year due to increasing prices. Consumption remains relatively flat from about April onward.

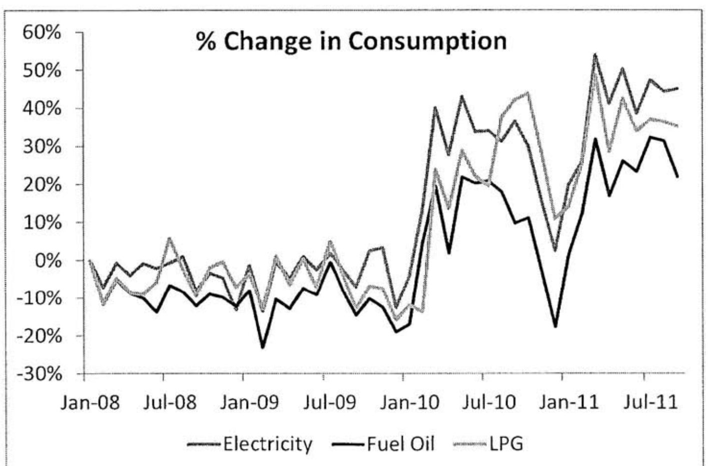
To get a better sense of the total cost picture, we examine the change in total monthly cost by fuel type below:



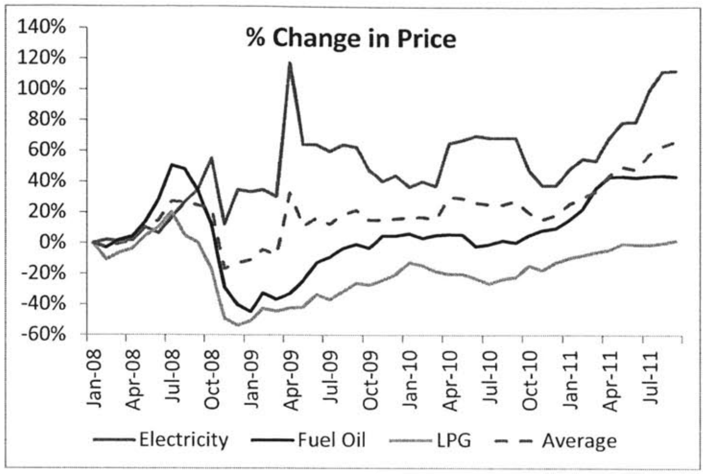
Here we notice an upward trend for all three fuel types, with electricity costs leading the way at a nearly 200% cost increase from January 2008 to September 2011. One potential explanation for the disproportionate rise in electricity costs would be a shift in the plant energy consumption mix to be more concentrated in electric energy. The chart below shows that the mix has stayed relatively constant over this time period. Indeed, the split is nearly 1/3 for each energy type.



Total consumption over this period has not stayed so constant however:



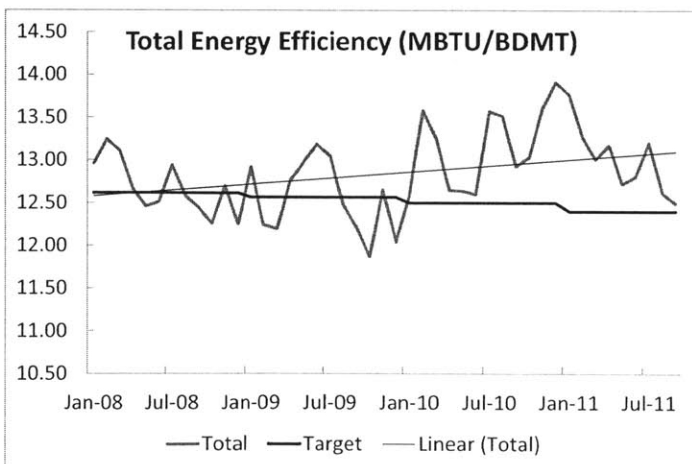
Here we notice several things. First, there is a sharp increase in consumption for all fuel types around the start of 2010, just as we saw in the first chart. This coincides with the startup of a new machine at that time. Similarly, the dip near January 2011 coincides with the shutdown of machines 1 and 2 for maintenance activities. Additionally, we note that prior to 2010, the consumption for each fuel type was relatively stable, within a +5% and a -20% band. Given these trends shown above, we might reasonably guess that electricity prices increased to a greater extent than prices of fuel oil or LPG. Indeed, the price history shows such a trend:



From an energy basis, electricity is almost always more expensive than other fossil fuels. This relationship holds true for A2 as well. Thus, changes in electricity prices have a greater effect to total costs than do changes in fuel oil or LPG prices.

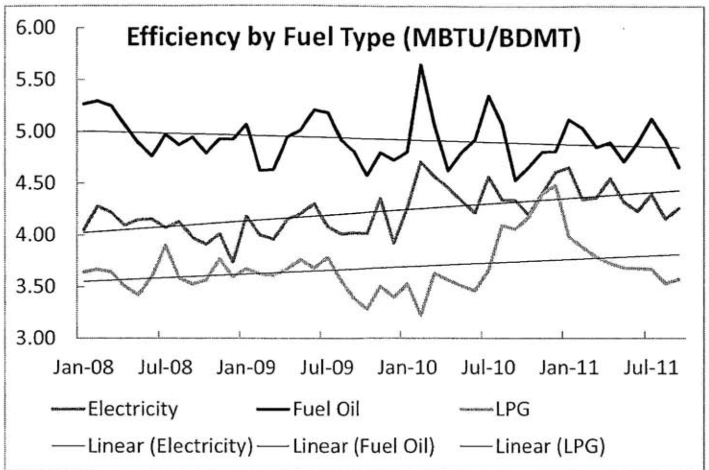
Profits, Sustainability, and Efficiency

It goes without saying that there are two levers which can be used to generate greater profits: raise revenues by producing (and selling) more stuff, and lowering costs. With the installation of a new machine, A2 is taking a very big step towards the former. But rising energy prices will diminish the attractiveness of increased production, making energy efficiency a primary concern. Below, we see the total production-based energy efficiency for A2:



We have plotted here the actual energy production efficiency in terms of MBTU per bone dry metric ton, along with the linear regression line for this data and the internal target set by the company for comparison. The linear regression indicates an overall trend of increasing consumption per unit production, or decreasing energy efficiency.

The graph below shows the production efficiency in MBTU/BDMT for each of the three fuel types, as well as the linear regression over this time period.

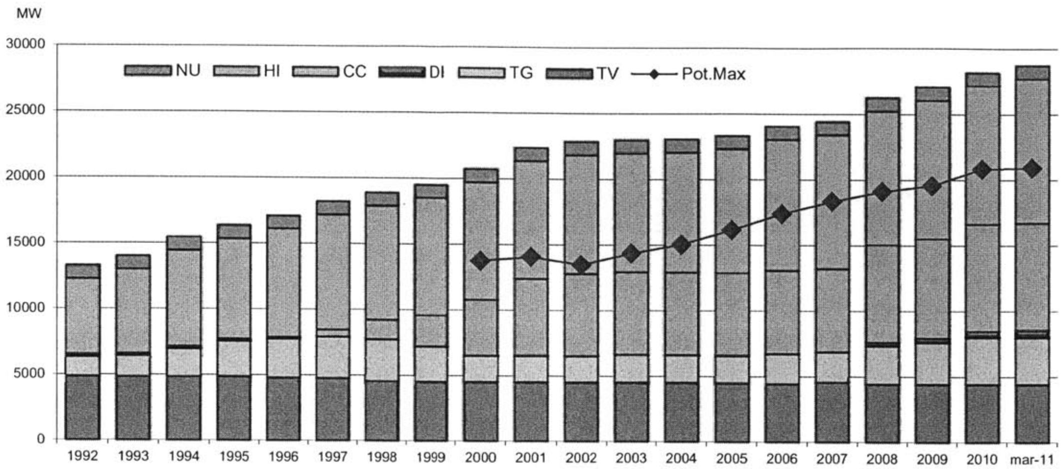


Here we notice that while fuel oil usage has been improving, the energy efficiency for both electricity and LPG is decreasing over the time period. We do note that efficiency is stable or improving for all three fuel types almost until January 2010. At this point, both electrical and LPG efficiency appear to decline (i.e. consumption per unit production starts rising).

Appendix B: Analysis of Electricity Markets & Recent Trends in Country 1

Generation Trends

The electricity markets in Country 1 have undergone considerable change from 2002-2011. This time period saw a slightly slower rate of growth in generating capacity as compared to the previous 10 years, with the majority of new capacity coming through new natural gas combined cycle power plants. These plants are called combined cycle because they pair a Brayton cycle (using a gas turbine) with the traditional steam-driven Rankine cycle. In this setup, the exhaust from the gas turbine is used to reheat condensed steam, which then drives the steam turbine to produce additional electricity.

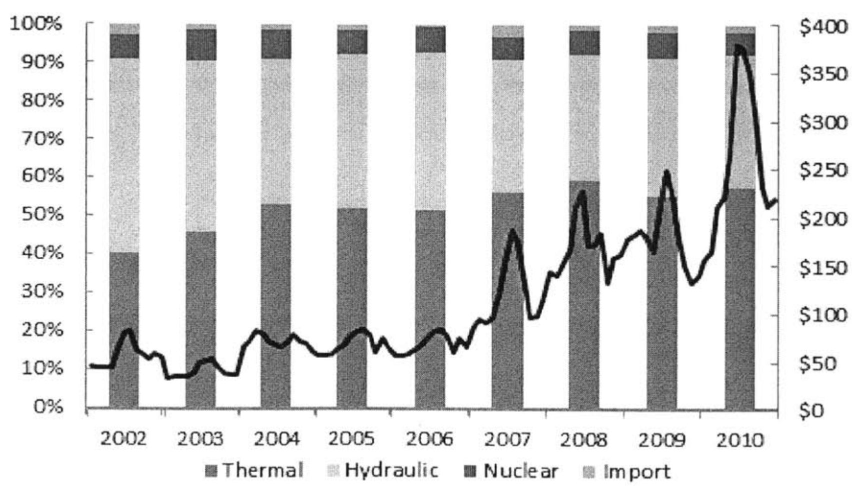


Electric generating capacity in MW. TV=steam turbine, TG=gas turbine, DI=diesel, CC=combined cycle, HI=Hydraulic, NU=Nuclear

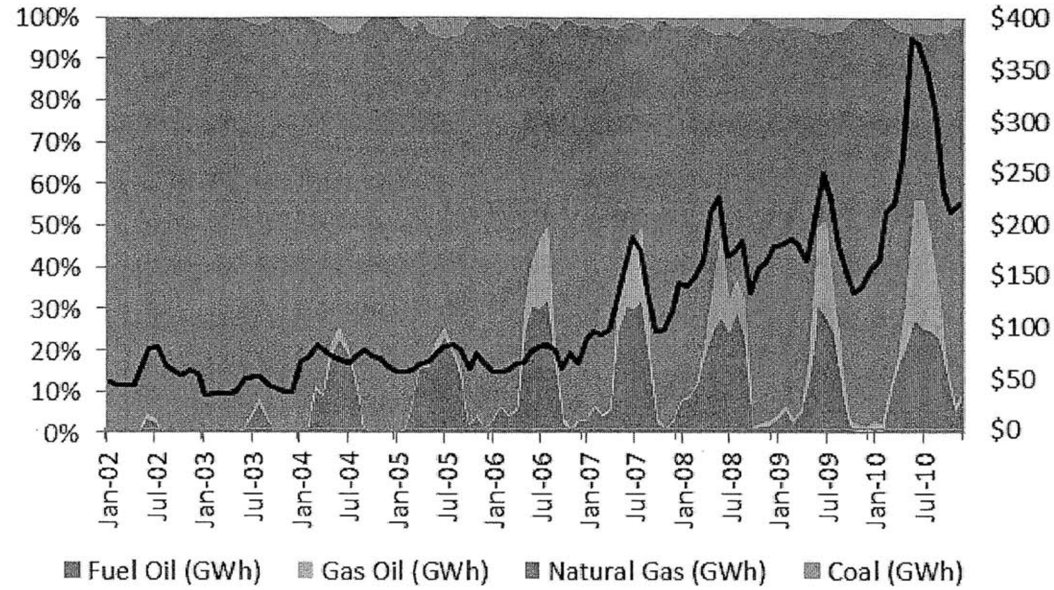
The figure above highlights the substantial growth in combined cycle generating capacity over the time period. Further, we note that the maximum power demand has increased as a percent of generating capacity (blue line).

Fossil Fuel Prices and Consumption for Electricity Generation

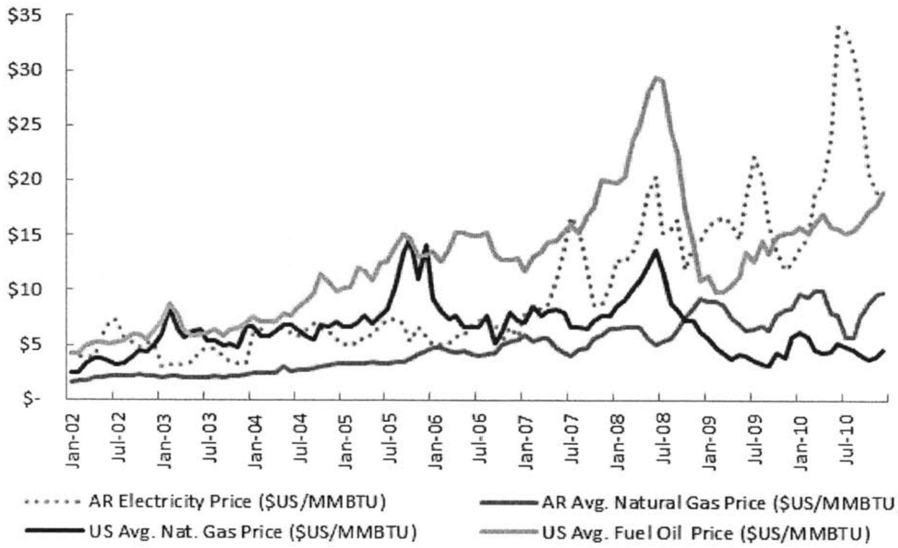
Over this same time period, average electricity prices per MWh have increased significantly. The chart below shows the average price trend in comparison to the shifting makeup of the generation fleet:



Here, we notice that the average price per MWh increases by nearly a factor of seven. It becomes apparent that these price increases have occurred as the generating fleet has become more heavily-weighted toward fossil fuels and the excess capacity above demand has decreased. Further, we note increasing seasonal price variation in the years 2007-2011, with the peak prices occurring during the winter months. One item of note is that natural gas is the primary fuel used for heating the residential sector. During the winter months, natural gas demand increases sharply, while supply cannot necessarily keep up. Thus electricity generators must shift to using other fuels. The estimated breakdown in fuel use for electricity generation is shown below:



The chart above shows the percentage of generation from all thermal combustion sources attributable to each fossil fuel type. We note that natural gas makes up the majority of fossil fuel-based power generation throughout this period. However, it is supplemented significantly during the winter months - so much so, that in the winter of 2010, fuel oil and gas oil combined to make up over 50% of thermal generation. Further, by overlaying the average price per MWh curve onto the fossil fuel breakdown, we can see that, since 2007, the spikes in price appear to align exactly with the periods of fuel oil and gas oil use. Clearly, seasonal variation in average electricity prices could be possible due to price discrepancies between these fuels and natural gas in the winter months. In fact, that is exactly what we see in the graph below:

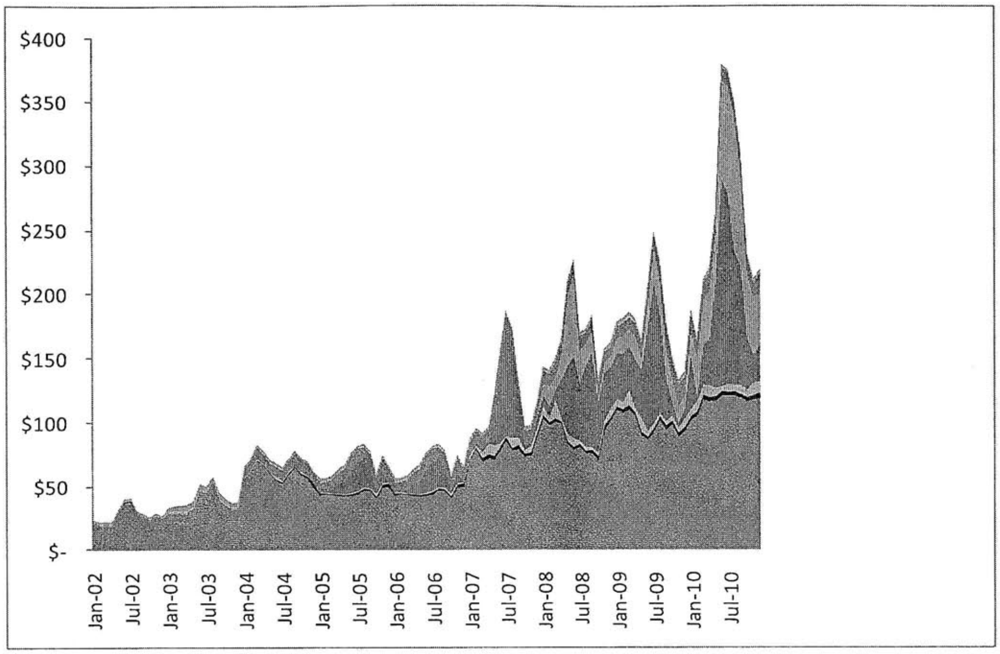


There are several interesting points to note about the above graph. First, the prices for natural gas in Country 1 do not necessarily correlate to natural gas prices in the U.S. In fact, until late 2008, gas prices in Country 1 were lower than in the U.S. Prices have been climbing more or less continuously since 2002, with exceptions for seasonal variations between the summer and winter months. In contrast, the U.S. market has seen higher levels of volatility, and lower prices since 2008 due primarily to increased production capacity. The seasonality in Country 1's market emerges in 2006, with prices rising during the summer.

Second, historical average fuel oil prices for Country 1 have been difficult to find. Thus, fuel oil prices in the U.S. are used as a proxy. Based on limited data from Country 1, it appears that fuel oil prices in the U.S. generally trended lower during this time period (based on 2010 data). Although the absolute prices are undoubtedly different, the trends in relative costs are likely to be similar. Using this logic, we can say that fuel oil prices are substantially higher than natural gas prices on an energy basis. Further, from a technical standpoint, the process of generating electricity from fuel oil or gas oil is typically somewhat less efficient than using a gas turbine. Specifically, the heavy use of NGCC power plants further increases this discrepancy in generating efficiency within Country 1.

Details of Electricity Charges

Now that we have seen the broader macroeconomic conditions driving the electricity market in Country 1, we shall examine the details of consumption according to the energy bills. Fortunately, the government-run electricity market regulator keeps records for the average spot price. The details of the historical trend for this information are shown below.



From the graph above, we can see the steady increase in electricity prices, coupled with the extreme peaks and valleys noted in the most recent years. Here, it is readily apparent that a temporary dispatch overcharge has been the primary driver for the increased variability and extreme spikes in the energy price. This charge is established by the government as an extra fee applied for the act of dispatching the electricity and varies month-to-month. The extra demand charge is the cost associated with power demanded in excess of the previously agreed-upon allotment, and represents a substantial cost as well. Lastly, the energy price has increased approximately six-fold since 2002. This charge can be read as the effective cost to generate the electricity consumed.

Appendix C: Sample Interview Questionnaire

Discussion questions for A2 interviews

Interviewee: ______________________________

Title:

Time:

Date:

Location:

1. What is your role at A2?

2. In what way have you been involved with energy activities at A2?

3. Please describe the process for energy-savings projects:
   (Think about Output, Pathway, Connection, and Activity/Method – who does what, who must communicate with whom, how is the information transferred, what is actually done, and how?)

   Identification:

   Evaluation:

   Decision-Making:

   Financing:

   Implementation:

After-action review:

4. What happens during an energy site visit? (i.e. from GEST team, etc.) After? Before the next visit?

5. If energy projects were/are part of your role, what else falls under your responsibility?

How would you describe the split of time/effort between energy projects and your other responsibilities?

6. How long has the energy committee been in place? How long have the site energy visits taken place?

7. What were the goals/objectives of the energy committee? Is it meeting/did it meet them? Why or why not?

8. What is the role of LEAN Energy? What are its goals/objectives?

9. How are these goals similar/different from the Energy Committee?

10. Is LEAN Energy meeting these objectives? Why or why not?