Generating and Calculating Energy Intensity Savings from Manufacturing Productivity Improvement Projects

Glen LaPalme, Alternative Energy Systems Consulting, Inc.
Kirk Prather, California Manufacturing Technology Consulting
Ron Ishii, Alternative Energy Systems Consulting, Inc.
Gerald Church, California Manufacturing Technology Consulting

ABSTRACT

The objective of this paper is twofold: (1) to briefly describe how energy intensity savings (energy saved per unit of output) are obtained by applying lean manufacturing techniques that increase plant productivity, and (2) to present three different approaches used to model manufacturing energy efficiency gains resulting from plant productivity improvements. In 2004-05, Southern California Edison (SCE) contracted with California Manufacturing Technology Consulting (CMTC) to demonstrate that plant energy efficiency could be cost effectively realized as a result of factory productivity improvement projects partially funded by the utility. This approach differs from conventional utility energy efficiency programs, in that the emphasis is on increasing the efficiency of the whole manufacturing process and not just individual pieces of equipment such as lighting, motors, fans, pumps, compressors, boilers, etc. The energy savings estimation tool developed for this program evaluates the energy savings as being the result of one or a combination of the following energy saving impacts: material waste reduction, equipment (or process) energy efficiency improvement, and/or plant productivity improvements. Where suitable data was available (i.e., interval meter energy use and daily production levels) regression analyzes were performed to estimate the savings and/or compare to the results calculated with the program's energy savings estimation tool. This paper will also discuss lessons learned, data collection requirements for estimating and verifying project savings, estimated program impacts, and issues such as improving the sustainability of results.

Introduction

Southern California Edison (SCE) contracted with California Manufacturing Technology Consulting (CMTC), for the energy efficiency budget program period 2004-05, to offer an innovative program called "VeSM+" and to test whether applying lean manufacturing and quality improvement techniques to increase plant productivity could be a viable utility incentive program for increasing energy efficiency among their manufacturing customers. "VeSM+" is an acronym for "Value and energy Stream Mapping (VeSM) Advantage Plus™". The name refers to the addition of energy modeling to classic value stream mapping, which is a powerful lean manufacturing diagnostic and analysis tool.

The goal of the VeSM+ program was to realize energy savings for manufacturing production lines by improving manufacturing productivity. As a part of this effort, SCE contracted with Alternative Energy Systems Consulting (AESC) to develop an energy savings estimation tool that would help CMTC standardize the estimating and reporting of energy savings for the utility. Some of the development team objectives were to:

- Develop a simple model that is fairly easy to use;
- Minimize plant data collection requirements;
- Maintain flexibility so that the estimation tool is not limited to a narrow set of productivity improvement types; and
- Create a platform that connects the results of productivity improvements to production and energy usage changes.

Some of the original concerns in the development of the evaluation tool were the following:

- Many sites have load uncertainty which complicates baselining energy intensity;
- Unforeseen changes to production baselines can originate from many sources: operations, change in product output, weather, equipment, etc.;
- Statistical methods are difficult with limited data sets or data not randomly selected;
- Many sites can implement the developed productivity improvement into their operations almost immediately after participation in the improvement projects, but other sites will need time to implement planned changes on other equipment and work groups in their factories; and
- If the model is too simple, determining full site impacts may be difficult.

The calculation approaches described herein differ from the more conventional approaches of optimizing equipment energy efficiency. However, the standard verification terminologies and methodologies developed for the latter have been employed (i.e., International Performance Measure and Verification Protocol). To target where energy savings actually occurred, three areas of improvement were classified: (1) Material Waste Minimization, (2) Equipment Efficiency Improvements, and (3) Plant Productivity Improvements.

Also, to provide flexibility, three possible productivity improvement calculation pathways were developed. The appropriate choice depended on the availability of data, plant configuration, and type of productivity improvement being considered. The options are the following:

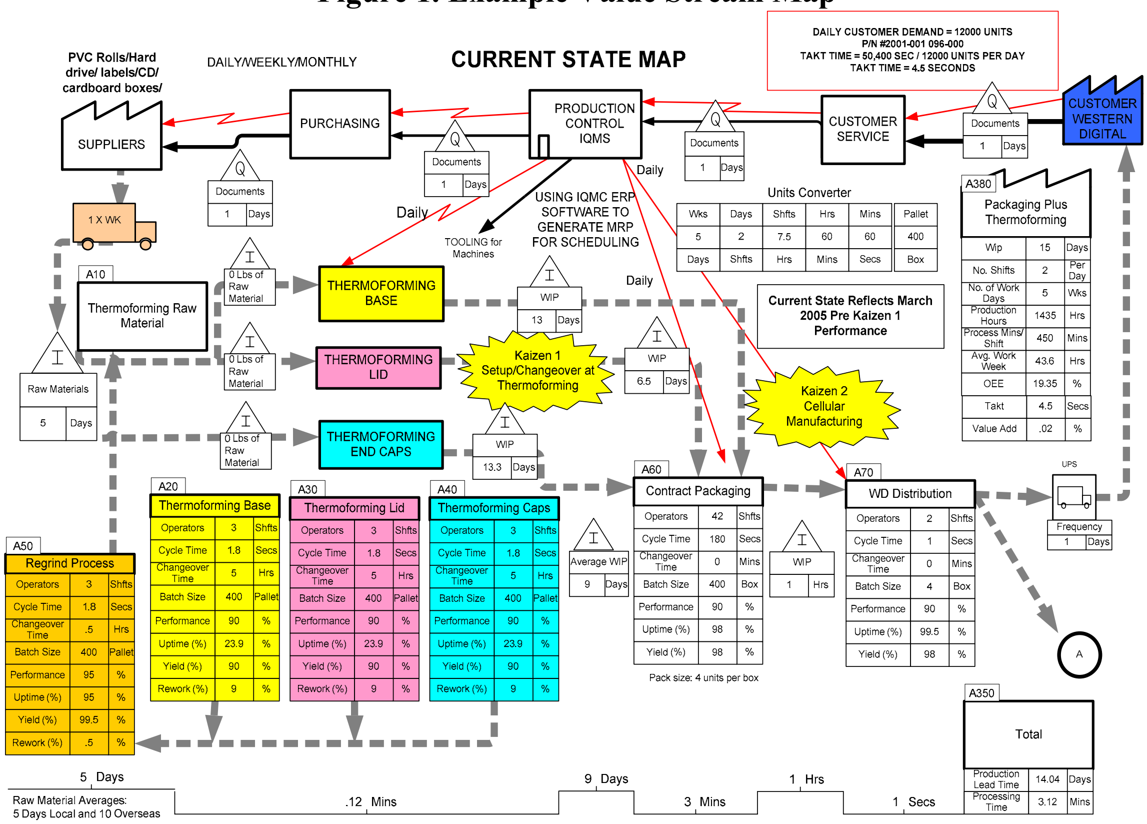
- Option A-1, Complete Facility Audit
- Option A-2, Partial Facility Audit
- Option C-1, Whole Plant Billing Analysis

The differences between these options are best described by their data requirements. One of the greatest challenges to conducting the energy savings analysis for the VeSM+ program was being able to clearly and quickly communicate data needs. Unfortunately, not all sites maintain or can readily provide equipment specifications, daily end-use operating hours, daily quality yield, and daily production data in a user-friendly format. It was important to understand the hierarchy of data requirements and to be realistic when requesting plant information.

Process Improvement Events

The VeSM+ client engagement program was designed by CMTC to help a manufacturing company make a jumpstart improvement in manufacturing production efficiency (and thus energy efficiency) in a short time - ideally within 3-4 months, definitely within 12 months. See Figure 1 for an example of a value stream map from CMTC. The project approach with the client primarily utilizes their own personnel plus one or more lean manufacturing and/or quality improvement consultants. The consulting resources for a VeSM+ contract consisted of approximately three to four man weeks of effort and the target energy efficiency improvement was about 118,000 kWh/yr per client plant engagement contract. The client had to commit 30% of a $25,000 fixed fee engagement project cost which paid primarily for the diagnostic study phase. SCE paid 70% of the total consulting project cost which essentially paid the consulting fees for two productivity improvement projects.

Figure 1. Example Value Stream Map



Source: Church

The first of four phases of the engagement was a diagnostic study where CMTC consultants worked with management to pick a product or product line with promising opportunities for increasing both productivity and energy efficiency. The assigned consultant would then develop a current state "value stream map"[1] of all the process steps in the selected manufacturing process, including energy consumption, for the selected product (or product line) from receipt of an order (or forecast) to the shipment of the product. Based on the information

[1] Rother and Shook in their book "Learning to See" describe value stream mapping as "all the actions (both value added & non-value added) currently required to bring a product through the main flows… production flow from raw material into the arms of a customer." Toyota practitioners call it "product and information flow." CMTC use special software to graphically show the flow with related tables for each process with all its pertinent parameters of cycle time, elapsed time, yield rate, production rates, etc.

revealed in the mapping, the consultant would then identify a list of potential productivity or quality improvements, develop a future state map based on practical and realistic performance goals, and provide preliminary estimates of the corresponding reduction in energy intensity. The first diagnostic phase ended with a consultant and management meeting and the selection of the two best short range improvement projects that would also save the most energy.

The next stage was the improvement phase where two improvement projects called "Kaizen"[2] events, or "Kaizens", were conducted. Lean manufacturing practitioners have learned that a very cost effective way to make rapid improvements is to put together a small team of workers and supervisors, and to sometimes include technical expertise from engineers or technicians (if appropriate) on the team. These teams then focus full time for about 40 hours on fixing a problem or making an improvement.

One effective way for employees to learn quickly, especially for shop personnel, is to learn by doing. The Kaizens often start with short training sessions on techniques that will be applied. Then team members immediately implement or demonstrate the improvement technique for which they were trained. Typically, CMTC would provide the experienced leader or facilitator and the Kaizen team would meet full time for one week (40 hours) on assignments such as reducing the setup time on a machine, creating a new manufacturing cell, eliminating/reducing a major cause of product defects, etc. In smaller companies, where elapsed time is required to gather data on experiments between analysis sessions, it is usually necessary for the team to meet once a week for one or more hours for a period of 8-13 weeks. Also smaller plant operations can not afford to spare key people from daily production responsibilities for 5 days without interruption.

The following list illustrates the variety of lean manufacturing productivity and quality improvement techniques used in Kaizens: one piece flow versus traditional batch and queue, line balancing, work cells, reduction of bottlenecks, setup time reduction, defect reduction or elimination, workers becoming trained and certified to perform in-line inspection checks, redesign of work stations and production lines, mistake proofing, and the like.

The third phase of the engagement was to implement the improvements so that they can be placed into practice, sustained and if appropriate expanded. For example, if the Kaizen team developed the procedure and demonstrated reducing a machine setup from 5 to 2 hours, all setup personnel on similar equipment would need to be trained, possibly new tools purchased, or special equipment acquired, to fully implement the improved procedures. It is also important to convince plant managers to track relevant performance metrics in order to demonstrate and sustain the targeted productivity improvement.

The fourth phase of the engagement was to develop the energy savings calculations, using before and after data, based on what was accomplished. CMTC monitored production data and held periodic review meetings to check on the progress and the sustainability of the original results. Ideally in the post period, clients will have improved results from additional implementation of what was learned and originally accomplished during the productivity improvement engagement with the consultants. Spillover effects have tremendous savings potential, but thus far have been difficult to verify. To get an idea of the overall impact of a program of this type, it has recently been reported that the potential for energy savings from

[2] "Kaizen" comes from Japanese terminology roughly meaning "improvement" and in practice usually involves a special team assigned to solving a problem quickly. Kaizen teams that meet for 2-5 days full time are sometimes called Kaizen blitzes.

productivity improvements in many manufacturing plants can be as high as 50% (Oppenheim, 2006).

Energy Models

One of the early challenges of the program was to quickly and accurately estimate the potential energy savings from a variety of productivity improvement alternatives. As in all energy analysis the cost of the effort (e.g., data collection and system modeling) needs to be weighed against the value of the results (e.g., estimated savings of 10,000 kWh/yr versus 1,000,000 kWh/yr). For this reason, three (3) different calculation approaches were developed for the VeSM+ program: Complete Facility Audit (Option A-1); Partial Facility Audit (Option A-2); and Whole Plant Billing Analysis (Option C-1). Table 1 is the program's data requirement matrix for each option.

The intention of these guidelines was to provide direction for CMTC field consultants, who may have little or no energy auditing experience, on what energy models to use given different project and estimation constraints. Also, it was hoped that at some sites more than one option would be computed so comparisons of the calculation approaches could be made. The following sections detail each estimation option.

Table 1. Estimation Methodologies and Data Requirement Matrix

Option	Production Equipment Audit	Material Waste Audit	Equipment Efficiency Audit	Equipment Utilization Audit	Support Equipment Audit	Utility Bill Data	Production Data	Improvement Report
A-1	x	x	x	x	x	x	optional	x
A-2	optional	optional	optional	optional	x	x	x	x
C-1	optional	optional	optional	optional	x	x	x	x

Option A-1, Complete Facility Audit

Option A-1 requires a complete audit of both the production line equipment and the supporting equipment systems. The goal of this approach is to create a baseline production energy model for the entire facility that could then be modified, based on specific productivity improvements, to create a post case model to compare with the baseline for determining energy savings.

The estimated energy consumption for each stage of production ($EC_{PROD(n)}$) and supporting equipment ($EC_{SE(n)}$) are based on the simplest operating factors of end-use energy consumption – i.e., connected load (CL), load factor (LF), utilization factor (UF), and approximate hours of operation (HR). The governing equation for both end-use types is the following:

$$EC_{PROD/SE} = \sum_{1}^{n} EC_{PROD(n)/SE(n)} = \sum_{1}^{n} CL_{(n)} \times LF_{(n)} \times UF_{(n)} \times HR_{(n)}$$

Utility load factors, minimum efficiency standards, and rules of thumb were used to populate the model. See Tables 2 & 3 for examples. At this point, the goal was to get a 'reasonable' accounting of all the energy consuming equipment.

Table 2. Stipulated Load Factors for Commercial and Industrial End-Uses

Load Type	Load Factor
Continuous Use	0.9
Process Equipment	0.8
Equipment Machining	0.5
Machine Tools	0.3

Table 3. Typical Values for Supporting Equipment

Supporting Equipment	Assumptions	Load Factor	Utilization Factor
Lighting	Standard Lighting, 1.5 Watts/ft^2	0.9	1
	New Lighting, 1.0 Watts/ft^2	0.9	1
HVAC	400 ft^2/ton, 1.15 kW/ton, 1300 hr/yr	1	1
Air Compressors	Standard Controls	0.85	1
	VSD or Poppet Valve Controls	0.6	1
Process Ventilation	Continuous Operation	0.8	1

The total estimated energy consumption (EC_{TOTAL}) was compared to the last 12 months of monthly billing data to validate the baseline energy consumption model. If the total calculated baseline energy use in the model was not within 10% of the actual metered energy consumption, then the equipment assumptions were re-evaluated. If needed, additional site inspections or plant operator surveys were conducted. Also, the decision to further evaluate actual end-use performance was based on the equipment most impacted by the productivity improvement event, or Kaizen, the size of the preliminary savings estimate, the cost of conducting measurement and verification, and the identification of secondary energy conservation measures.

For Material Waste Minimization (MWM-A-1) measures, the estimated energy savings (EES) were based in the following equation:

$$EES_{MWM-A-1} = \sum_{1}^{n} EES_{MWM(n)} = \sum_{1}^{n} EC_{PROD(n)} \times MWR_{(n)}$$

Where $MWR_{(n)}$ is the percent Material Waste Reduction of production stage *n*. The implied assumption in this equation is that the relationship between energy consumption and waste is linear. This estimate does not include the potential reduction in energy consumption of supporting equipment, which could result from fewer hours of overall plant operation required to meet the same level of production.

The baseline consumption for the efficiency improvement is the original baseline energy consumption minus any estimated energy savings for the material waste reduction. For the Equipment Efficiency Improvements (EEI-A-1), the governing equation is as follows:

$$EES_{EEI-A-1} = \sum_{1}^{n}((EC_{PROD(n)}) \times (1 - EFF_{pre(n)} / EFF_{post(n)}))$$

This equation captures the increased operating efficiency of the production equipment that is expected from minimizing idle loads or improving current operating practices to run equipment at or near peak efficiency. An interesting example from the 2004-05 SCE program involved improving the operating efficiency of compression molding machines. This Kaizen enhanced worker procedures and workplace design for the machine operators so they could more quickly unload, clean and reload the resistance-heated molds on the compression molding machines. These procedural changes significantly reduced the mold heat loss during the unload-reload cycle, thus reducing the energy used to mold the product and increasing the molding machine operating efficiency.

For Plant Productivity Improvements (PPI-A-1), the model assumes that the supporting equipment energy consumption (indirect) remains constant relative to the production line equipment energy consumption (direct), which varies as production levels change. In other words, an increase in production levels proportionally increases production energy consumption ($EC_{CP(n)}$) but is assumed not to affect the energy consumption of the supporting equipment ($EC_{SE(n)}$). As a result, productivity improvement energy savings can be calculated in terms of kilowatt-hours only using the following equation:

$$EES_{PPI-A-1} = \sum_{1}^{n}(EC_{CP(n)}) \times \left[\frac{EC_{SE}}{\sum_{1}^{n}(EC_{CP(n)})} - \frac{EC_{SE}}{\sum_{1}^{n} EC_{NP(n)}} \right]$$

Consequently, the program savings estimates were based on the reduction in supporting energy consumption per unit of total production energy and were limited to the baseline production level, which is a more conservative estimate. If the plant increases its output because of the additional production capacity created by the program improvements, additional savings per unit of production should occur. It was assumed that the new production energy consumption ($EC_{NP(n)}$) is a function of the estimated increase in production line equipment utilization. Accepting this premise, the new total production energy consumption estimate will exceed the current total production energy consumption. Lastly, baseline adjustments were made to account for savings from multiple improvement gains to avoid double-dipping when calculating savings; these corrections are not presented here.

Option A-2, Partial Facility Audit

Option A-2 is the second stipulation approach and is based on an audit of the supporting equipment and an analysis of the monthly utility bill data. The approach is similar to the methodology used for PPI-A-1. The difference is that the stages of production are not itemized. Instead, the estimated energy cost of production is approximated by subtracting estimated energy consumption of the supporting equipment (EC_{SE}) from the total annual energy consumption reported in the utility bills (EC_{UTIL}). The general equation is the following:

$$EES_{A-2} = (EC_{UTIL} - EC_{SE}) \times \left(\frac{EC_{SE}}{(EC_{UTIL} - EC_{SE})} - \frac{EC_{SE}}{(EC_{UTIL} - E_{SE}) \times \frac{PIP_{post}}{PIP_{pre}}} \right)$$

- For Material Waste Minimization (MWM-A-2), the Process Improvement Parameter (PIP) is the increase in acceptable production throughput (100% - waste %).
- For Equipment Efficiency Improvements (EEI-A-2), the PIP is the pre- and post-equipment efficiency.
- For Plant Productivity Improvements (PPI-A-2), the PIP is the pre- and post-utilization.

All three improvement types could affect the production schedule and reduce the operating hours of the entire plant. Of particular interest is any reduction of weekend or overtime operation. It is during these overtime periods that the energy intensity is typically the highest and the potential savings are the greatest. So far, neither of the Options A-1 or A-2 of the standard tool calculation are capable of accounting for these changes. For these conditions to be modeled, an entire plant billing analysis is required.

Option C-1, Whole Plant Billing Analysis

A more detailed calculation approach involves developing a model of the facility's energy intensity. The standard calculation for estimating energy savings from a reduction in energy intensity at a specific Production Quantity (PQ) is (Papadaratsakis, 2003):

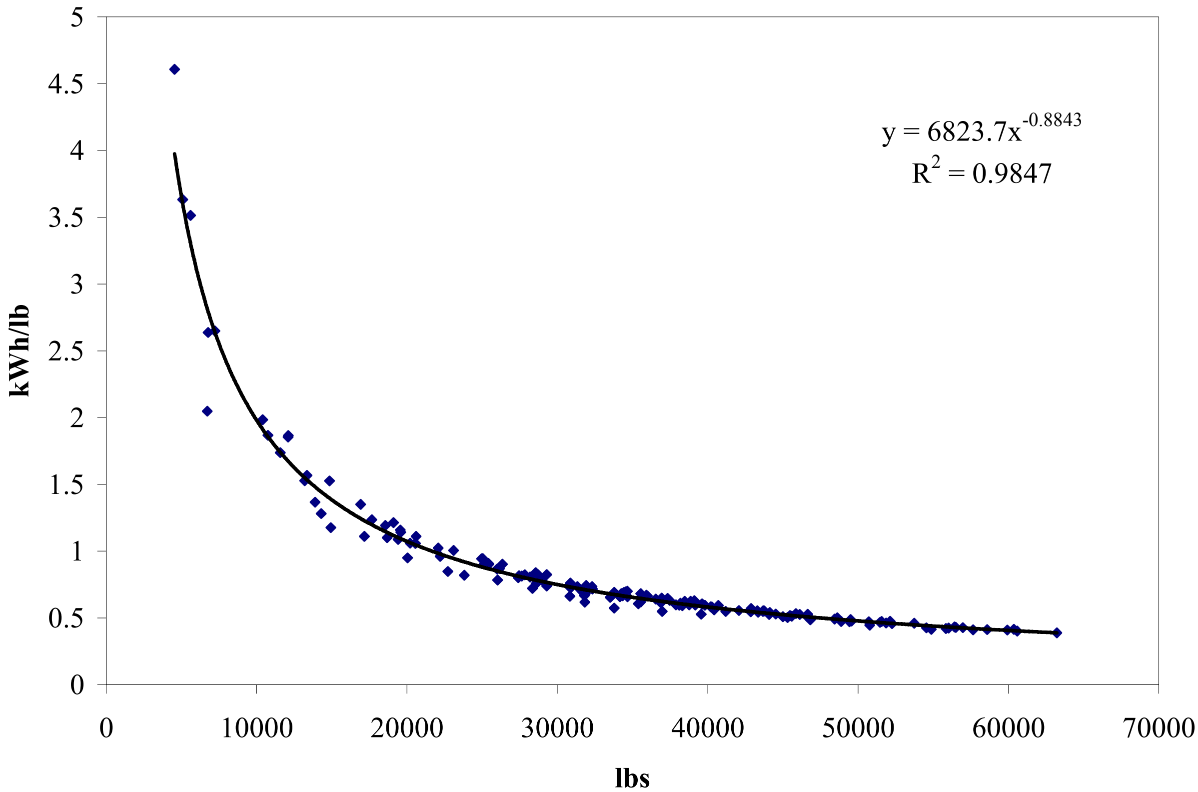
$$EES = (CEI - NEI) \times PQ$$

Based on the work done for this program, we found that energy intensity is best modeled using a power trend with daily production as the independent variable. The general expression for the Current Energy Intensity (CEI) at the current (baseline) production level (CP) is the following:

$$CEI = a \cdot CP^{b}$$

Even though the productivity improvements will increase the production capacity (i.e., more widgets per day), this non-linear approach was used to try to ascertain more accurately how much energy is saved when producing the same quantity at higher productivity levels or at different times. Figure 2 is an example energy intensity curve.

Figure 2. Example Energy Intensity Curve



In this example, a closer look at the data revealed that most of the low system efficiency operations (i.e., high energy intensity) in the graph took place on weekend days. It is presumed that weekend or overtime operation is required to meet customer shipping obligation because the plant is limited by the baseline utilization and productivity levels. As a result, the whole plant must be brought online on the weekend or continue to operate after hours just to run one of the plant's product lines. Consequently, all or most of the supporting equipment (lights, air compressors, water chillers, etc.) may be running, while only a small fraction of the production equipment is being utilized. Hence the ratio of support energy to direct energy is greatly increased, resulting in a higher operating energy intensity.

The next step in the calculation is to estimate the New Energy Intensity (NEI). For Material Waste Minimization (MWM-C-1), NEI was determined using the following equation:

$$NEI_{MWM-C-1} = CEI \times \frac{(1 - WL_{pre})}{(1 - WL_{post})}$$

Where, WL is the Waste Level, pre and post. Here the CEI curve is being proportionally adjusted downward based on the reduction in material waste. For Equipment Efficiency Improvements (EEI-C-1), the NEI is the following:

$$NEI_{EEI-C-1} = CEI \times \frac{EFF_{pre}}{EFF_{post}}$$

Again, if this efficiency improvement is successful it will be proportionally reduced future energy intensity. For a Plant Productivity Improvement (PPI-C-1), the NEI is a function of the new level of production (NP).

$$NP = CP \times \frac{UF_{post}}{UF_{pre}}$$

The NEI resulting from increased utilization (UF) is the following:

$$NEI_{PPI-C-1} = a \cdot (NP)^{b}$$

To account for the impact of simultaneous improvements, these equations can be combined to represent the overall impact of the process improvements on the facilities energy intensity.

$$NEI = a \cdot \left(CP \times \frac{UF_{post}}{UF_{pre}} \right)^{b} \times \frac{EF_{pre}}{EF_{post}} \times \frac{(1 - WL_{pre})}{(1 - WL_{post})}$$

Weaknesses in this approach were the difficulty of modeling a facility with multiple and unrelated product lines, and identifying savings from specific improvements on some production equipment but not all the production equipment. Efforts to develop multivariate linear regression models using Excel were not successful. Possible reasons for the poor model quality include non-linear relationships between end-use energy consumption and units used to normalize the production data (e.g., pounds of plastic), and/or discrepancies between the actual time of production and the date production orders were recorded as complete. More sophisticated multivariate curve fitting techniques, which were beyond the scope of this project, may produce better results and should be considered in future estimation and verification work.

Program Results

The goal of the VeSM+ program was to implement productivity improvements at 22 manufacturing sites and achieve 2,587,200 kWh/yr energy savings in the form of reduced energy intensity. The average targeted savings per site was approximately 118,000 kWh/yr. Originally 24 sites were targeted in the contact duration period from mid-2004 to the end of 2005. Of the original 24 company plants that had committed to this program, CMTC was only unable to start or finish work for two client engagements because one company went into chapter 11 and another changed ownership. The VeSM+ program completed 22 company engagements. However, several clients needed to finish implementing projects after all the Kaizens were finished, either implementing the improvements on additional machines or finishing their production line renovations in progress.

Based on commitments to complete two unfinished implementation projects within calendar 2006, as of July 2006, CMTC and AESC jointly circulated a report projecting savings of 4,627,808 kWh/yr for the program contract, which exceeded our original contract goal of approximately 2 million kWh/yr. This is an average annual savings of 210,354 kWh per site for all 22 sites contracted, and 257,400 kWh per site for the 18 sites for which energy savings were estimated. A summary of the energy savings by improvement type and calculation methodology are summarized in Table 4.

Table 4. Estimated Electrical Energy Savings by Approach and Improvement

Estimation Approach	Material Waste Minimization		Equipment Efficiency Improvement		Plant Productivity Improvement		Totals
	Sites	kWh	Sites	kWh	Sites	kWh	kWh
Option A-1	2	167,584	2	313,334	12	922,136	1,403,054
Option A-2					2	503,092	503,092
Option C-1	3	184,752			4	2,536,910	2,721,662
Totals	5	352,336	2	313,334	18	3,962,138	4,627,808

Example results for individual company sites ranged from zero claimed energy savings in several plants to one large plant that demonstrated savings over 1 million kWh/yr. Among several improvements at one site, CMTC quality consultants helped a company team investigate and find hidden causes of defects in machine setups, material handling, and storage of parts. The team implemented low cost, simple fixes that obtained up to 2% improvement in 1st pass yield in this very high energy use factory. In another case, the Kaizen teams implemented single piece flow (versus batch and queue), level mix plant loading with line balancing, and cross-trained workers to help each other in virtual work cells. These changes resulted in an over 90% increase in monthly output; preventing the addition of a 3rd shift and helping the company avoid losing a major contract with Boeing. The total plant energy use increased significantly but the energy used per piece declined by 47%, not to mention the parallel corresponding reduction in labor cost which greatly exceeded the energy savings in dollars. Typically, performance verification was based on plant operations several months before and after implementation the Kaizen events.

The exceptional energy savings projects outweighed the cases with no or disappointing energy savings, although all the engagements achieved good returns in overall operating cost reduction. For this range in performance, CMTC learned some valuable lessons about when and where productivity improvements tend to generate the highest energy savings. As a result of the overall achievements of the 2004-05 SCE contract, CMTC has since contracted for variations of this program in the 2006-08 funding period with SCE and three more investor owned utilities in California. Except for some large California municipal utilities, the original SCE sponsored VeSM+ program with various changes will soon be tested across the manufacturing sector of almost the entire state of California.

In addition to the direct program impact, additional energy savings opportunities totaling 2,042,754 kWh/yr were identified and presented to the program participants as potential energy efficiency opportunities. It is known that at least 40% of these secondary savings, mostly lighting projects, have been implemented. In future programs, with concerted effort this spillover effect could easily be expanded to target other types of energy conservation measure, including no/low cost opportunities.

Conclusion

Over the past 30 years energy conservation opportunities in the manufacturing sector have shifted from gross waste reduction to the application of advanced energy efficient technologies and production optimization (Shipley and Neal, 2006). However, productivity improvement projects (including product quality and yield improvements) have been generally ignored by government and utility policy makers as important industrial energy efficiency improvement strategies. One reason is productivity improvement projects, while reducing energy intensity, sometimes increase total factory energy consumption as a result of higher levels of production made possible by successful productivity improvement techniques. Also, some believe that productivity improvements tend to be less reliable or less permanent, and/or less sustainable than a hardware solution to achieve energy efficiency. On the regulatory side, many observe that non-hardware solutions are sometimes more difficult or expensive to audit and verify in the years following the project.

The 2004-05 VeSM+ program, as developed and tested by CMTC and SCE, has demonstrated that applying lean manufacturing and best quality techniques to entire production lines/facilities can cost-effectively reduce a facility's energy intensity and additionally deliver significant non-energy related cost reduction benefits, helping the manufacturing sector stay competitive in the local and global economies. Productivity savings that develop significant energy savings yield even greater cost savings in material and labor costs. These non-energy cost benefits are an advantageous consequence of the VeSM+ program because they make available to management unanticipated capital that could be invested into other energy efficiency and/or productivity opportunities at the facility. It is our conclusion that productivity improvement programs are a cost-effective complement to standard energy efficiency programs in the right application and site. Therefore, programs that encourage productivity gains while lowering energy intensity should be included in the utility's energy efficiency portfolio.

With all that in mind, this type of program still faces a unique set of implementation and accounting challenges, in addition to those of the conventional energy efficiency programs. For example, successfully sustaining productivity improvements requires a management's commitment to continually investing and documenting improved procedures, maintaining performance metrics, creating positive employee and management expectations, and offering employee rewards/incentives for maintaining and increasing productivity gains that have been achieved. Otherwise, unless continuous improvement rates exceed negative productivity factors, like employee turnover and other inevitable negative changes in sales and production, the gains achieved will erode over time. Also, estimation and verification of energy savings from productivity improvements will be more, not less, challenging than the standard equipment replacements or control upgrades. In part, this is a result of the discrete nature of manufacturing operations which must quickly transform to respond to fluctuations in customer demand, product changeovers, new technologies or other market conditions. Despite the challenges of sustaining and enhancing manufacturing process changes, many world class companies have dramatically demonstrated remarkable and measurable continuous improvements in product quality and production productivity (including energy efficiency) gains in the last 30 years. The Toyota Co. reported in a 2006 article in Time magazine that they decreased the energy required to produce Toyota cars by 30% since 2001. It is likely that world class companies will continue to or further implement practices that reduce their energy related cost of production. The important question to ask is will the majority of the companies be foreign owned, adding to the many competitive advantages they may already posses, or will they be domestic manufacturing firms whose historical advantage has been a willingness to adapt and innovate.

Fortunately, this work of finding a way to cost-effectively encourage both manufacturing productivity and energy efficiency is not evolving in a vacuum. The experience of prior incentive programs and the availability of current verification protocol provide a roadmap and subsequent vantage point from which to advance this type of program. A case in point is California's Standard Performance Contract (SPC) Program, which has undergone many program modifications to make it more cost-effective on all levels: participation, administration, energy accounting, and validation of project/program performance. As has been done for the SPC program, developing "reasonable" standard estimation and verification protocol for specific lean improvements will greatly increase the effectiveness of delivering energy savings from factory productivity improvements in the future.

References

Church, G. 2005: "Value and Energy Stream Mapping (VeSM^{TM}) Linking Manufacturing Improvement to Energy Efficiency", *Proceedings of the 2005 World Energy Engineering Conference*. Lilburn, GA: Association of Energy Engineers.

Oppenheim, B. 2006: "Impact of Productivity of Energy Conservation", *Strategic Planning for Energy and the Environment*, Vol. 26, No. 3. Lilburn, GA: Association of Energy Engineers.

Papadaratsakis, Kyriaki, Donald J. Kasten, and Michael Muller. 2003. "On Accounting for Energy Savings from Industrial Productivity Improvements." *Summer Study on Energy Efficiency in Industry 2003 Sustainability and Industry: Increasing Energy Efficiency and Reducing Emissions.* Washington, D.C.: American Council for an Energy-Efficient Economy.

Rother, Mike and John Shook. 2000. "Training to See: A Value Stream Mapping Workshop." University Park, IL: Productivity Press, Incorporated.

Shipley, Anna and Neal Elliott. 2006. "Ripe for the Picking: Have We Exhausted the Low-Hanging Fruit in the Industrial Sector." Washington, D.C.: American Council for an Energy-Efficient Economy.