Industrial Energy: Counseling the Marriage Between Energy Users and Efficiency Programs

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ABSTRACT

Industrial energy users and the efficiency programs that serve them enjoy a long and storied partnership. Each partner operates with the best of intentions, but with agendas that are not always reconcilable. At best, this yields a marriage that is not as fruitful as it can be. At worst, it creates alienation and wastes the value that this union has the potential to generate.

Most marriages need periodic renewal, as the partners pause to take stock of their past progress and their future vision. The marriage of industrial facilities and energy programs is no different. If industrial energy efficiency is to reach its full potential, programs must evolve beyond a courtship based on the "low hanging fruit" of easy, low-cost improvements. What began as an effort to reduce utility bills can become a strategic partnership for boosting industry competitiveness and economic growth. This approach necessarily involves capital investment choices. Aside from the usual technical analyses, industry managers and program administrators will need to effectively navigate the procedures and politics of corporate investment. This suggests an evolution in energy program communications and conduct.

This report compares the business-as-usual marriage between industry and energy efficiency programs. Drawing from a survey of stakeholders,[1] we extrapolate lessons-learned and offer a vision for sustaining that marriage in the future [Note: please read the footnote below to become familiar with the acronyms used in this report]. What are the opportunities and rewards? Equally important, how can the partners work together more productively? What does this vision imply for future program design and conduct? This report, submitted for the 2013 Industrial Energy Technology Conference, will offer suggestions. A companion social media platform will invite readers to react with comments that will refine our basic vision. It is our intention to have this document evolve into a public discussion—one that we hope lasts far beyond the close of the conference.

INTRODUCTION

Since their inception in the 1970s, government and utility energy programs for the industrial sector have offered technical support for diagnosing, designing and engineering energy solutions. By its very nature, technical support stimulates onsite industrial program interaction. To the extent that interaction is confined to discrete projects or events, the assistance can be provided by consulting experts during episodic facility visits. However, intermittent assistance tends to yield intermittent results. An energy manager, integral to a company or facility, provides the leadership and organizational continuity for implementing change.

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[1] This report is derived from a non-scientific survey of 30 industrial energy stakeholders conducted during the summer of 2012. Respondents are mostly corporate end-users but some program administrators and solution providers are included as well. Respondents included large, energy-consuming manufacturing companies with annual revenues of $10 billion or more; medium-sized manufacturers with annual revenues between $1 billion and $10 billion; small manufacturers with annual revenues below $1 billion, and *facilitators*, which can be solution providers, trade groups, or coordinators of government- or utility-sponsored assistance programs. Each facilitator observes dozens of mostly smaller companies. The acronym "SME" is used in this report to refer collectively to small and medium-sized energy-consuming enterprises. A scientific survey would have collected a much larger number of responses, using a sample frame that included respondents from each industry in proportion to their population numbers. This approach would have anticipated industry-specific generalities in the data collected from survey responses. Even had this been achieved, the knowledge of any "average tendency" for a given industry would be of little use to an energy program administrator planning the next facility engagement. Simply put, each facility is unique in its approach to energy management, which underscores the need for individualized outreach.

Traditionally, industrial energy efficiency has focused on hardware and equipment. Program efforts may entail energy assessments of facility buildings and their major mechanical and electrical systems. It is also common to provide feasibility and design studies to support individual energy projects. Assistance of this nature has certainly caused the implementation of many energy efficiency improvements. However, evidence suggests that much efficiency potential across industry remains untapped [Russell 2010]. This is due in large part to conflicting organizational priorities that prevent proposed changes. These are "change management" issues—tasks that cannot be addressed with technical skills and hardware alone.

SURVEY OF INDUSTRY REACTIONS TO ENERGY PROGRAMS

A growing number of utilities and governments offer energy management advisory programs to supplement the typically scarce resources available to industrial facility managers. As the scope and variety of advisory programs evolve, so do industry strategies for employing these resources. In general, advisory and analysis measures include energy assessment studies that investigate potential energy improvements for a system or entire facility, feasibility analyses for specific projects, and some combination of financial assistance such as a cost rebate or low-interest loan.

Some program administrators insist that industry remains unaware of program incentives. The survey responses suggest that even when industrial managers are aware of such incentives, they vary widely in their willingness and ability to utilize them. Industry receptiveness varies with corporate cultures, as no two companies are alike in their setting of priorities and the pace at which these are pursued. Similarly, no two energy managers are alike in their combination of skills, empowerment, and abilities to inspire their colleagues to action. At the same time, the design and content of energy programs will vary as will industry's reaction. The immediate implication for future assistance program design is that one-size-fits-all offerings will have limited potential. Programs will depend more on custom measures that nuance the delivery of program services. To successfully engage the SME segment, programs may rely more on account reps that spend more time with a portfolio of clients, providing each with analytical and administrative support—therefore becoming an effective adjunct to facility management.

All respondents indicate that third-party consultants and contractors are employed to varying degrees to assist with the analysis, design, and fabrication of capital projects (21 large, five SMEs, and four facilitators' observations of SMEs). Of these, the majority tend to employ local, trusted vendors with whom a long-term relationship has been established (12 total, eight large, four SMEs and facilitators). By contrast, there was one large company respondent that uses outsourcing sparingly, pointing to the difficulty of orienting an outsider to the complex facilities that an internal engineering team can adequately analyze. The kind of work that is outsourced varies. Companies tend to use their own staff for the engineering and installation of smaller projects. In a couple instances, respondents say that they retain critical feasibility studies while outsourcing simple, run-of-the-mill analysis. Some others do exactly the opposite. One large company respondent notes that third-party analyses boost the credibility of the staff's internally generated improvement concepts.

The overwhelming preference for long-term, trust based vendor relationships frequently eschews formal bidding procedures. But when bidding is performed, requests for proposals are usually issued to a well-established short list of familiar vendors. The bidding process is most often performed at the facility level as opposed to corporate, favoring local vendors. Especially among SME facility managers, the local vendors often enjoy professional group or even personal relationships. Note that two companies (one large, one SME) issue corporate direction to its facilities dictating the use of specific vendors. The large company limits such direction to certain technologies such as lighting retrofits.

Only some of the 30 respondents were openly enthusiastic about program support. Their comments yield a provisional segmentation of their attitudes:

POSITIVE PROPONENTS (2 OF 30 RESPONDENTS). These respondents were energy managers, who claim that their job was made possible largely or entirely by direct funding from a utility assistance program.

MOTIVATED OPPORTUNISTS (10 OF 30). These respondents indicate that they (or their program patrons) actively seek energy improvements because of the incentives. To paraphrase respondents, proposed energy improvements are prioritized only if incentives are involved (3 respondents, all SMEs); at least some initiatives are instigated by assistance programs (2 SME, 1 large); securing utility rebates is a precondition for approving projects (1 SME); and it's difficult to do energy improvements without utility support (1 large). One facilitator notes that incentive deadlines motivate many companies to act with more alacrity. The same facilitator states that companies are not attracted to incentives just for the money; their investments are driven by true business fundamentals (but see next point).

CASUAL OPPORTUNISTS (10 OF 30). These respondents indicate that their companies pursue capital projects as they normally will, not because of incentives, but they will pick up any incentives that happen to be available. Paraphrased comments: Will use utility incentives if available (2 large, 2 SME); good projects stand on their own merit, however, mid-sized companies in particular have learned to expect and seek incentives (1 facilitator); project timing coincides with the availability of incentives (1 large); incentives don't speed up implementation, but they do improve feasibility analyses (1 large, one SME); incentives make renewable energy projects more likely (1 large); and rebates are to be preferred over tax incentives simply because it's easier to apply rebates to a specific budget within the business unit (1 large). One facilitator, contrary to the above, says that some SMEs are really responding to the incentive money. Once they are aware of the offer, then they begin to investigate the potential for improvements.

DISMISSIVES (8 OF 30 RESPONDENTS). These respondents indicate pessimism, if not hostility, toward program assistance. To paraphrase: reluctant to pursue assistance offerings due to volume of paperwork, too many points of contact, would need consultant help to navigate the process (3 SMEs); incentives are a small dollar volume relative to replacement needs (2 large); not able to take advantage of assistance programs because of the possible appearance of impropriety (1 large); audit suggestions are redundant to what they already know (1 large); and incentives help, but it's the magnitude of savings that will ensure project approval (1 facilitator).

LIMITS TO PROGRESS

Survey respondents commented on the hurdles, or at least extenuating circumstances, that determine the pace and volume of energy improvements. Note, however, that the respondents speak mostly from the perspective of middle managers from facility departments. These respondents may have strong knowledge of facility management agendas, but not all will necessarily understand or correctly interpret the dynamics of their top management's capital investment practices. Nor do corporate leaders always understand the realities of facilities management. In short, capital projects are often deliberated by decision-makers with disparate agendas and less than perfect knowledge. Dissenting opinions may exist within an organization's management team regarding what is, can be, or should be done regarding energy improvements.

A previously published report describes anecdotal observations of decision biases exhibited by corporate managers [McKinsey 2011]. These can be categorized as:

- **Confirmation bias.** Decision makers' analyses tend to be more harshly critical of reasons to accept an investment; analysis of reasons to reject proposals is not nearly as strident. This leads to a tendency to underinvest.
- **Bias derived from inappropriate analogies**. The business world tends to rely on analogies, acronyms, and jargon—all forms of verbal shorthand—to communicate ideas. When such messages are wrongly interpreted, bad decisions can be made. Energy issues tend to be complex and are especially susceptible to this. The term "energy efficiency" may mean something different to each member of a management decision team. Energy program communications need to be crafted with this problem in mind.
- **Champion bias.** In some organizations, decision makers react more to the power and personality of an investment's proponent, rather than being convinced by the merit of the proposal itself.

Returning now to our survey, respondents also reveal disconnects between decision-makers within an organization. At least two respondents (both large companies) note that corporate leaders provide staff with few resources to back sustainability pledges made to the public. In one example, there are no accountabilities to compel the chief financial operating officer to make investments in sustainability outcomes—despite the company's public pledges. At least three respondents note that energy managers are simply not empowered to pursue energy-saving investments if these would supersede the competing wishes of operations or maintenance directors. One large company respondent notes that energy projects are more difficult to implement if the impacts are felt across departmental lines. Supporting this idea, another respondent notes that an energy improvement is more easily accepted when the idea comes from the department that has responsibility for the impact. Another reason for stalled energy projects is ever-changing incumbents among the decision team. Incoming managers bring with them a learning curve and a different set of values and priorities. The greater the rate of management turn-over, the greater the chance for delaying, postponing, or outright cancelling capital project proposals.

Industrial investment priorities are shaped by operational philosophies. One facilitator describes the staff of one facility that stubbornly believes in a fixed ratio of energy per ton of product produced. To them, "energy efficiency" means a reduction of output and revenue. Old operating rules-of-thumb last for years, assuming a fixed trade-off among time, energy and money. All too often, these assumptions don't change even as the prices of these inputs vary.

Perhaps the most common barrier to industry's investment in energy improvements is a combination of fear and misunderstanding. A lack of information, or sometimes misinformation, feeds this fear. At least seven respondents (two large, two SMEs, and three facilitators) claim that the balance of an industrial organization cannot see the value of energy improvements. Many key decision-makers perceive no vested interest in the outcomes of such improvements. Fear can be further nuanced from individual survey responses: fear of projects failing to deliver promised results, or fear of adverse affects on production yield, capacity, or quality. Fear also breeds resistance: one facilitator suggests that staff on the shop floor can purposely derail corporate energy directives by simply failing to comply with them. Note that organizational politics can play a role: one respondent indicated that unionized facility staff were reluctant to suggest any changes that might impact collective bargaining work arrangements. Another facilitator says that long-time facility workers are often jaded by past episodes of failed energy efficiency promises. A different respondent, however, says that staff resistance to energy-related changes is minimal. As one large company respondent notes, a lot of the older staff have some good energy-saving ideas on the shelf that were passed over by earlier management teams.

Individual respondents also cite a lack of internal skills, a shortage of funds for employing consulting help (particularly among SMEs), and a lack of time to improve anything "that's not broken." Refusal to acquire outside expertise, for whatever reason, is a failure to benefit from new skills and experience. At least one large company respondent describes a cross section of his organization's staff—which includes an aging cohort of energy-smart professionals with sensitivities shaped by the 1970s oil shocks. Most employees added during the 1990s (a time of relatively low energy prices) tend to be less concerned with energy; unfortunately, these individuals are now entering their greatest years of organizational influence. Meanwhile, today's new hires include young people with a better appreciation for sustainability concepts. This should bode well for future support of sustainability agendas.

The hurdles discussed here—lack of resources, disparate internal philosophies, and disconnects of authority—explain industry's affinity for quick, cheap, easy energy solutions. Some respondents suggest that the easy solutions are becoming harder to find. To make more progress, energy program administrators will need to increasingly address their client's cultural and organizational issues in addition to the usual hands-on, technical aspects of energy cost control. This implies an agenda that not only takes more time, but aligns energy policy with economic and workforce development initiatives. In short, the traditional engineer-to-engineer dialogue of yesterday's energy programs is probably not sufficient to maximize capital investment in energy improvements.

ENERGY PROGRAM IMPACTS

Despite the many difficulties, many energy managers can and do overcome barriers. Two SME respondents note that their organizations originally avoided energy improvements in favor of other investments. But once some initial energy project results were available, managers were convinced and wanted more! Four respondents reiterate that project success is often predicated on non-energy benefits. Specifically: 90 percent of energy projects also have a productivity impact (one large company, one facilitator); energy improvements provide a four-fold return in the form of production improvements (one large company); and two other large companies claim that non-energy benefits "dominate" the returns from energy projects. There's still room for improvement: at least one large company respondent says the company experiences an implementation success rate for energy proposals of 30 percent or less. A facilitator claims an 80 percent implementation rate.

At least one respondent notes that energy improvements are harder to justify with today's relatively low gas prices. Upon reflection, this may reveal a strategic opportunity. The industrial sector is experiencing a re-shoring of production facilities on domestic soil. This is due in part to lower gas prices. But does this not underscore the need to invest in new facilities? If so, this investment is an opportunity to implement advanced, energy-saving technologies that will hedge these new facilities against future energy price increases.

CRITICAL SUCCESS FACTORS

What is it that allows some companies to implement more energy improvements than others? For many respondents, it begins with leadership: the influence of key top managers who communicate an inspired vision across all departments. Exactly who performs this role is determined more by personality and power than it is any specific job title.

One critical success factor cited by many respondents is that facilities need an internal energy management program of their own design and making. Energy-related goals, assignments, and accountabilities can then be coordinated with annual and multi-year capital investment plans. Absent a true energy management protocol, facilities are reduced to random projects—a hit-or-miss proposition at best.

A few respondents note that it is critical to have an energy champion at the facility site who can effectively "sell" improvement concepts to the balance of the organization. As one facilitator states, facilities are more likely to pursue energy improvements if care has been taken to explain the larger business impacts to key decision-makers. Another facilitator notes that skeptics are always present to varying degrees among a facility's decision-making team. To overcome their resistance, energy proponents—both internal champions and energy program administrators—are advised to make contact with as many of the relevant key managers as possible. Use this inner networking opportunity to reiterate the business impacts relevant to these managers' respective departments.

Once a vision is in place, protocols are needed for execution. Eleven respondents (eight large, two SMEs, one facilitator) note that it is crucial to have a staff team dedicated to at least monitoring or investigating energy performance. In some instances, teams are organized at corporate levels, providing itinerant service to facilities. Some other facilities have their own local team, which may in turn receive corporate guidance. Note that almost all respondents have a capital budgeting process of some kind, which should not be confused with an "energy strategy." Three respondents (one large and two SMEs) claim to have a formal energy management strategy. A few respondents attribute success to supportive corporate leadership. In one case, this means instilling a work environment that incents and inspires new ideas. One large company respondent describes "mature energy thinking" as a work environment where staff at all levels submit energy improvement ideas on their own initiative. In this situation, energy improvements are perceived not as a distraction, but as a viable business solution.

ENERGY PROGRAM ADMINISTRATORS' OBSERVATIONS AND RECOMMENDATIONS

Energy program administrators pre-screen facility management teams for their ability and willingness to support energy improvement initiatives. Another facilitator recommends a facility screening strategy per this acronym: MAN (money, authority, need). In other words, evaluate the decision team to determine which individuals have each of these three attributes. This helps to plan the subsequent communication strategy.

At a tactical level, one facilitator notes that facts and figures serve the energy champion well when justifying proposed improvements. The better the analysis, the less room there is for capital budget politics. And as noted above, energy improvements are more likely to occur when they are linked somehow to other core-business investments. To synthesize comments from survey respondents, Table 1 offers a provisional checklist of attributes that facilitate capital investment for energy improvement purposes. The more these attributes are in place, the greater the likelihood of success.

Table 1. Provisional Checklist for Successful Capital Investment in Energy Improvements

LEADERSHIP

- Top management support for cost improvement in general, and good projects in particular
- An empowered energy champion who has influence with multiple departments and directors
- Individuals familiar with the project from its inception are on the approval team
- The project development team draws membership from all departments to be affected by the change

CULTURE

- Company has a formal self-improvement idea generating mechanism
- A history of successful energy improvement projects
- A work culture that is amenable to change and new knowledge

ORGANIZATIONAL MECHANISMS

- Clear accountability for energy performance results
- Corporate goals for sustainability or overall cost improvement
- Capital spending decision-makers are located at production facilities
- Flexible investment evaluation criteria to recognize non-energy benefits
- Ability to schedule the energy improvement to coincide with expected shut-down maintenance episodes

BUSINESS RELEVANCE

- Clear articulation of energy impacts and their linkage to core business goals
- Evidence of a facility's deferred or pent-up demand for capital investment
- Knowledge of the capital renewal cycle for the industry and corresponding windows of opportunity for investment.
- Ability to link discrete energy projects to a current business goal or need

OPENNESS TO OUTSIDE RESOURCES

- Willingness to apply for energy program benefits
- A consultative relationship with vendors and consultants

CONCLUSIONS FOR FUTURE PROGRAM DESIGN AND CONDUCT

The potential for manufacturing energy improvement, and therefore the investment that enables these improvements, is changing. Despite the volume of potential low- and no-cost improvements discovered by program-sponsored energy audits, many of these remain unimplemented. As one respondent notes, the "low hanging fruit" has a tendency to grow back in the absence of ongoing monitoring and control. The advent of certified energy management standards such as ISO 50001 should help in this regard [ISO 2013]. But even as programs and standards are mass-promoted, industry will respond one company at a time, each on its own timetable, as key energy champions within each company are willing and able to muster the internal influence and resources needed to commit to energy management. Future program outreach may require program administrators to continually screen, coach, and support energy champions as they muster the organizational support needed to advance their energy improvement agendas. This task will draw on communication, financial, and change management skills in addition to the usual engineering expertise.

Respondents to the survey conducted for this report reiterate the fact that energy improvements are not a priority, but rather a welcome indirect benefit of industrial investment. The advancement of industrial energy efficiency program goals must more effectively detect, document, and promote the affinities between energy savings and core business goals, then communicate these fully to key decision-makers in each organization.

To some observers, relatively low natural gas prices currently dilute the urgency for energy efficiency improvements. A more strategic perception would note the need to build more capacity in response to the re-shoring of production facilities—a trend driven in part by today's low natural gas prices [Young, et. al. 2012]. Capital investments made today can provide needed capacity while ensuring that facilities are efficient from their inception, therefore minimizing the future liabilities of energy waste.

The true business impacts of energy improvements remain underappreciated by professionals that influence industrial investment decisions. Even as energy program outreach to each facility requires some message refinement, so does the communication and advice offered by economic development advisors like those representing Small Business Administration (SBA) programs and state economic development offices. Advice given to SMEs in particular is sometimes counterproductive to energy efficiency goals. This suggests the need for greater coordination between, for example, utility companies and local economic development offices.

Per the classic engineering mindset, many industry stakeholders equate energy efficiency measures with capital expenditure projects. Less technical observers may anticipate energy measures that result from behavioral and procedural change. Both groups are correct. The marriage of these philosophies calls for energy management as a *process* of continuous improvement, relying as much on performance measurement and staff action as it does capital projects. Accordingly, state and utility energy programs are evolving to support energy management practices as a complement to the project approach. This evolution is not without challenge: while capital projects involve a change of equipment, energy management imposes change on personnel roles and accountabilities. The suggestion of organizational change breeds fear and resistance in ways that the project approach does not. Compared to a capital project, the energy management process does not make a neat, one-time funding proposal. To compete effectively in the capital budgeting process, facility managers would rather *do things right*—pursue projects—as opposed to *doing the right things* that true energy management would require. Energy efficiency programs can coach facilities as they develop energy management disciplines over time—beginning with the easy, low-cost improvements, then by developing monitoring and maintenance best practices for current assets. Once these competencies are in place, energy champions can more convincingly justify capital investment in advanced technologies, pointing to energy as well as other ancillary benefits.

Program efforts can make better use of vendor-supplied expertise, as some respondents indicate. Industry's preference for trusted vendor relationships is a foundation for a true partnership with the customer. The vendor would move beyond selling commodity products, forming an advisory or consultative relationship that poses energy improvements to the customer as business solutions. "Trust" itself is a form of capital, crucial for customers to become more comfortable with the change that comes with energy improvements.

The concept of energy management—and the energy manager—remains new especially to smaller industrial facilities. With unfamiliarity comes a perception of risk. Program sponsorship allows industrial facilities to build energy management competencies with minimal risk of time and resources. While intermittent assistance from outside consultants is helpful, episodic visits of this sort cannot address the organizational change issues that so often stall the implementation of efficiency initiatives. As a full time, on site employee, the energy manager can boost implementation rates by navigating the organizational issues that result from change.

Energy managers will play a pivotal role in the adoption of strategic energy management protocols such as ISO 50001 [ISO 2013]. When a company adopts a formal protocol, it is really the initiative of a handful of individuals, with the balance of the organization remaining indifferent. The most effective energy managers will be individuals with sufficient gravitas to persuade their colleagues to invest in the effort that such protocols require. While the external marketing of these programs is helpful, industry's acceptance will largely depend on the professional acumen, insight, and motivation embodied in its energy managers.

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Industrial Energy Efficiency Technical Review Guidelines and Best Practices

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ABSTRACT

Objective:

The role of technical review is to mitigate risk to DSM program administrators. If done effectively, technical review should aid the cost effectiveness of DSM programs by improving on targeted net-to-gross ratios and savings persistence.

Ex-post impact evaluations of programs have detailed protocols for evaluators to follow, however those conducting the technical review of ex-ante projects have limited guidance material to follow.

The objective of this paper is to assess the benefits and costs of ex-ante technical review for large, unique and, primarily, industrial projects to develop a framework for technical review practice that advises an appropriate approach and rigor for maximizing the cost-effectiveness of DSM programs.

Methodology and Scope of Research:

1. Empirical analysis of reported energy savings at the application, reviewed (contracted), measurement and verification (M&V) and evaluation stages for multiple large or industrial incentive programs.
    a. Assess impact of technical review rigor on reviewed values compared to M&V results
    b. Assess impact of technical review rigor on reviewed values compared to evaluation results (net-to-gross)
    c. Assess impact of technical review rigor on program participation
2. Identify examples of appropriate approaches to technical review based on empirical results.
3. Develop methods to screen potential projects to maximize program cost effectiveness, considering the effective useful life, free-ridership (partial and deferred) and incremental savings and costs..
4. Develop stratified approaches and practices for performing base case, measure and cost analysis.

Results: Development of a framework to align various large, capital incentive, DSM program designs to a standard approach for technical review.

PART A: JURISDICTIONAL REVIEW OF INDUSTRIAL ENERGY EFFICIENCY PROGRAM EX-ANTE TECHNICAL REVIEW

To identify and assess the benefits and costs of industrial energy efficiency program ex-ante technical review, a review of North American industrial energy efficiency programs was conducted. Research considered program design and objectives, delivery models in order to identify specific jurisdictions with established and substantial industrial energy efficiency programs that are, for the most part, administered and reported independently of commercial and other sector programs.

The following programs were deemed to represent the best combination of applicability and access to relevant information:

- BC Hydro's Power Smart Partners - Industrial (Transmission and Distribution)
- Wisconsin's Focus on Energy – Industrial
- California Public Utilities Commission's (CPUC) Southern California Industrial and Agricultural (SCIA) and Pacific Gas & Electric's (PG&E) Fabrication, Process and Manufacturing

Review of Impact Evaluation reports, and other information made available by the above organizations, was conducted in order to identify instances and establish benchmarks for commonly reported metrics that could be used as indicators and comparisons for program and technical review success, as shown in the table below.

Table 1. Impact Evaluation Metrics and Indicators

Impact Evaluation Metric	Program Success Indicator
Net-to-Gross ratios	Cost effectiveness; quality of technical review
Verified savings vs. Gross savings	Quality of technical review
Incentives as a percentage of total expenditures	Cost-effectiveness; program administration efficiency
Total expenditures as a percentage of budget	Program participation
Target achievement	Program participation
Various utility cost and benefit to cost ratios (TRC)	Cost-effectiveness

While the practices employed by evaluation professionals are fairly standardized, there are some notable exceptions, such as the CPUC policy that "spillover" is not included in net reported savings results. Thus, caution must be employed when comparing Impact Evaluation report results.

Significant findings:

- Both BC Hydro's Power Smart Partners – Industrial and Wisconsin's Focus on Energy – Industrial achieved very high realization rates, at 96.5% (average PSI Transmission and Distribution, CY 2005 - 2010[1]) and 97% (average FY02 – CY10), respectively.
  - Focus on Energy included confidence intervals for the accuracy of their ex-ante reported project savings, which is an observed best practice.
- BC Hydro's Power Smart Partners – Industrial (F2003-F2006) program achieved the highest net-to-gross ratio, of programs researched, by a significant margin, at 91%.
  - Approximately 30% and 65% higher than Focus on Energy and PG&E results, respectively. Per note above, CPUC results do not include spillover.
- CPUC Impact Evaluation reports include several recommendations for program practice improvements, most significantly those specific to baseline establishment.
- Energy Trust of Oregon prepares "true-up" reports to evaluate project and program persistence beyond the initial evaluation period.
  - Similarly, FoE reports lifetime and lifecycle (run-rate) in addition to first-year savings.

Further investigation into BC Hydro's Power Smart – Industrial technical review process was conducted in order to gain context for the above results. Investigations were designed to gather information that is applicable to the time period of the evaluation results[2] (F2003 – F2006), review practice evolutions applicable to the later range of the gross verified (measurement and verification) vs. gross reported data provided (~CY2007 – 2010) for calculation of realization rates, as well as the most recent review practices[3] (2012).

From these investigations, it is clear that Power Smart has pursued continuous improvement of the technical review process over several program cycles, with the objective of improving customer satisfaction and review efficiency, while maintaining technical review accuracy. From a date preceding the F2003 – F2006 program cycle, Power Smart Industrial technical review established and later refined a robust review scope, based on demand-side management (DSM) industry principles. This scope and a general approach have contributed to their success in achieving high realization rates.

More recently, the primary shift in their approach is to make the review process more proactive by involving the technical review engineers at the earlier stages of project development. Most recently, this has resulted in an engineering department dedicated to field services that act as a liaison between program participants, account managers and technical review engineers. While this is a new development for BC Hydro, the deployment of technical field services to program participants is conducted in other North American industrial energy efficiency programs. The difference, observed in the case of BC Hydro, is the integration with their technical review process.

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[1] Previous reports of earlier program cycles yielded similar results, though the actual results are no longer available

[2] Willis staff includes Steve Ireland, former manager of Power Smart Technical Services (1996 – 2006) and other Power Smart personnel, including the author (2005 – 2009). Thus, some of this research was internal, based on personal experience.

[3] Interview with Loren Gudbjartsson, January 17, 2012

Conclusions

BC Hydro's Power Smart Partners – Industrial and Wisconsin's Focus on Energy – Industrial programs provide examples of best practices for industrial technical review in terms of a scope and approach to achieve accurate results (realization rate). BC Hydro's program achieves high participation levels and above average customer satisfaction with the review process.

In all cases of industrial energy efficiency programs reviewed, the most significant opportunity to mitigate risk and improve program cost effectiveness through the technical review process is in a more proactive management of the net-to-gross ratio. As identified in CPUC Impact Evaluation reports, this can be achieved, for the most part, with improvements to base case establishment practices.

Empirical results and testimony suggest that pro-active technical review (i.e. involvement at the early stage of project/opportunity identification) is instrumental in achieving efficiency in the review process. Additionally, technical resources are best equipped to implement and manage the improved baseline establishment practices suggested by CPUC evaluation results; however, early (pro-active) involvement is necessary in order for net-to-gross, and subsequently cost-effectiveness improvements, to be realized.

PART B: INDUSTRIAL TECHNICAL REVIEW APPROACH AND FRAMEWORK

This part is divided into two sub-parts, based on the conclusions in Part A:

1. Presentation of technical review best practices for establishing a base case.
    - Assessing the timing and impact of the remaining life of existing system
    - Establishing the anticipated replacement in absence of "the project"
2. Presentation of a technical review standard to align ex-ante accuracy with the appropriate review rigor.

The following technical review approach and framework is intended for pro-active involvement of program technical resources, as per the conclusions in Part A.

Best Practices for Base Case Establishment

Efficiency project persistence is often conceptualized as the effective measure life (EML) or effective useful life (EUL) and administered by estimates and/or standards for the operable lifetime of the installed project; or the median project lifetime in a sample of a population of similar project types[4]. In this manner, the year-over-year project savings are calculated relative to a baseline that is based on pre-existing equipment, for the entire period of the EUL.

As stated in the CPUC SCIA and PG&E Impact Evaluations, "This assumption would only be justifiable in situations where the program induced an early replacement of equipment that would otherwise have had a very high probability of continuing in operation for a period equal to the EUL of the new equipment."

This does not properly account for the anticipated replacement in absence of the project, which should limit the project persistence or impact the incremental savings in any case where it is less than the EUL.

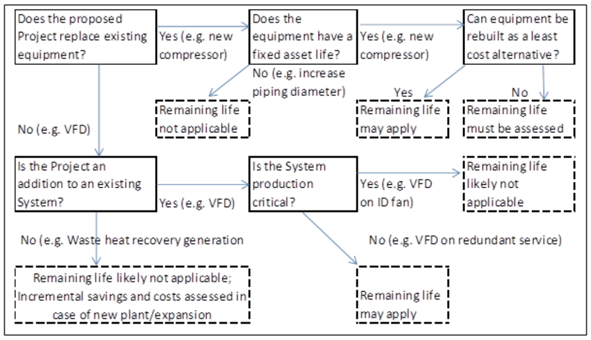
However, the CPUC Impact Evaluation's position that efficiency programs' ability to influence early replacement projects (i.e. anticipated replacement in absence of project > savings period) is a rare occurrence, does not appropriately recognize the industrial operating and economic environment. In the present day industrial sector, it is the norm for equipment to run well beyond the manufacturers specified technical asset life, especially in facilities with good maintenance practices, or in the case of equipment that can be rebuilt at a significantly lower cost than replacement. These factors need to be considered when assessing remaining life.

Additionally, from a technical perspective[5], the issue of remaining life does not apply to all projects. The following decision flow provides guidance as to the need to consider remaining life of existing equipment for different project scenarios.

Figure 1. Remaining Life Decision Flow Chart

[4] As explained in the Focus on Energy Evaluation Business Programs: Measure Life Study. KEMA: August 25, 2009

[5] Economic considerations are outside the scope of this paper; these should be addressed by program design e.g. incentive payback thresholds and tiered incentive rates.



In the case of equipment that can be rebuilt as the least cost option, a general gauge for the applicability of remaining life is if the rebuild is expected to cost more the half the cost of replacement, then replacement would likely be considered in absence of an incentive. However, participant and project specific context should be included in the assessment.

Determining the remaining life of existing, operable, equipment is not an exact science. It is often overlooked by program applicant and non-technical program staff (sales/account management), especially since willful ignorance is typically in their interest, as it impacts a potential incentive. This leads to difficult and conflictive situations for technical review personnel, whereby applying an appropriate method will often have a negative impact on participant satisfaction. Lowering an expected incentive may have detrimental impact in cases where conditional approval has already been sought and received based on the anticipated incentive. This is a primary example of the benefits of proactive involvement of technical review personnel, who are best equipped to effectively manage the issue of remaining life to maximize program cost-effectiveness.

For practicality reasons, the "project incentive persistence" should be de-coupled from the "program reported persistence", in order to provide the flexibility to maintain program satisfaction/ participation while reporting based on best available information. Because determining the remaining life of equipment is not an exact science, technical review recommendations should be based on categorizing projects according to standard remaining life bins, based on pre-defined project characteristics. The intention being that the standard would provide accurate forecasts for the population of projects for a given program, without expecting that the values are accurate in every case.

With the involvement of technical resources at the project inception stage, professional judgments can be applied in order to categorize and bin potential opportunities, thus setting appropriate expectations for project incentives. In order to make informed discretionary decisions, program specific tools should be developed that enable the merits of individual projects to be assessed. For example, the Table 2 below, based on data from the Ontario Power Authority's (OPA) Process and Systems Upgrades Initiatives, depicts estimates of the program break-even periods (full and incremental cost basis), based on full "project incentive persistence" (10 years). As shown in Table 2, it may be in the programs interest to provide a full incentive, even if the anticipated replacement timeline is less than the savings period. An alternative, also shown below, is to use demand-side management cost tests, such as total resource cost ratios.

Table 2. Project Payback vs. Program Break-even

Project Payback (years)									
Simple Payback (w/o incentive)	5.0	4.4	4.0	3.6	3.3	3.1	2.9	2.7	2.5
Project Payback (w/ incentive)	3.0	2.4	2.0	1.6	1.3	1.1	1.0	1.0	1.0
Program Break-even (years)									
Project basis (incentive only)	4.7	4.7	4.7	4.7	4.7	4.7	4.4	3.9	3.5
Program basis (all costs)	9.4	9.4	9.4	9.4	9.4	9.4	8.7	7.8	7.0
Project lifetime for TRC of 1.0	8.1	7.2	6.5	5.9	5.4	5.0	4.7	4.4	4.2
Project lifetime for TRC of 1.4	12.4	10.7	9.4	8.5	7.7	7.1	6.6	6.2	5.8

Technical Review Standard Framework

While the findings in Part A regarding the leaders in industrial energy efficiency program technical review best practices are highly specialized/specific, they are not unique. BC Hydro's industrial energy efficiency programs have previously been identified as industry leading in areas of program design and implementation by various bodies other jurisdictions. BC Hydro's industrial project incentive technical review scope has been adapted and applied to other North American industrial energy efficiency programs, such as the Ontario Power Authority's Industrial Accelerator Program and Process and Systems Upgrades Initiatives. A modified version of this scope is presented below:

1. Establish a **base case**, including:
    a. System and general operation description
        i. Including, changes to the operation of the system, known or anticipated, in absence of, or in addition to, the project.
    b. System boundary and documentation of all energy consuming equipment within
    c. Current condition of the system and establishment of **remaining life**
        i. Analysis of the anticipated economic and technical end-of-life of current equipment and anticipated replacement in the absence of the project, resulting in a determination of the number of years that the equipment replacement has been accelerated and the consequential impact on energy savings
    d. Detailed operation of the system
        i. Hours of operation and relationship with production, or other global variables
        ii. Operating parameters (local variables) and performance (efficiency)
    e. Development of the baseline energy consumption
        i. Accounting for the base case operation, operational changes, and condition, including anticipated replacement in absence of the project
        ii. Based on metered data and/or models/simulation, as applicable
            - Models and simulations for theoretical base cases (where anticipated replacement < savings period) based on assessment of standard technology efficiencies/energy performance standards
2. Measure analysis, including:
    a. Estimation of energy savings: at appropriate interval (e.g. hourly, daily, seasonal or annual) and duration (e.g. first-year, lifetime, etc.), including:
        i. Applicability and estimation of interactive effects, within and outside of the system boundary
        ii. Applicability and determination of incremental versus full savings (per base case, remaining life and associated baseline energy consumption)
            - Incremental relative to the energy performance standards of equipment that would be installed in the absence of the project and higher efficiency capital improvements directly influenced by the incentive.
    b. Determination of expected project life, based on measure life and remaining life (per base case) – i.e. the minimum value
3. Project cost analysis, including:
    a. Assessment of project cost estimate accuracy
    b. Assessment of cost eligibility, as per program rules and relevance to the project scope
    c. Applicability and determination of incremental versus full costs (per base case, remaining life)
        ii. Incremental relative to equipment that would be installed in the absence of the project and higher efficiency capital improvements directly influenced by the incentive.
4. Assessment of other benefits and costs, including:
    a. Changes in operating and maintenance costs, production/productivity, etc.
5. The benefit of the project to ratepayers in accordance with conservation and demand management industry standards (not in technical review scope)

Discussion with program personnel provides insight into BC Hydro's technical review process, design and a general overview of the expectations and approach. However, it does not provide a public standard that other program administrators can consistently implement in order to achieve comparable technical review realization rates and effectively mitigate risk. To that end, a framework for conducting the above scope has been developed based on Willis' experience in performing technical review services for the OPA's industrial programs. This framework attempts to incorporate parts of the BC Hydro process, design and approach, as well as elements of best practices from other industrial energy efficiency programs, previously identified, to effectively and appropriate mitigate risk.

For the purpose of technical review, risk is defined as the product of project materiality and savings uncertainty. The critical variables for technical review best practices for mitigating risk, while achieving accuracy (realization rate), customer satisfaction (timeliness and ease) and cost-effectiveness (NTGR and incentives as % of budget) are the appropriateness of information requirements and the rigor of review.

In order to develop a standard framework for applying the appropriate rigor (including information requirements) to the above-described technical review scope a stratified, a risk-based approach was developed. A continuum of information requirements and review approaches were developed for each technical review scope item and divided into appropriate tiers; between two and four. As shown in Table 3, below.

The quantitative scope items that impact the energy savings – specifically, the baseline electricity consumption and estimated future consumption/energy reduction – were further divided into their components (e.g. power, operating variability, operating hours, etc.) and uncertainty assumptions were generated for each component, as shown in Figure 2, below.

Table 3. Tiered Information Expectations and Approach by Review Scope Item

SoW Item	Tier 1: < 1,000 MWh	Tier 2: 1,000 – 1,750 MWh	Tier 3: 1,750 – 3,000 MWh	Tier 4: > 3,000 MWh
Base Case – System Description, Boundary and Equipment, Current Condition/ Remaining Life (1.a, 1.b & 1.c) *In case of anticipated replacement < savings period; Description of standard efficiency base case system in absence of the project consistent with adjacent*	**Expectations** - Provision of major equipment information (model, type, capacity, hp, etc.) - Description of system function/operation and current condition is sufficient, unless: - Condition description raises issues regarding equipment remaining life. - System information or TR experience suggests potential for Interactive Effects (in which case, a PFD or other details may be required) **Review Approach** - Discussion or information requests, as necessary to address application deficiencies and understand base case system operation (including future in absence of project) - Refer to previous section for review of remaining life and anticipated replacement	**Expectations** - Provision of all energy-consuming equipment information (model, type, capacity, hp, etc.) and specifications/performance curves for major equipment - Description of system function/operation, w/ PFDs, P&IDs and SIDs, as available, typically required. - Current equipment condition should be accompanied by equipment age, run-time, previous failures, and/or current operation and maintenance issues/costs. **Review Approach** - Site-visit, discussion and information requests, as necessary to address application deficiencies and understand base case system operation (including future in absence of project). - Refer to previous section for review of remaining life and anticipated replacement		

SoW Item	Tier 1: < 1,000 MWh	Tier 2: 1,000 – 1,750 MWh	Tier 3: 1,750 – 3,000 MWh	Tier 4: > 3,000 MWh
Base Case – Detailed Operation and Baseline Energy (1.d & 1.e) *In case of anticipated replacement < savings period; Where anticipated replacement is a like-for-life replacement, use existing base case. Otherwise, see below.*	**Minimum Requirements (for Remaining Life > 0)** Power Estimates: 100% T2 (±12.5%), or 75% T3 + 25% T1 (±10.6%) Power Variation: T1 Operating Hours: T1 **Review Approach** - Review includes independent calculation of the Baseline Energy for Application validation and M&V Plan purposes. - Review of operating variations and cross-reference of operating variables limited to check of application calculations, corrections only if necessary, and (verbal) confirmation of assumptions applied in Application.	**Minimum Requirements (for Remaining Life > 0)** Power Estimates: 50% T4 + 50% T3 (±4.5%), or 75% T4 + 25% T2 (±4.3%) Power Variation: T2 Operating Hours: T2 **Review Approach** Review includes independent calculation of the Baseline Energy for Application validation and M&V Plan purposes. Including, for variable systems, independent review of operating variations and cross-reference of operating variables (equipment performance/ efficiency[6]) to check Baseline Energy estimate.	**Minimum Requirements (for Remaining Life > 0)** Power Estimates: 50% T4 + 50% T3 (±4.5%), or 75% T4 + 25% T2 (±4.3%) Power Variation: T3 Operating Hours: T3 **Review Approach** Review includes independent calculation of the Baseline Energy for Application validation and M&V Plan purposes. Including, for variable systems, regression analysis of power and correlating variable(s) (or suitable alternative) + independent review of operating variables (equipment performance/ efficiency) for extrapolation to annual baseline	**Minimum Requirements (for Remaining Life > 0)** Power Estimates: 90% T4 + 10% T1 (±2.1%) Power Variation: T4 Operating Hours: T4 **Review Approach** Review includes independent calculation of the Baseline Energy for Application validation and M&V Plan purposes. Including, regression analysis of power and correlating variable(s) + independent review of operating variables (equipment performance/ efficiency), if appropriate (summation of 8,760 data may be sufficient).
Base Case – Modeled Baseline Energy	**Expectations** - Estimated load based on comparable benchmark **Review Approach** - As above, to extent possible	**Expectations** - Calculated load based on equipment specifications and assumed loading **Review Approach** - As above, to extent possible	**Expectations** - Calculated load based on equipment specifications and comparable benchmark for loading factors **Review Approach** - As above, to extent possible	**Expectations** - Calculated load based on equipment specifications and comparable benchmark for loading factors **Review Approach** - As above, to extent possible

[6] Establishing base case equipment performance/efficiency is often for the purpose of projecting post-project energy consumption

SoW Item	Tier 1: < 1,000 MWh	Tier 2: 1,000 – 1,750 MWh	Tier 3: 1,750 – 3,000 MWh	Tier 4: > 3,000 MWh
Measure Analysis – Energy Savings (2.a)	**Expectation** T1 **Review Approach** - Information requests, as necessary to understand calculations. - Complete and correctness review of application estimate, if it meets above expectation (average operating point analysis acceptable; multi-points for variable operation/different modes, incl. seasonality) - Benchmark comparison to published results and internal experience, if possible. - Alternative estimate developed (per Energy Savings T1 standard) if expectation not met, or application estimate outside benchmark range. - Consideration of savings deterioration (relative to deteriorating base case) for project lifetime. If < 10% of savings, document qualitative expectation. If > 10%, see T3	**Expectation** T2 **Review Approach** - Information requests, as necessary to understand calculations (incl. samples). - Detailed review and check of application estimate, if it meets above expectation (average operating point analysis acceptable, if ~even distribution expected; multi-points for variable operation/ different modes, incl. seasonality) - Benchmark comparison to published results and internal experience, if possible. - Alternative estimate developed (per Energy Savings T2 standard) if expectation not met, or application estimate outside benchmark range. - Assessment of savings deterioration (relative to deteriorating base case) for project lifetime. If < 10% of savings, document assessment. If > 10%, see T3	**Expectation** T3/T4 **Review Approach** - Information requests, as necessary to understand calculations (incl. samples). - Alternative estimate developed (per Energy Savings T3 standard) for comparison to application estimate (continuous operating point analysis expected, unless even distribution documented; in which case, multi-points for different modes, incl. seasonality). - Benchmarking to comparable (verified) installations/case studies is a last resort for cases involving proprietary solutions (preferably 3rd party results), or measures that are otherwise impractical to independently estimate projected consumption. - Assessment/investigation of savings deterioration (relative to deteriorating base case) for project lifetime. If, notable deterioration expected, apply quantification of deterioration to lifetime energy savings.	
Measure Analysis – Interactive Effects (2.a.ii)	**Expectation:** per Base Case System Description and Boundary **Review Approach** Potential existence/impact considered based on information provided and reviewers knowledge of similar systems. If expected to exist, but less than 10%, no quantitative analysis (just acknowledged). Otherwise, apply adjacent approach.		**Expectation:** per Base Case System Description and Boundary **Review Approach** Potential existence/impact considered based on information provided, reviewers knowledge of similar systems and/or independent research, if likely to exist. Quantitative estimate developed/integrated within Baseline Energy and Energy Savings	
Measure Analysis – Incremental Savings (2.a.iii)	**Review Approach** - If Remaining Life/ anticipated replacement > savings period, incremental savings are not applicable. - If Remaining Life/anticipated replacement < savings period, Incremental Savings integrated within Energy Savings analysis based on separate Baseline Energy values for respective periods (pre & post-anticipated replacement date)			

SoW Item	Tier 1: < 1,000 MWh	Tier 2: 1,000 – 1,750 MWh	Tier 3: 1,750 – 3,000 MWh	Tier 4: > 3,000 MWh
Measure Analysis – Expected Project Life (2.b)	**Review Approach** Expected Life = minimum of remaining life (anticipated replacement) and measure life Measure life review based on Wisconsin Measure Life Study		**Review Approach** Expected Life = minimum of remaining life (anticipated replacement) and measure life Measure life review based on Wisconsin Measure Life Study, permanence of implemented measure and assessment of technical useful life of critical equipment to be installed	
Project Costs Green = down Tier (lower risk) Red = up Tier (higher risk)	Other Tier Inclusions: >50% sensitivity margin[7] for Projects < 1,750 MWh T1 Exclusions: < 10% margin	Other Tier Inclusions: >25% margin <3,000 MWh (>1,750), or <10% margin <1,000 MWh T2 Exclusions: >25% margin, or <10% margin	Other Tier Inclusions: >25% margin > 3,000 MWh, or <10% margin < 1,750 MWh (>1,000) T3 Exclusions: >25% margin, or <10% margin	Other Tier Inclusions: < 10% margin < 3,000 MWh (>1,750) T4 Exclusions: >25% margin
Estimate Accuracy (3.a)	**Requirements** - Breakdown of Project costs by major cost categories (separation of equipment costs from total sufficient for turnkey vendor solutions) - Budgetary quote for major equipment, if available **Review Approach** - Information requests, as necessary to meet requirements - Completeness and correctness review of application estimate - Benchmark comparison to similar projects/equipment	**Requirements** - Breakdown of Project costs by major cost categories and (significant) line items, as appropriate - Budgetary quotes for all significant equipment **Review Approach** - Information requests, as necessary to meet requirements - Completeness/correctness review - Benchmark assessment of project costs, or (if similar comparisons not available) - Assessment via independently obtained comparative equipment quotes	**Requirements** - Breakdown of Project costs by major cost categories and (significant) line items, as appropriate - Budgetary quotes for all significant equipment and construction, if applicable **Review Approach** - Information requests, as necessary to meet requirements - Completeness/correctness review - Assessment via comparative equipment and construction quotes, if feasible - Benchmark comparison of other (soft) costs	**Requirements** - Breakdown of Project costs by major cost categories and (significant) line items, as appropriate - Budgetary quotes for all significant equipment and construction, if applicable **Review Approach** - Information requests, as necessary to meet requirements - Completeness/correctness review - Assessment via comparative quotes, or estimation methods, if necessary (quotes not available/account for less than 75% of project costs) - Benchmark comparison of other (soft) costs

[7] Sensitivity margin is a calculation of the % change in project costs before the incentive is impacted, per program rules. The above example is based on the OPA's Process and Systems Upgrades Initiatives, limitations of a one-year post-incentive payback and 70% of project costs.

<table>
<tr><th>SoW Item</th><th>Tier 1: < 1,000 MWh</th><th>Tier 2: 1,000 – 1,750 MWh</th><th>Tier 3: 1,750 – 3,000 MWh</th><th>Tier 4: > 3,000 MWh</th></tr>
<tr><td>Project Cost – Eligibility (3.b)</td><td colspan="4">Requirements as per Estimate Accuracy (3.a) above
Review Approach
- Determination of cost item eligibility and applicability to project scope
- Additional information requests for cost item details, as necessary, to assess eligibility in case of questionable cost items</td></tr>
<tr><td>Project Cost – Incremental Costs (3.c)</td><td colspan="4">Requirements as per (modeled) Base Case System Description (1.a) and Estimate Accuracy (3.a) above
Review Approach
- If Remaining Life/ anticipated replacement > savings period, incremental costs are not applicable.
- If Remaining Life/anticipated replacement < savings period, Incremental Costs calculated as the difference between the equipment that would be installed in the absence of the project, per (modeled) Base Case, and higher efficiency capital improvements directly influenced by the incentive. Apply applicable Project Cost – Estimate Accuracy (3.a) Tier approach above.</td></tr>
<tr><td rowspan="2">Other Benefits/Costs (OB/C)
Green = down Tier (lower risk)
Red = up Tier (higher risk)</td><td>Apply incentive calculation sensitivity margin approach above + Other Tier Inclusions: If OB/C <5% of project benefits (PB), for all projects
T1 Exclusions: If OB/C > 25% PB</td><td>Apply incentive calculation sensitivity margin approach above + Other Tier Inclusions: If OB/C <10% of PB, for project all projects or > 25% OB/C of PB <1,000 MWh
T2 Exclusions: If OB/C >25% PB or <5%</td><td colspan="2">Apply incentive calculation sensitivity margin approach above + Other Tier Inclusions: If OB/C >25% of PB, for projects >1,000 MWh
T3 Exclusions: If OB/C <10% of PB</td></tr>
<tr><td>Expectation
Explanation of the source of benefits or costs
Review Approach
- Information requests, as necessary to meet requirements
- Application value accepted unless it significantly deviates from reviewer’s experience. In case of upward deviation, expectations and review adjusted to T2.
- If no OB/C’s identified, reviewer does not investigate</td><td>Expectation
- Explanation and calculation of other benefits or costs must be provided.
- Values based on comparables, industry standards, benchmarks, etc. typically acceptable, unless actual data is readily available
Review Approach
- Information requests, as necessary to meet requirements
- Completeness and correctness review of the calculation
- Validation of benefit/cost source
- Independent calculation only if necessary/practical</td><td colspan="2">Expectation
- Explanation and calculation of other benefits or costs must be provided
- Values should be based on actual data, whenever possible/feasible
- Provision of asset maintenance agreements and/or extended warranties, if applicable/purchased
Review Approach
- Information requests, as necessary to meet requirements
- Independent calculation for verification of application value or determination of alternative value</td></tr>
</table>

Figure 2. Technical Review Uncertainty Estimations

Accuracy Assumptions - Uncertainty Estimations			
T1	**T2**	**T3**	**T4**
Base Case: Baseline Energy Consumption			
Power Estimates kW from nameplate data, (with context e.g. loading estimate/ description from operator): 10 - 30% — 20%	kW from Amps, with estimated Volts and power factor: 10 - 15% — 12.5%	kW from Amps, with power factor measurement and estimated Volts, or vice versa, with motor spec pf info: 5 - 10% — 7.5%	kW measurements, or calculation based on measured Amps, Volts and power factor: 0.5 - 2.5% — 1.5%
Power/Production Variations (estimations include assumption that base case production is representative of future production)			
Constant Operation Mean power from spot measurement, with **constant** loading justification (for calc: Baseline Energy = mean power x operating hours): 10 - 20% ***Variable Operation*** Annual extrapolation of operation (load or other operating parameter) based on < 2 weeks continuous data, with production/mode variation cross-reference, but without a correlating parameter for extended period: 10 - 20% — 15%	Mean power from multiple spot measurements (within short period) that demonstrate **constant** loading + justification (for calc: Baseline Energy = mean power x operating hours): 5 - 15% Annual extrapolation of operation based on > 2 weeks (incl. multiple production cycles) of continuous data, with production/mode variation cross-reference, but without correlating parameter for extended period: 5 - 15% — 10%	Mean power from multiple spot measurements, distributed over course of year/time of day, that demonstrate **constant** loading + justification (for calc: Baseline Energy = mean power x operating hours): 2.5 - 7.5% Annual extrapolation of operation based on > 2 weeks (incl. multiple production cycles) of continuous **load** data, with correlating parameter for full year: 2.5 - 7.5% — 5%	12+ month power/load data: 0 - 5% — 2.5%
Operating Hours (estimations include assumption that base case production is representative of future production)			
Constant Operation (typically single motor system, or multiple motors that always run together, or are totally independent)			
Annual operating hours estimated from operating/production schedule and operator experience: 10 - 20% — 15%	Annual hours from < 2 weeks continuous operating data/log extrapolation + supporting info from schedule/operator experience: 5 - 15% — 10%	Annual hours from > 2 weeks continuous operating data/log extrapolation + supporting info from schedule/operator experience: 2.5 - 7.5% — 5%	12+ month operating log (or 8,760 system, less maintenance and shutdown): 1 - 4% — 2.5%
Variable Operation (including multiple motor systems, with sequencing based on demand)			
Annual opeating hours (per motor) from extrapolation of operation data/log based on < 2 weeks continuous data, with production/mode variation cross-reference: 10 - 20% — 15%	Annual opeating hours from extrapolation of operation data/log based on > 2 weeks (incl. multiple production cycles) of continuous data, with production/mode variation cross-reference: 5 - 15% — 10%	Annual operating hours from extrapolation based on > 2 weeks (incl. multiple production cycles) of operation log/run-time data, with correlating parameter for full year: 2.5 - 7.5% — 5%	12+ month operating log (alternatively, all motors operate 8,760 hours, less maintenance and annual shutdown, with supporting information): 1 - 4% — 2.5%
Energy Savings: Post-Project Projected Consumption or Energy Reduction %			
Efficiency measure correlated to a current operating parameter, including production/operating hours (in case of specific efficiency improvement)			
Uncertainty of **average savings %** (single-point) based on engineered/experienced estimate/ benchmark & new equipment specs (if applicable) — 20%	Uncertainty of projected consumption based on spot measured operating conditions and/or detailed engineering calculation & new equipment specs, **for each distinct mode** — 10%	Uncertainty of projected consumption based on continuous measured operating conditions & new equipment specs — 5%	
Efficiency measure relates to changing operating parameters; no pre and post-project correlation			
Uncertainty of projected consumption based on engineering calculation (incl. new equipment specs, if applicable) + projected operation (e.g. reduced flow, pressures, etc.) based on benchmarking/ industry experience — 20%	Uncertainty of projected consumption based on engineering calculation (incl. new equipment specs, if applicable) + calculation/simulation of projected operation (e.g. reduced flow, pressures, etc.) based on spot measurement of current conditions — 10%	Uncertainty of projected consumption based on engineering calculation (incl. new equipment specs, if applicable) + calculation/simulation of projected operation (e.g. reduced flow, pressures, etc.) based on continuous measurement of current conditions — 5%	

Table 4. Technical Review Savings Uncertainty and Risk by Tier

	Tier			
	1	**2**	**3**	**4**
Electricity Savings Range (MWh/yr)	**< 1,000**	**1,000 < x < 1,750**	**1,750 < x < 3,000**	**> 3,000**
Assumed Mean Project Size by Tier (MWh/yr)	550	1,375	2,375	4,000
PR Tier Treshold based on Levelized Risk (MWh/yr)	1,000	1,750	3,000	5,000
Uncertainty Estimates				
Base Case	43%	25%	14.5%	7.1%
Power	28%	14.5%	9.5%	4.6%
Measurement Accuracy - Option A	13%	4.5%	4.5%	2.1%
Measurement Accuracy - Option B	11%	4.3%	4.3%	n/a
Variation	15%	10%	5.0%	2.5%
Operating Hour Variability	15%	10%	5.0%	2.5%
Electricity Savings	**54%**	**32%**	**19%**	**12%**
Projected Consumption/% Reduction	20%	10%	5%	5%
Incentive Risk				
Incentive Risk based on Assumed Mean Project Size	$59,400	$88,138	$89,181	$93,960
Levelized Incentive Risk for Max Savings per Tier	$108,000	$112,175	$112,650	$117,450

The uncertainty assumptions are based on Willis' project and measurement and verification (M&V) data analysis experience[8]. The uncertainty assumptions were combined via uncertainty calculation methods to arrive at total energy savings uncertainty values. Table 4 presents the project materiality ranges (in MWh/year) and associated expected uncertainty, based on the assumptions in Figure 2 and description of review and requirements in Table 3.

These values represent the expected maximum savings result uncertainty, within the bounds of appropriate project assumptions. Meaning, greater deviations are possible, if due to contradiction of a given assumption or in the event of an unforeseen circumstance (the majority of unforeseen circumstances should be mitigated by appropriate technical review). Also meaning, the average savings results are expected to deviate from estimated values by a lesser percentage (especially in the lower tiers), but confidence intervals cannot be developed at this time.

The initial technical review risk associated with each tier was calculated based on the median project materiality and the uncertainty. The materiality bandwidths and subsequent risk calculations were iterated until an approximately levelized technical review risk was achieved for all tiers, as depicted in Table 4, above. The combination of the above tables make-up a technical review standard framework that can be applied to any industrial energy efficiency, energy acquisition, capital incentive program.

[8] Work is under way to track an update assumptions based on future verified data

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Lean, Energy, and Savings: Energy Impacts of Lean Manufacturing

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ABSTRACT

Most utility energy efficiency programs for industry focus on equipment replacement. A key result is confidence in the amount of resulting energy savings. Utility programs focusing on behavior – that is, using a piece of equipment more optimally – often suffer from a perceived inability to accurately quantify resulting savings.

The last few decades have seen a proliferation of Lean Manufacturing practices across industry, where organizations focus on eliminating waste. Energy is often a component of these wastes, but challenges in quantifying results have slowed the inclusion of Lean in utility energy efficiency programs.

In 2011 the Northwest Energy Efficiency Alliance completed an effort that applied energy concepts within the Manufacturing Extension Partnership organizations of the Northwest. A critical project component was quantifying the energy savings from a Lean implementation at a food processing facility. This paper provides details on that project's approach, results, and next steps.

BACKGROUND

In 2010, the Northwest Energy Efficiency Alliance (NEEA) launched a project to apply energy knowledge and support for the region's Manufacturing Extension Partnerships (MEPs). The MEPs work to make small- and mid-sized businesses more competitive via many improvement approaches, the most common being the application of Lean Manufacturing (Lean) principles.[1] As a part of that effort, NEEA's project team, led by EnerNOC, determined the energy savings that resulted from implementation of process improvements identified using Lean principles. In fall 2011, EnerNOC worked with the Oregon MEP (OMEP) and a food-processing facility in Oregon to estimate energy savings from a reduction in start-up time for their manufacturing process (6). The success of this approach led to broader consideration of the application of Lean principles in the context of energy efficiency programs.

Lean Manufacturing and the Seven Deadly Wastes

Lean emphasizes maximizing customer value while minimizing waste. This philosophy is based in part on the practices of Henry Ford who, in his classic 1926 book *Today and Tomorrow*, said that if a processing step doesn't add value to the product, it's a waste. Simply put, if a particular action or activity does not add value to a product that the customer is willing to pay for, then that action or activity is wasteful and therefore should be eliminated.

The philosophies of Ford and American quality pioneer Dr. William Edwards Deming were taken to heart by the Japanese during the reconstruction of Japanese industry following World War II and became key concepts of *Kaizen*. *Kaizen* is a philosophy of improvement through waste elimination, productivity improvements, and sustained continuous improvement that is considered to be the "building block" of all Lean production methods (2).

Lean principles are different than mass production principles in that they focus on increased flexibility and quick response to changing customer demand. This, in turn, can lead to high quality at the lowest cost in the shortest amount of time. Toyota Motor Corporation management took Lean concepts and developed a management philosophy called Toyota Production System (TPS), from which the original seven "deadly" wastes were identified:

1. Transportation – Moving products unnecessarily
2. Inventory – All components and finished product not fulfilling current orders
3. Motion – Equipment, product, or people or moving more than required or necessary

[1] The Lean Enterprise Institute – a non-profit education, publishing, research, and conference organization –describes Lean in more detail at http://www.lean.org/WhatsLean/.

4. Waiting – Product not in transport or processing, waiting for the next production step

5. Over-processing – More work done to a product than necessary

6. Overproduction – Production ahead of demand – considered the worst type of waste because it hides and/or causes the other wastes

7. Defects – Additional effort and cost are needed to fix defects

Recently, additional wastes have been suggested to reflect products rejected by the customer, waste of unused human talent, and other wastes. While these additions have been useful in practice, they have not been standardized as areas of focus.

The steps to achieve Lean are summarized in Figure 1 on the next page, which illustrates the five-step thought process for Lean implementation (4):

1. Specify value from the standpoint of the end customer by product family.

2. Identify all the steps in the value stream for each product family, and wherever possible eliminate those steps that do not create value.

3. Make the value-creating steps occur in tight sequence, so the product flows smoothly toward the customer.

4. Removing wasteful steps and establishing flow creates the ability to deliver only what the customer wants when they want it, which is referred to as “pull.”

5. As value is specified, value streams identified, wasted steps removed, and flow and pull introduced, begin the process again and continue it until a state of perfection is reached in which perfect value is created with no waste.

Lean’s Universal Application

According to the U.S. Environmental Protection Agency (EPA), most of the major U.S. companies that have been recognized by the EPA’s ENERGY STAR program are also leaders in implementing Lean and Six Sigma. This shows that energy waste is already being acknowledged by leading Lean companies (3).

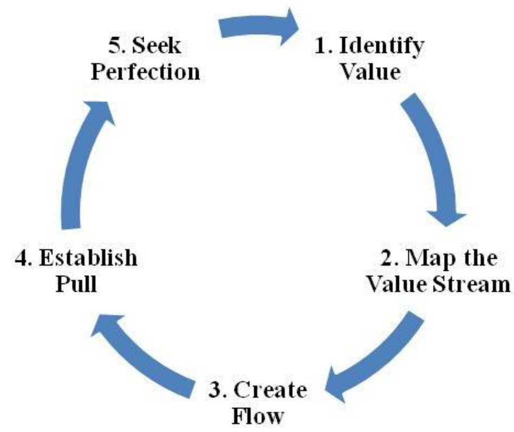

Figure 1. Five-Step Lean Process (4)

To create momentum for energy performance improvements within individual manufacturing sectors and increase the number of companies benefitting from greater energy efficiency awareness, the EPA has produced a series of energy efficiency guides. These industry-specific guides are currently available for 14 manufacturing industries. However, implementation of Lean is not limited to manufacturing. Recently, companies in service industries such as banking and healthcare have been adopting Lean methods to reduce waste in service delivery and administrative processes and to more effectively meet customer needs (1).

Energy Is Secondary In Lean

There are four basic goals of a lean enterprise (5):

1. Improve quality

2. Eliminate waste

3. Reduce lead time

4. Reduce total costs

Reducing manufacturing process energy consumption is not an explicit goal of Lean. However, there are clear links between the energy use and wastes in the production process, such as the use of electricity to heat, cool, and light underutilized inventory spaces (7); energy can be thought of as a marker species for waste. As a result, significant opportunities to reduce energy costs may be overlooked. While this paper focuses on measureable energy savings, indirect or embedded energy savings can also be achieved through Lean principles and are worth further study.

PROJECT IMPETUS

As this began project, we came to the conclusion that there was still a lot to learn about Lean and how it could impact energy consumption within a facility.

- This project just scratches the surface with lean – The investigation into the energy impacts of Lean at this customer is just a tiny part of a larger on-going project at this facility. There are a lot of Lean projects out there yet to be done, meaning that there's still a lot more to investigate.

- Almost no literature/research – While quite a lot has been written about Lean in general, not much has been written about the relationship between Lean and energy or how to quantify the energy impacts of lean manufacturing.

- Interest in new programs – Utilities are always looking for new and innovative programs – whether it's new technologies or new approaches of encouraging efficiency. Encouraging lean manufacturing improvements for the sake of energy efficiency improvements certainly qualifies as one as an innovative program.

- Non-energy benefits – As most traditional Lean improvements target other types of waste, within a utility program these can be seen as non-energy benefits (NEBs). Example NEBs include reduced man power, reduced insurance liability exposure, reduced staff hours, reduced scrap materials, and higher productivity.

- Potential to expand pilots, step, and repeat – The approaches used in this analysis provide the potential for replication not only within the same facility, but within other facilities of a variety of different types. While Lean was initially aimed at manufacturing facilities, it has been adopted even by companies in service industries. Each iteration provides the opportunity to refine and expand the process, so that a consistent and open approach can be eventually developed.

BEGINNING OF PROJECT

Facility Management's Desire to Estimate Energy Savings from Changes in Operations

On behalf of the customer, a consulting engineer with OMEP engaged NEEA and EnerNOC to estimate energy savings that might result from the Lean process improvements implemented at the customer's facility. The customer's goal was a 10% reduction in overall energy consumption. Specifically, the customer's management was interested in estimating the energy savings that might be obtained by decreasing the daily start-up time from two hours to one hour.

Defining the Approaches to Estimating Energy Savings

Figure 2 illustrates the energy consumption that occurs as the facility starts up its production lines. The energy consumed during the standard two-hour start-up is represented by the line running diagonally from the origin of the chart (0, 0) to the point at which full production begins after two hours. The goal of reducing the start-up time to one-hour is represented by the second, steeper diagonal line that begins at the point in time "1" and reaches full production after one hour (where it meets the vertical dashed line). The two triangles formed by these two lines represent the energy consumed during the start-up process. Geometrically, they are equal in area, which demonstrates the fact that cutting start-up in half also halves start-up energy consumption.[2]

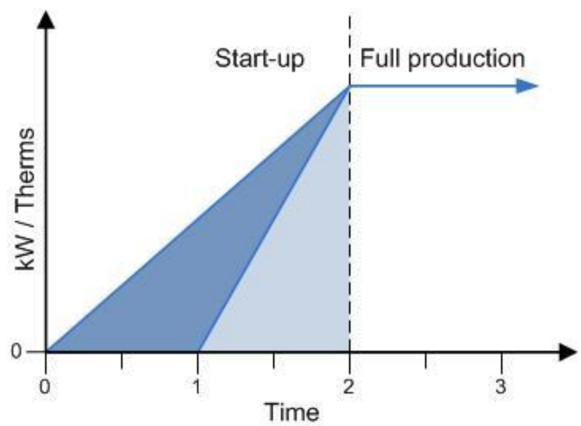

Figure 2. Energy Use at Start-Up

ENERGY SAVINGS METHODOLOGIES

In an attempt to estimate the potential energy savings resulting from the Lean Manufacturing improvements, EnerNOC created models by means of both top-down (facility-wide) and bottom-up (end-use) approaches.

[2] This simplified diagram assumes that the ramp-up of energy consumption levels over the full period of the start-up are constant, whereas startup activities are probably more step-wise.

Comparing the Methodologies

Top-Down.

Top-down models attempt to attribute aggregate energy consumption data to different processes, with the primary purpose of identifying long-term trends in energy consumption. Inputs commonly used by top-down energy models at the facility level include documented energy consumption, production, operating characteristics, and normalized for weather-dependent processes. Strengths of the top-down approach include the need for only aggregate data that is widely available, the ability to detect trends over time when historical data is used, and ability to compare across facilities. Top-down models do not include technological detail, overestimating adjustments to energy systems, and tend to ignore—or at least are unable to take into account—technological changes or unique attributes of business practice optimizations.

Bottom-Up.

Bottom-up models are models that use input data that are more granular than the facility as a whole. The detailed data input of bottom-up modeling allows for the estimation of energy consumption of different end-uses and the effects of technology change and or specific behavior changes. However detailed data, especially broken down by energy end-use, are difficult and expensive to acquire on a large scale. Two classes of models can be identified within bottom-up models: statistical and engineering. Statistical models are regression models that establish a relationship between facility energy consumption and various end-uses. Engineering models estimate the energy consumption of various end-uses by taking into account energy ratings and usage of equipment. They provide detailed profiles of individual facilities, but are data intensive. EnerNOC used an engineering approach to develop our bottom-up approach for this customer.

While it appears at first glance that the bottom-up approach might be more suitable for estimating the energy savings of a one-hour reduction in production start-up, both approaches are, in fact, necessary. As will be described in the following sections, there are inputs to the top-down model that are not included in the bottom-up approach and *vice versa*. Using these two approaches in a complementary manner will help avoid omitting potentially important inputs and factors in energy consumption at the facility.

Top-Down Models

To estimate the electric and natural gas energy consumption at the facility, EnerNOC developed two OLS (ordinary least squares) regression models. These models use monthly values—such as monthly utility bills, local weather, and monthly production and product mix data —as independent variables to determine monthly energy consumption. From the monthly energy consumption baselines one can then estimate monthly energy savings due to the implementation of lean practices or process optimization.

The independent variables were analyzed both individually and in combination to determine which were best able to model monthly energy consumption. When determining the best independent variables, one of the first tasks is to establish whether a statistical relationship exists between energy consumption and the independent variable. Using an exhaustive process, EnerNOC evaluated both linear and non-linear forms of each independent variable to determine which “significant, independent” variables would result in models consistent with criteria set forth in ASHRAE Guideline 14-2002 “Measurement of Energy and Demand Savings.” EnerNOC used the following statistical indicators of model quality to determine the optimal combination of independent variables for each model:

- *t*-Statistic – The coefficient for every independent variable has a *t*-statistic greater than |2.0|, indicating that the coefficient is significantly different from zero at the 0.05 level of significance.[3]
- R^2 (Quality of Fit) – Model possesses an R^2 greater than 75%, which means the regression model captures at least 75% of the variation in monthly energy consumption. In the analyses for this paper, we use the adjusted R2, which tempers the R^2 to account for the fact that increasing the number independent variables tends to inflate the R^2 value.
- CV-RMSE – Must be less than 0.25; the Coefficient of Variation of the Root Mean

[3] A critical *t-value* of |2.0| is used to generalize the process. For the regression analyses performed for this paper, the true critical *t-value* would have been 2.086, based on a 0.05 level of significance and 20 degrees of freedom.

Square Error (CV-RMSE) is used to describe how well a mathematical model represents the variability in the given data set. The lower the CV-RMSE, the better the model.

After the model is established, the baseline energy consumption is estimated using the coefficients from model along with pre-implementation data for the factors they represent. The following equation is used to calculate electric energy savings:

$$kWh_S = kWh_B - kWh_L \tag{1}$$

Where:

- kWh_S = Annual kWh saved
- kWh_B = Annual pre-implementation electricity consumption from top-down model
- kWh_L = Annual post-implementation electricity consumption from top-down model

Baseline consumption and savings are established in a similar way for natural gas.

Top-Down Electricity Model.
Independent variables analyzed for inclusion the electricity model included:

- Monthly weather (heating degree days [HDD] and cooling degree days [CDD]) measured at a local airport
- Monthly total production of all products
- Monthly production for each of five individual products

EnerNOC found weather data to be statistically insignificant for modeling electricity consumption, so it was not included in the final model. Production data for individual products were statistically insignificant for all but one product. That one product was most significant in non-linear (as both the square and cube of itself) relationships with electricity. We also found that the product of the monthly production of three products was the most significant predictor of monthly electricity use.

Monthly electricity consumption at the facility was modeled using the equation below.

$$kWh_B = \underset{(13.1)}{345{,}459} + \underset{(9.4)}{7{,}373{,}155}BGD + \underset{(5.7)}{346{,}199}A^2 - \underset{(-6.0)}{218{,}751}A^3 \tag{2}$$

- Adjusted R^2 = 0.856
- F-Statistic = 42.64 (significant at 0.01 level of significance)
- VC-RMSE = 0.05

Where:

- kWh_B = Monthly electricity consumption (kWh)
- BGD = Product of the monthly production of three products: Beta, Gamma, and Delta (millions of lbs)
- A^2 = Square of monthly production of product alpha (millions of lbs)
- A^3 = Cube of monthly production of product alpha (millions of lbs)

The values in parentheses below each coefficient in the model are the t-*statistics* for each independent variable. The absolute value of each is far greater than 2, indicating that each is significantly different from zero at the 0.05 level of significance.

The electricity model had an adjusted R^2 of 0.86, meaning that 86% of the variation in monthly electricity consumption is explained by the variation in the four independent variables.[4] The VC-RMSE of the electric model was 0.05.

Top-Down Natural Gas Model.
For the natural gas model, EnerNOC analyzed the same set of independent variables as for the electric model.

For natural gas, EnerNOC found heating degree days (HDD) to be significant. Production data for individual products were also statistically significant. By regressing different combinations of products, three products were revealed as very strong predictors of natural gas consumption – one of which is the square root of monthly production.

[4] The adjusted R^2 tempers the R^2 to account for the fact that increasing the number independent variables tends to inflate R^2.

Monthly natural gas consumption at the facility was modeled using the equation below.

$$NG_B = 5.36H + 7{,}947A^{0.5} + 71{,}983B - 40{,}875D \quad (3)$$
$$(3.1) \quad (2.9) \quad (6.8) \quad (-3.7)$$

- Adjusted R^2 = 0.941
- F-Statistic = 1,407.29 (significant at 0.01 level of significance)
- VC-RMSE = 0.06

Where:

- NG_B = Monthly natural gas consumption (Therms)
- H = Monthly heating degree days
- $A^{0.5}$ = Square root of monthly production of product alpha (millions of lbs)
- D = Monthly production of product delta (millions of lbs)
- B = Monthly production of product beta (millions lbs)

Once again, the values in parentheses below each coefficient are the *t-statistics* for each independent variable, each of which is statistically significant at the 0.05 level of significance.

The natural gas model had an adjusted R^2 of 0.94 with a VC-RMSE of 0.06.

Bottom-Up Models

A "bottom-up" analysis entails identifying all energy using equipment, estimating or measuring the amount of energy each piece of equipment uses, and then using that information to determine energy use during a given period. This is a laborious task because identifying all energy-using equipment can be a challenge. Food processing facilities are complex and contain a large number of motor-driven systems, boilers, ovens, and other energy-consuming devices. In addition to identifying the equipment associated with specific processing lines, both the refrigeration and compressed air systems contributed to the facility's overall energy use and were, therefore, included in this assessment.

In brief, our approach consisted of developing a list of all energy-using equipment within the facility, deploying data loggers to collect information on equipment use patterns for some of the production equipment, and then estimating the input from various other major uses (e.g., lighting, compressed air, and energy associated with the refrigeration system) using additional sources. The efforts were linked to produce a single estimate of total energy consumed on a daily basis at the facility, and this estimate was compared to actual plant data to evaluate its accuracy.

Bottom-Up Electricity Model.

The electricity analysis started with identifying the electricity-consuming equipment on each production line. These were mostly motors used for mixing or conveying the food products. There were almost 60 pieces of electricity-consuming equipment involved with the production lines.

Using data on motor horsepower, voltage, amp draw, and utilization factor, EnerNOC estimated daily electricity consumption for a variety of end-uses using engineering methods (Table 1). Data from loggers were used when available to validate the engineering estimates.

Table 1. Summary of Daily Electricity Consumption

End-Use	**Daily Consumption (kWh)**
Production line motors	1,336
Compressor and condensers	9,506
Evaporator fans	4,541
Lighting	1,658
Office HVAC	2,912
Compressed air	1,592
Total Daily Plant Electricity Consumption	**21,545**

Bottom-Up Natural Gas Model.

Natural gas consumption at the customer's facility was limited to two 200 horsepower high-pressure steam boilers. Each boiler was 85% efficient and able to provide 6,900 lbs of steam per hour. The steam was used in all the production lines as well as for producing hot water. Average hourly natural gas consumption during 2010 was 51.2 therms per hour. The daily natural gas consumption was estimated to be 1,229 therms per day.

ESTIMATED NERGY SAVINGS

The estimated total daily energy savings due to the one-hour reduction in daily start-up time was 5.1 MMBtu, or approximately 2.6%, which was about one-quarter of the customer's goal of 10%. The annual value of these savings was about $31,000.

Electricity

Once the daily plant electric energy was categorized, estimates of the impacts from shutting down a production line earlier were made. This required some engineering judgment due to the lack of certainty in some impacts, such as the savings due to reduced refrigeration load on the blast freezers.

The electricity savings estimate is based on the assumption that the amount of heat removed by the refrigeration system did not change (since no product was yet being cooled). In addition, the production lines ran one hour less on high load (i.e., one hour more on low load), and the evaporator fans in the blast freezer ran for 15 hours per day rather than 16. (The evaporator fans in the other freezer and cooler did not run any more or less frequently because there was no change to this process). Further, there was some heat rejection from the blast freezers to the ambient, so the compressors and condensers did not have to work as hard to remove that heat. Energy savings from reduced blast freezer use were assumed to be about 5% of overall compressor and condenser daily electricity use. It was necessary to calculate these savings using engineering estimates due to a scarcity of logged data.

In order to compute electricity savings, the analysis summarized in Table 1 was repeated assuming 15 hours of production time. Lighting, office HVAC, and compressed air energy use were excluded as it was assumed that those end-uses too would remain unchanged. Table 2 shows that total estimated electricity savings were approximately 758 kWh (2.6 MMBtu) per day or 3.5% of daily plant use. Annually, electricity savings would be approximately 277,000 kWh with a value of about $22,000.

Table 2. Electricity Savings Potential Estimate

End-Use	Production Period Consumption (kWh)	
	15-Hour Production Period	**16-Hour Production Period**
Production Line Motors	1,263	1,336
Evaporator Fan Energy	3,141	3,351
Compressors & Condensers	9,031	9,506
Total Consumption	**13,436**	**14,194**
Electricity Savings	***758***	**–**

Natural Gas

Estimating the natural gas savings was more straightforward than for electricity. Since there was only one end-use, it was possible to determine the hourly consumption from the daily consumption. It was only left to determine the gas consumption rate during startup.

A significant volume of hot water was used to clean the facility each day. This water was heated using steam from the two boilers. However, decreasing the length of the startup was not likely to have a significant impact on cleaning water use.

Steam was used for cooking only during production hours. While the boilers were ready to provide steam during non-production hours, no cooking steam was consumed during startup, since no product was ready to be cooked.

One hour's worth of the daily natural gas consumption of 1,229 therms is 51.2 therms and provided a starting point for determining the natural gas savings. Since little steam would be used during startup, the amount of gas saved was less than 51.2 therms. EnerNOC estimated that one-half of the hourly consumption, or 25.6 therms (2.56 MMBtu), would be a reasonable savings figure.[5] This is about 2% of daily natural gas consumption or annual savings of approximately 9,340 therms with a value of about $9,000.

[5] It was necessary to estimate natural gas savings, since it was not possible to measure steam use for cooking at the facility.

Conclusions

The top-down analyses provided energy consumption estimates at the monthly level. A lack of variability in the data between production and non-production hours made it impossible to provide accurate estimates at more granular levels, such as daily or hourly. However, taking the monthly estimates and dividing by the number of hours in a month did result in figures close to the average hourly consumption figures from the billing data.

The bottom-up analyses could have been fine-tuned to provide estimates close to the hourly consumption figures from the billing data. However, the same issue arises as with the top-down analyses in that one cannot easily differentiate between production and non-production hours. As a result, it was very difficult to accurately estimate the energy savings from a one-hour reduction in start-up by simply estimating the average energy use over a one-hour period of the day.

No follow-up was built into the project to determine the accuracy of the project's estimates. In addition, as indicated earlier, the savings – while innovative – did not represent a significant share of overall energy use in the facility.

NEXT STEPS

Based on these conclusions, EnerNOC identified several next steps, many of which have already been implemented in similar projects.

Model Improvement

The total value of the electricity and natural gas savings were estimated to be approximately $31,000. This estimate is based on available data and we feel that it could have been improved significantly were more granular data available to improve the quality of the models and results. Improved granularity could be accomplished by:

- Having access to more data loggers installed on major processes and equipment to provide more points of measurement (e.g., individual motors and other points of energy consumption).
- Obtaining more frequent (e.g., hourly) observations for all points of measurement (energy consumption as well as production).

Universal Applications of These Models

The modeling approaches used in this analysis are very common. What is innovative is their use in this application. Continual application of the approaches in a variety of facility types is possible. The only limits are adequate production and energy data. While Lean was initially aimed at manufacturing facilities, it has been adopted even by companies in the service industries. Each iteration of the process described herein provides the opportunity to refine and expand the process so that a consistent and collaborative approach is eventually developed.

Energy Savings from Other Types of Waste

The approach taken in this assessment to determine the potential energy savings from a one-hour reduction in start-up time could also be adapted to estimating the energy-saving impacts of reducing or eliminating other types of waste. Looking back at the seven "deadly" wastes identified by Toyota Motor Corporation, there are three wastes where there is the potential to identify and realize energy savings:

- Transportation – The customer currently has refrigerated space in several off-site facilities. Will moving those spaces to sites closer to their facility reduce fuel and labor costs to move the products? And will the shorter distance reduce the amount of energy required to cool the products?
- Inventory – Are products being made at a rate less than the capacity of the line? Is there a pinch point in the line that constrains the entire line's capacity? Both of these problems could be resulting in wasted energy consumption.
- Motion – Like many food processing facilities, the energy inputs to the processes may not be located in the most efficient location. Could the boilers be distributed to locations closer to the points where steam and hot water are needed? The ability to distribute energy inputs could lead to lower losses.

Energy Mapping

A detailed energy mapping combined with a thorough evaluation of each of the Lean manufacturing improvements made at the facility could reveal a significant number of points where energy savings are occurring.

How Energy Is Used In Each of the Seven Deadly Wastes

Future research could quantify how energy is used (and wasted) in each of the seven deadly wastes. Not all manufacturing facilities experience all seven types of waste. However, the ability to identify which wastes are more likely to occur by industry type could prove extremely valuable.

Which Waste Should Be Targeted?

Quantifying energy consumption and waste by type of waste and industry would then allow business owners and operators the ability to target specific wastes for correction. The ability to target wastes further provides the ability to prioritize and budget for necessary investigations and improvements.

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Industrial Energy: Counseling the Marriage Between Energy Users and Efficiency Programs

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ABSTRACT

Industrial energy users and the efficiency programs that serve them enjoy a long and storied partnership. Each partner operates with the best of intentions, but with agendas that are not always reconcilable. At best, this yields a marriage that is not as fruitful as it can be. At worst, it creates alienation and wastes the value that this union has the potential to generate.

Most marriages need periodic renewal, as the partners pause to take stock of their past progress and their future vision. The marriage of industrial facilities and energy programs is no different. If industrial energy efficiency is to reach its full potential, programs must evolve beyond a courtship based on the "low hanging fruit" of easy, low-cost improvements. What began as an effort to reduce utility bills can become a strategic partnership for boosting industry competitiveness and economic growth. This approach necessarily involves capital investment choices. Aside from the usual technical analyses, industry managers and program administrators will need to effectively navigate the procedures and politics of corporate investment. This suggests an evolution in energy program communications and conduct.

This report compares the business-as-usual marriage between industry and energy efficiency programs. Drawing from a survey of stakeholders,[1] we extrapolate lessons-learned and offer a vision for sustaining that marriage in the future [Note: please read the footnote below to become familiar with the acronyms used in this report]. What are the opportunities and rewards? Equally important, how can the partners work together more productively? What does this vision imply for future program design and conduct? This report, submitted for the 2013 Industrial Energy Technology Conference, will offer suggestions. A companion social media platform will invite readers to react with comments that will refine our basic vision. It is our intention to have this document evolve into a public discussion—one that we hope lasts far beyond the close of the conference.

INTRODUCTION

Since their inception in the 1970s, government and utility energy programs for the industrial sector have offered technical support for diagnosing, designing and engineering energy solutions. By its very nature, technical support stimulates onsite industrial program interaction. To the extent that interaction is confined to discrete projects or events, the assistance can be provided by consulting experts during episodic facility visits. However, intermittent assistance tends to yield intermittent results. An energy manager, integral to a company or facility, provides the leadership and organizational continuity for implementing change.

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[1] This report is derived from a non-scientific survey of 30 industrial energy stakeholders conducted during the summer of 2012. Respondents are mostly corporate end-users but some program administrators and solution providers are included as well. Respondents included large, energy-consuming manufacturing companies with annual revenues of $10 billion or more; medium-sized manufacturers with annual revenues between $1 billion and $10 billion; small manufacturers with annual revenues below $1 billion, and *facilitators*, which can be solution providers, trade groups, or coordinators of government- or utility-sponsored assistance programs. Each facilitator observes dozens of mostly smaller companies. The acronym "SME" is used in this report to refer collectively to small and medium-sized energy-consuming enterprises. A scientific survey would have collected a much larger number of responses, using a sample frame that included respondents from each industry in proportion to their population numbers. This approach would have anticipated industry-specific generalities in the data collected from survey responses. Even had this been achieved, the knowledge of any "average tendency" for a given industry would be of little use to an energy program administrator planning the next facility engagement. Simply put, each facility is unique in its approach to energy management, which underscores the need for individualized outreach.

Traditionally, industrial energy efficiency has focused on hardware and equipment. Program efforts may entail energy assessments of facility buildings and their major mechanical and electrical systems. It is also common to provide feasibility and design studies to support individual energy projects. Assistance of this nature has certainly caused the implementation of many energy efficiency improvements. However, evidence suggests that much efficiency potential across industry remains untapped [Russell 2010]. This is due in large part to conflicting organizational priorities that prevent proposed changes. These are “change management” issues—tasks that cannot be addressed with technical skills and hardware alone.

SURVEY OF INDUSTRY REACTIONS TO ENERGY PROGRAMS

A growing number of utilities and governments offer energy management advisory programs to supplement the typically scarce resources available to industrial facility managers. As the scope and variety of advisory programs evolve, so do industry strategies for employing these resources. In general, advisory and analysis measures include energy assessment studies that investigate potential energy improvements for a system or entire facility, feasibility analyses for specific projects, and some combination of financial assistance such as a cost rebate or low-interest loan.

Some program administrators insist that industry remains unaware of program incentives. The survey responses suggest that even when industrial managers are aware of such incentives, they vary widely in their willingness and ability to utilize them. Industry receptiveness varies with corporate cultures, as no two companies are alike in their setting of priorities and the pace at which these are pursued. Similarly, no two energy managers are alike in their combination of skills, empowerment, and abilities to inspire their colleagues to action. At the same time, the design and content of energy programs will vary as will industry’s reaction. The immediate implication for future assistance program design is that one-size-fits-all offerings will have limited potential. Programs will depend more on custom measures that nuance the delivery of program services. To successfully engage the SME segment, programs may rely more on account reps that spend more time with a portfolio of clients, providing each with analytical and administrative support—therefore becoming an effective adjunct to facility management.

All respondents indicate that third-party consultants and contractors are employed to varying degrees to assist with the analysis, design, and fabrication of capital projects (21 large, five SMEs, and four facilitators’ observations of SMEs). Of these, the majority tend to employ local, trusted vendors with whom a long-term relationship has been established (12 total, eight large, four SMEs and facilitators). By contrast, there was one large company respondent that uses outsourcing sparingly, pointing to the difficulty of orienting an outsider to the complex facilities that an internal engineering team can adequately analyze. The kind of work that is outsourced varies. Companies tend to use their own staff for the engineering and installation of smaller projects. In a couple instances, respondents say that they retain critical feasibility studies while outsourcing simple, run-of-the-mill analysis. Some others do exactly the opposite. One large company respondent notes that third-party analyses boost the credibility of the staff’s internally generated improvement concepts.

The overwhelming preference for long-term, trust based vendor relationships frequently eschews formal bidding procedures. But when bidding is performed, requests for proposals are usually issued to a well-established short list of familiar vendors. The bidding process is most often performed at the facility level as opposed to corporate, favoring local vendors. Especially among SME facility managers, the local vendors often enjoy professional group or even personal relationships. Note that two companies (one large, one SME) issue corporate direction to its facilities dictating the use of specific vendors. The large company limits such direction to certain technologies such as lighting retrofits.

Only some of the 30 respondents were openly enthusiastic about program support. Their comments yield a provisional segmentation of their attitudes:

POSITIVE PROPONENTS (2 OF 30 RESPONDENTS). These respondents were energy managers, who claim that their job was made possible largely or entirely by direct funding from a utility assistance program.

MOTIVATED OPPORTUNISTS (10 OF 30). These respondents indicate that they (or their program patrons) actively seek energy improvements because of the incentives. To paraphrase respondents, proposed energy improvements are prioritized only if incentives are involved (3 respondents, all SMEs); at least some initiatives are instigated by assistance programs (2 SME, 1 large); securing utility rebates is a precondition for approving projects (1 SME); and it's difficult to do energy improvements without utility support (1 large). One facilitator notes that incentive deadlines motivate many companies to act with more alacrity. The same facilitator states that companies are not attracted to incentives just for the money; their investments are driven by true business fundamentals (but see next point).

CASUAL OPPORTUNISTS (10 OF 30). These respondents indicate that their companies pursue capital projects as they normally will, not because of incentives, but they will pick up any incentives that happen to be available. Paraphrased comments: Will use utility incentives if available (2 large, 2 SME); good projects stand on their own merit, however, mid-sized companies in particular have learned to expect and seek incentives (1 facilitator); project timing coincides with the availability of incentives (1 large); incentives don't speed up implementation, but they do improve feasibility analyses (1 large, one SME); incentives make renewable energy projects more likely (1 large); and rebates are to be preferred over tax incentives simply because it's easier to apply rebates to a specific budget within the business unit (1 large). One facilitator, contrary to the above, says that some SMEs are really responding to the incentive money. Once they are aware of the offer, then they begin to investigate the potential for improvements.

DISMISSIVES (8 OF 30 RESPONDENTS). These respondents indicate pessimism, if not hostility, toward program assistance. To paraphrase: reluctant to pursue assistance offerings due to volume of paperwork, too many points of contact, would need consultant help to navigate the process (3 SMEs); incentives are a small dollar volume relative to replacement needs (2 large); not able to take advantage of assistance programs because of the possible appearance of impropriety (1 large); audit suggestions are redundant to what they already know (1 large); and incentives help, but it's the magnitude of savings that will ensure project approval (1 facilitator).

LIMITS TO PROGRESS

Survey respondents commented on the hurdles, or at least extenuating circumstances, that determine the pace and volume of energy improvements. Note, however, that the respondents speak mostly from the perspective of middle managers from facility departments. These respondents may have strong knowledge of facility management agendas, but not all will necessarily understand or correctly interpret the dynamics of their top management's capital investment practices. Nor do corporate leaders always understand the realities of facilities management. In short, capital projects are often deliberated by decision-makers with disparate agendas and less than perfect knowledge. Dissenting opinions may exist within an organization's management team regarding what is, can be, or should be done regarding energy improvements.

A previously published report describes anecdotal observations of decision biases exhibited by corporate managers [McKinsey 2011]. These can be categorized as:

- **Confirmation bias.** Decision makers' analyses tend to be more harshly critical of reasons to accept an investment; analysis of reasons to reject proposals is not nearly as strident. This leads to a tendency to underinvest.
- **Bias derived from inappropriate analogies**. The business world tends to rely on analogies, acronyms, and jargon—all forms of verbal shorthand—to communicate ideas. When such messages are wrongly interpreted, bad decisions can be made. Energy issues tend to be complex and are especially susceptible to this. The term "energy efficiency" may mean something different to each member of a management decision team. Energy program communications need to be crafted with this problem in mind.
- **Champion bias.** In some organizations, decision makers react more to the power and personality of an investment's proponent, rather than being convinced by the merit of the proposal itself.

Returning now to our survey, respondents also reveal disconnects between decision-makers within an organization. At least two respondents (both large companies) note that corporate leaders provide staff with few resources to back sustainability pledges made to the public. In one example, there are no accountabilities to compel the chief financial operating officer to make investments in sustainability outcomes—despite the company's public pledges. At least three respondents note that energy managers are simply not empowered to pursue energy-saving investments if these would supersede the competing wishes of operations or maintenance directors. One large company respondent notes that energy projects are more difficult to implement if the impacts are felt across departmental lines. Supporting this idea, another respondent notes that an energy improvement is more easily accepted when the idea comes from the department that has responsibility for the impact. Another reason for stalled energy projects is ever-changing incumbents among the decision team. Incoming managers bring with them a learning curve and a different set of values and priorities. The greater the rate of management turn-over, the greater the chance for delaying, postponing, or outright cancelling capital project proposals.

Industrial investment priorities are shaped by operational philosophies. One facilitator describes the staff of one facility that stubbornly believes in a fixed ratio of energy per ton of product produced. To them, "energy efficiency" means a reduction of output and revenue. Old operating rules-of-thumb last for years, assuming a fixed trade-off among time, energy and money. All too often, these assumptions don't change even as the prices of these inputs vary.

Perhaps the most common barrier to industry's investment in energy improvements is a combination of fear and misunderstanding. A lack of information, or sometimes misinformation, feeds this fear. At least seven respondents (two large, two SMEs, and three facilitators) claim that the balance of an industrial organization cannot see the value of energy improvements. Many key decision-makers perceive no vested interest in the outcomes of such improvements. Fear can be further nuanced from individual survey responses: fear of projects failing to deliver promised results, or fear of adverse affects on production yield, capacity, or quality. Fear also breeds resistance: one facilitator suggests that staff on the shop floor can purposely derail corporate energy directives by simply failing to comply with them. Note that organizational politics can play a role: one respondent indicated that unionized facility staff were reluctant to suggest any changes that might impact collective bargaining work arrangements. Another facilitator says that long-time facility workers are often jaded by past episodes of failed energy efficiency promises. A different respondent, however, says that staff resistance to energy-related changes is minimal. As one large company respondent notes, a lot of the older staff have some good energy-saving ideas on the shelf that were passed over by earlier management teams.

Individual respondents also cite a lack of internal skills, a shortage of funds for employing consulting help (particularly among SMEs), and a lack of time to improve anything "that's not broken." Refusal to acquire outside expertise, for whatever reason, is a failure to benefit from new skills and experience. At least one large company respondent describes a cross section of his organization's staff—which includes an aging cohort of energy-smart professionals with sensitivities shaped by the 1970s oil shocks. Most employees added during the 1990s (a time of relatively low energy prices) tend to be less concerned with energy; unfortunately, these individuals are now entering their greatest years of organizational influence. Meanwhile, today's new hires include young people with a better appreciation for sustainability concepts. This should bode well for future support of sustainability agendas.

The hurdles discussed here—lack of resources, disparate internal philosophies, and disconnects of authority—explain industry's affinity for quick, cheap, easy energy solutions. Some respondents suggest that the easy solutions are becoming harder to find. To make more progress, energy program administrators will need to increasingly address their client's cultural and organizational issues in addition to the usual hands-on, technical aspects of energy cost control. This implies an agenda that not only takes more time, but aligns energy policy with economic and workforce development initiatives. In short, the traditional engineer-to-engineer dialogue of yesterday's energy programs is probably not sufficient to maximize capital investment in energy improvements.

ENERGY PROGRAM IMPACTS

Despite the many difficulties, many energy managers can and do overcome barriers. Two SME respondents note that their organizations originally avoided energy improvements in favor of other investments. But once some initial energy project results were available, managers were convinced and wanted more! Four respondents reiterate that project success is often predicated on non-energy benefits. Specifically: 90 percent of energy projects also have a productivity impact (one large company, one facilitator); energy improvements provide a four-fold return in the form of production improvements (one large company); and two other large companies claim that non-energy benefits "dominate" the returns from energy projects. There's still room for improvement: at least one large company respondent says the company experiences an implementation success rate for energy proposals of 30 percent or less. A facilitator claims an 80 percent implementation rate.

At least one respondent notes that energy improvements are harder to justify with today's relatively low gas prices. Upon reflection, this may reveal a strategic opportunity. The industrial sector is experiencing a re-shoring of production facilities on domestic soil. This is due in part to lower gas prices. But does this not underscore the need to invest in new facilities? If so, this investment is an opportunity to implement advanced, energy-saving technologies that will hedge these new facilities against future energy price increases.

CRITICAL SUCCESS FACTORS

What is it that allows some companies to implement more energy improvements than others? For many respondents, it begins with leadership: the influence of key top managers who communicate an inspired vision across all departments. Exactly who performs this role is determined more by personality and power than it is any specific job title.

One critical success factor cited by many respondents is that facilities need an internal energy management program of their own design and making. Energy-related goals, assignments, and accountabilities can then be coordinated with annual and multi-year capital investment plans. Absent a true energy management protocol, facilities are reduced to random projects—a hit-or-miss proposition at best.

A few respondents note that it is critical to have an energy champion at the facility site who can effectively "sell" improvement concepts to the balance of the organization. As one facilitator states, facilities are more likely to pursue energy improvements if care has been taken to explain the larger business impacts to key decision-makers. Another facilitator notes that skeptics are always present to varying degrees among a facility's decision-making team. To overcome their resistance, energy proponents—both internal champions and energy program administrators—are advised to make contact with as many of the relevant key managers as possible. Use this inner networking opportunity to reiterate the business impacts relevant to these managers' respective departments.

Once a vision is in place, protocols are needed for execution. Eleven respondents (eight large, two SMEs, one facilitator) note that it is crucial to have a staff team dedicated to at least monitoring or investigating energy performance. In some instances, teams are organized at corporate levels, providing itinerant service to facilities. Some other facilities have their own local team, which may in turn receive corporate guidance. Note that almost all respondents have a capital budgeting process of some kind, which should not be confused with an "energy strategy." Three respondents (one large and two SMEs) claim to have a formal energy management strategy. A few respondents attribute success to supportive corporate leadership. In one case, this means instilling a work environment that incents and inspires new ideas. One large company respondent describes "mature energy thinking" as a work environment where staff at all levels submit energy improvement ideas on their own initiative. In this situation, energy improvements are perceived not as a distraction, but as a viable business solution.

ENERGY PROGRAM ADMINISTRATORS' OBSERVATIONS AND RECOMMENDATIONS

Energy program administrators pre-screen facility management teams for their ability and willingness to support energy improvement initiatives. Another facilitator recommends a facility screening strategy per this acronym: MAN (money, authority, need). In other words, evaluate the decision team to determine which individuals have each of these three attributes. This helps to plan the subsequent communication strategy.

At a tactical level, one facilitator notes that facts and figures serve the energy champion well when justifying proposed improvements. The better the analysis, the less room there is for capital budget politics. And as noted above, energy improvements are more likely to occur when they are linked somehow to other core-business investments. To synthesize comments from survey respondents, Table 1 offers a provisional checklist of attributes that facilitate capital investment for energy improvement purposes. The more these attributes are in place, the greater the likelihood of success.

Table 1. Provisional Checklist for Successful Capital Investment in Energy Improvements

LEADERSHIP

- Top management support for cost improvement in general, and good projects in particular
- An empowered energy champion who has influence with multiple departments and directors
- Individuals familiar with the project from its inception are on the approval team
- The project development team draws membership from all departments to be affected by the change

CULTURE

- Company has a formal self-improvement idea generating mechanism
- A history of successful energy improvement projects
- A work culture that is amenable to change and new knowledge

ORGANIZATIONAL MECHANISMS

- Clear accountability for energy performance results
- Corporate goals for sustainability or overall cost improvement
- Capital spending decision-makers are located at production facilities
- Flexible investment evaluation criteria to recognize non-energy benefits
- Ability to schedule the energy improvement to coincide with expected shut-down maintenance episodes

BUSINESS RELEVANCE

- Clear articulation of energy impacts and their linkage to core business goals
- Evidence of a facility's deferred or pent-up demand for capital investment
- Knowledge of the capital renewal cycle for the industry and corresponding windows of opportunity for investment.
- Ability to link discrete energy projects to a current business goal or need

OPENNESS TO OUTSIDE RESOURCES

- Willingness to apply for energy program benefits
- A consultative relationship with vendors and consultants

CONCLUSIONS FOR FUTURE PROGRAM DESIGN AND CONDUCT

The potential for manufacturing energy improvement, and therefore the investment that enables these improvements, is changing. Despite the volume of potential low- and no-cost improvements discovered by program-sponsored energy audits, many of these remain unimplemented. As one respondent notes, the “low hanging fruit" has a tendency to grow back in the absence of ongoing monitoring and control. The advent of certified energy management standards such as ISO 50001 should help in this regard [ISO 2013]. But even as programs and standards are mass-promoted, industry will respond one company at a time, each on its own timetable, as key energy champions within each company are willing and able to muster the internal influence and resources needed to commit to energy management. Future program outreach may require program administrators to continually screen, coach, and support energy champions as they muster the organizational support needed to advance their energy improvement agendas. This task will draw on communication, financial, and change management skills in addition to the usual engineering expertise.

Respondents to the survey conducted for this report reiterate the fact that energy improvements are not a priority, but rather a welcome indirect benefit of industrial investment. The advancement of industrial energy efficiency program goals must more effectively detect, document, and promote the affinities between energy savings and core business goals, then communicate these fully to key decision-makers in each organization.

To some observers, relatively low natural gas prices currently dilute the urgency for energy efficiency improvements. A more strategic perception would note the need to build more capacity in response to the re-shoring of production facilities—a trend driven in part by today's low natural gas prices [Young, et. al. 2012]. Capital investments made today can provide needed capacity while ensuring that facilities are efficient from their inception, therefore minimizing the future liabilities of energy waste.

The true business impacts of energy improvements remain underappreciated by professionals that influence industrial investment decisions. Even as energy program outreach to each facility requires some message refinement, so does the communication and advice offered by economic development advisors like those representing Small Business Administration (SBA) programs and state economic development offices. Advice given to SMEs in particular is sometimes counterproductive to energy efficiency goals. This suggests the need for greater coordination between, for example, utility companies and local economic development offices.

Per the classic engineering mindset, many industry stakeholders equate energy efficiency measures with capital expenditure projects. Less technical observers may anticipate energy measures that result from behavioral and procedural change. Both groups are correct. The marriage of these philosophies calls for energy management as a *process* of continuous improvement, relying as much on performance measurement and staff action as it does capital projects. Accordingly, state and utility energy programs are evolving to support energy management practices as a complement to the project approach. This evolution is not without challenge: while capital projects involve a change of equipment, energy management imposes change on personnel roles and accountabilities. The suggestion of organizational change breeds fear and resistance in ways that the project approach does not. Compared to a capital project, the energy management process does not make a neat, one-time funding proposal. To compete effectively in the capital budgeting process, facility managers would rather *do things right*—pursue projects—as opposed to *doing the right things* that true energy management would require. Energy efficiency programs can coach facilities as they develop energy management disciplines over time—beginning with the easy, low-cost improvements, then by developing monitoring and maintenance best practices for current assets. Once these competencies are in place, energy champions can more convincingly justify capital investment in advanced technologies, pointing to energy as well as other ancillary benefits.

Program efforts can make better use of vendor-supplied expertise, as some respondents indicate. Industry's preference for trusted vendor relationships is a foundation for a true partnership with the customer. The vendor would move beyond selling commodity products, forming an advisory or consultative relationship that poses energy improvements to the customer as business solutions. "Trust" itself is a form of capital, crucial for customers to become more comfortable with the change that comes with energy improvements.

The concept of energy management—and the energy manager—remains new especially to smaller industrial facilities. With unfamiliarity comes a perception of risk. Program sponsorship allows industrial facilities to build energy management competencies with minimal risk of time and resources. While intermittent assistance from outside consultants is helpful, episodic visits of this sort cannot address the organizational change issues that so often stall the implementation of efficiency initiatives. As a full time, on site employee, the energy manager can boost implementation rates by navigating the organizational issues that result from change.

Energy managers will play a pivotal role in the adoption of strategic energy management protocols such as ISO 50001 [ISO 2013]. When a company adopts a formal protocol, it is really the initiative of a handful of individuals, with the balance of the organization remaining indifferent. The most effective energy managers will be individuals with sufficient gravitas to persuade their colleagues to invest in the effort that such protocols require. While the external marketing of these programs is helpful, industry's acceptance will largely depend on the professional acumen, insight, and motivation embodied in its energy managers.

Comment [er1]: Probably should rework this. I get the point but the tone is wrong and drifting off scope.

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Foundations for Efficiency: Industrial Energy Efficiency Program Structures in the U.S. and Canada[1]

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ABSTRACT

Industrial energy efficiency programs at the state and provincial level in the U.S. and Canada have years of experience developing and supervising energy savings delivery systems under contract or regulatory frameworks using a variety of different models. Unfortunately, this wealth of experience is not broadly known. Drawing on the experience of a number of industrial energy efficiency programs in North America, this paper discusses several key elements of the different institutional models and some pros and cons associated with them. These elements include choices of: delivery institution, funding sources and management, target setting, contractual arrangements, and monitoring and verification processes.

The objective is to highlight as clearly as possible the lessons learned in program design and implementation in key states and provinces. These findings are presented for the practical consideration of governments and utilities in their efforts to develop or upgrade their own industrial energy efficiency efforts.

OVERVIEW OF ENERGY EFFICIENCY RESOURCE ACQUISITION

Energy efficiency resource acquisition programs seek to purchase energy savings in the public interest, often through financial or technical assistance. Although the decision process for creating these programs varies and can include government, utilities, consumer groups, and other stakeholders, it is usually a government entity that gives final approval of the volume of energy savings to be acquired and how it will be funded. The government entity may also assign responsibility for delivering the energy savings to one or more institutions in some form of contractual arrangement and supervise the results.

In North America, the main driver over the past twenty years for energy efficiency resource acquisition programs has been a desire by government regulators to ensure that low-cost energy efficiency resources are delivered to meet electric power demand as an alternative to more costly supply resources. Energy efficiency resources are often significantly less expensive than new (or even existing) sources of electricity generation. Acquiring these less expensive resources reduces overall energy costs for consumers. As the concept and delivery mechanisms have evolved, other additional objectives have become important in many programs, such as environmental compliance and energy supply security. In addition to electricity, savings from other types of energy, such as natural gas, also are now being acquired.

Thinking about energy efficiency as a "resource" that can be purchased is a novel concept. However, over thirty years of practical experience in energy efficiency resource acquisition have proven that energy efficiency resources can be calculated reasonably well and relied upon as a key resource to meet electricity system demands. Costs, resource characteristics, and availability over time can be analyzed and determined with reasonable certainty. As a result, for example, the four states of the U.S. Pacific Northwest are now relying with confidence on energy efficiency to meet 85% of their new demand for electricity over the next twenty years (6).

Energy efficiency resource acquisition for the public interest is now a big business. Total expenditures on energy efficiency programs (of which resource acquisition is the dominant part) have been growing sharply in recent years. Expenditures in 2011 were US$7 billion in the United States and US$1 billion in Canada (1, 2). In both countries, programs are run at the sub-national level: by U.S. states and Canadian provinces. Throughout the states and provinces there is great variation among

[1] This paper is drawn from a more comprehensive report published by ACEEE and the Institute for Industrial Productivity, *Energy Efficiency Resource Acquisition Program Models in North America.* http://aceee.org/research-report/ie126

programs, which provides particularly rich experience and food for thought for those interested in creating or improving their own energy efficiency resource acquisition programs. All of the programs have key elements in common, but include major differences in the choices made on those elements. The common elements and some key questions to decide on for each include:

- Assignment of one or more entities to undertake the acquisition. What organizations can best arrange efficient delivery of the energy savings, preferably at lowest cost to the public?
- Designation of funding sources and amounts. What funds are to be used for the acquisition? How should funds be allocated for different parts of the program? Who decides this and how?
- A method and system for determining acquisition targets. How much energy savings should be acquired? Who decides that and how?
- Completion of performance targets and contractual arrangements. What is each delivery entity required to deliver, when, and at what cost? What are the consequences for over- or under-delivery? How can flexibility be introduced to accommodate changing circumstances?
- A system for evaluating, measuring, and verifying of energy saving results. What is the system for evaluating, reporting, and verifying the energy savings delivered? Who is responsible for what? What methodologies are used?

Why Pursue Energy Efficiency Resource Acquisition?

The main reasons that public authorities in North America encourage energy efficiency resource acquisition programs are to ensure least-cost resource development by energy utilities, reduce environmental damage from energy use, enhance energy supply security, and reduce consumer energy bills. The relative priority of these objectives varies and shapes how programs are developed and implemented.

Least-Cost Resource Development. Delivery of electricity efficiency resources costs dramatically less than incremental electricity supply resources. In most electric power systems, delivery of reliable energy efficiency resources to meet electrical energy demands (kWh) costs somewhere between 15-50% of the costs of new power supply sources, such as a new power generating plant (4). Energy efficiency resources offer similar cost advantages for meeting power capacity (kW) needs. Costs of improvements in the efficienct of use of natural gas also are substantially lower than acquiring new natural gas resources over the medium term,[2] although gas industry structure and economics are different from those of the power sector.

Environmental Benefits. Environmental concerns rank high among the reasons for adopting energy efficiency resource acquisition schemes in most states and provinces because energy efficiency is arguably the cleanest energy resource from an environmental perspective. The unacceptable land footprint and ecological impacts, air and other local pollution impacts, and carbon emissions of many supply alternatives are avoided. In environmental analyses such as air quality improvement or carbon emission reduction plans, tapping into energy efficiency resources usually ranks at or near the top of the list of cost-effective measures (5).

Energy Security. Especially where delivered as a portfolio of measures with medium- and/or long-term reliability, acquisition of energy efficiency resources can provide a valuable hedge against energy supply disruptions or shortages and energy price volatility, including price spikes. In the recent Sixth Power Plan for the U.S. Pacific Northwest (6), for example, special attention is given to the role that energy efficiency resources can play in dealing with the risks of supply and price uncertainty.

Consumer Benefits. Implementation of cost-effective energy efficiency measures reduces the energy bills of consumers. Although returns vary, life-cycle returns on energy efficiency investments are generally robust, especially if other non-energy benefits are counted (3). In addition, by relying on least-cost energy efficiency resources, utilities are able to avoid more expensive supply resources. This eventually results in lower rates (relative to a no-efficiency program scenario) as capital costs of new generation do not need to be recovered in these rates. Generally speaking, a small rate increase in the near term (for energy efficiency program costs) results in holding rates at lower levels in the long term.

DELIVERY OPTIONS

The conclusions in this paper are based on examples from eight energy efficiency resource

[2] This remains true even in light of lower natural gas prices in North America due the shale gas boom. See Young et al. 2012. *Saving Money and Reducing Risk: How Energy Efficiency Enhances the Benefits of the Natural Gas Boom*. ACEEE. http://aceee.org/white-paper/saving-money-and-reducing-risk.

acquisition programs throughout the United States and Canada. The programs are:

- BC Hydro (British Columbia, Canada)
- Northwest programs (Washington and Oregon, United States)
- Energy Trust of Oregon (Oregon, United States)
- Wisconsin Focus on Energy (Wisconsin, United States)
- Detroit Edison (Michigan, United States)
- Enbridge Gas Distribution (Ontario, Canada)
- New York State Energy Research and Development Authority (NYSERDA) (New York, United States)
- Efficiency Vermont (Vermont, United States)

Details of these programs are provided in the accompanying report (see footnote 1).

Utilities Versus Non-Utilities

When developing its solution for acquiring energy efficiency resources, each state or province faced the issue of choosing an organization to deliver services. Utilities have existing relationships with customers, have significant staff and resources in place, and established mechanism for raising revenue and covering expenses. On the other hand, utilities historically have been in the business of selling energy and are generally rewarded for selling more. Asking a utility to work against what has been historically been in its financial interest requires the organization to redefine its purpose, as well as its mechanisms for cost recovery.

Further complicating delivery of uniform services across a state, as is likely to be the goal of the state public utility commission or legislature, is the fact that many states have several, if not dozens of utilities operating within their borders. As will be explained in the following sections, many states found it more advantageous to either take on these responsibilities or to create a new entity to be responsible for the delivery of energy efficiency services throughout all or a majority of the state. Since these entities work for one organization to provide services to a second organization, they are often referred to as a "third-party administrator."

Four of the programs studied represent energy efficiency resource acquisition programs managed by non-utility entities, whereas the remaining four programs are directly administered by utilities. The governance, incentives, operational scope, and institutional culture of the utility and non-utility delivery entities are different in many ways, influencing how they approach program delivery.

The non-utility entities include one government agency (the New York State Energy Research and Development Agency – NYSERDA), two independent nonprofit corporations (Efficiency Vermont and Energy Trust of Oregon), and the Statewide Energy Efficiency and Renewable Administration (SEERA) (together with its primary nonprofit corporation contractor), created by energy utilities in Wisconsin.

Among the non-utility entities, three of the programs were specially created for the purpose of acquiring energy efficiency resources (and, in some cases, renewable energy). The concentrated focus of these entities on energy efficiency resource acquisition and the lessons they have learned along the way are especially instructive. The fourth non-utility entity (NYSERDA) provides an example where funds collected from utility customers were provided to a well-established existing state agency to operate an energy efficiency resource acquisition program with those funds alongside its many other activities.

When a utility is tasked with acquiring energy efficiency, the challenge becomes how to provide it the same incentive to provide efficiency as to provide power. For example, in addition to earning a rate of return on energy provided, most regulated utilities in North American are also guaranteed a rate of return on all capital assets (power plants, transmission and distribution systems and other physical plant assets) too. This challenge has largely been overcome through various rate structures, the details of which are discussed later in this report, but it is important to understand that resolution of this fundamental issue was required by each state or province before energy efficiency could be pursued on scale.

Funding and Program Supervision

Although only four of the programs selected for study involve energy savings delivery directly by utilities, all of the models involve some level of participation by electricity and/or natural gas utilities,. All of the programs reviewed are primarily funded with money collected by utilities from end-use consumers. These funds may be collected through a special system benefit charge, or as an imbedded part of overall tariffs. The ways that funds are compiled, disbursed, and accounted for varies substantially. In addition, legally speaking, the non-utility entities that manage energy savings delivery programs in Oregon, Wisconsin, Vermont, and New

York do this “on behalf” of utilities, who are still obligated to pursue energy efficiency under longstanding laws or regulations. Thus all of the programs except the Bonneville Power Administration (BPA)[3] are supervised by state- or provincial-level public utility regulatory authorities. In addition, however, other state or provincial government departments may be closely involved and responsible for aspects of oversight.

Different Utility Delivery Models

Among the four programs where energy utilities directly acquire energy efficiency resources, two utilities are owned by private investors and two utilities are publicly owned. The differences in utility ownership create differences in utility governance and regulation that have an important bearing on how the public-interest energy efficiency resource acquisition programs are organized and overseen. Among the investor-owned utility programs, one is an electricity utility and the other a natural gas utility. The fuel type has a substantial bearing on the economic framework of programs. Although only one example of an energy efficiency resource acquisition program operated by an investor-owned electricity utility and regulated by a public utility commission was included in this study, it is important to understand that this is currently the most common model in the United States.

Fuels Included

Energy efficiency resource acquisition programs began with electricity. Natural gas efficiency acquisition programs were later started in a number of states and provinces (most focusing initially on residential customers), and have been expanding. A few programs acquiring energy savings based on usage of other fuels such as coal and purchased steam also have been undertaken. Among the five non-utility delivery systems studied all of them cover both electricity and natural gas, and two include other fuels to some extent as well.

Evaluation, Measurement and Verification

Tracking, calculation and validation of energy savings delivered by assigned delivery entities is important for all programs in order to protect public funds. In all the programs examined, tracking, calculations and compilation of results is first conducted by the delivery entities themselves and/or consultants they hire, typically applying methodologies agreed upon with supervising authorities. Methodologies vary substantially, however in almost all cases, supervising entities critically review reported savings amounts. In some cases, supervising entities rely on detailed review by others. The depth of review and the extent to which initially reported and subsequently validated savings differ vary substantially among programs.

[3] BPA operates across several states and is owned by and reports to the U.S. Federal Government. It primarily sells wholesale electricity to local utilities, but also serves some large retail customers.

CONCLUSIONS AND RECOMMENDATIONS

Adopting and Improving Energy Efficiency Resource Acquisition Programs

Summary suggestions for weighing each of the five choices posed in the section above are outlined below. Some thoughts then are provided on the development of energy efficiency resource acquisition efforts in other countries without the ratepayer-financed and energy utility customer service framework most common in North America, but still relying on similar basic concepts.

Choice of Delivery Entity. Although final choice of the best type of energy savings delivery entity depends on local circumstance, non-utility energy savings delivery entities are certainly worth considering. Circumstances that especially favor this model include:

- Broad total energy efficiency objectives and desires for holistic, cross-fuel end-user solutions;
- Complications in local energy utility industry structures (e.g., a large number of utilities or utilities without a history of promoting energy efficiency);
- Desires to blend together a variety of funding sources, including non-ratepayer fund; and
- Lack of interest on the part of local utilities to run programs.

The challenges faced in setting up an effective new non-utility entity should not be underestimated, however, these include heavy start-up investments in developing a market presence and consumer relations in addition to acquiring programs and implementation capacity. A long-term commitment is necessary. A local non-utility entity with the management skills, staff, and flexible procedures would be preferred.

If energy supply utilities are the preferred choice, notwithstanding the benefit of strong customer knowledge and infrastructure, the “throughput incentive” problem must be dealt with through regulatory changes to overcome disincentives for promoting energy efficiency that exist under traditional ratemaking regulation. A preferred approach is adoption of decoupling regulation as well as some type of performance incentive.

If a government entity is the preferred choice, it is recommended that an entity one-step removed from government be used or established, such as a publicly owned corporation. These entities have more flexibility and may have more market experience than a government department. Sustainable, earmarked funding sources are strongly preferred over annual budget appropriation.

Funding. Although many sources of funding are possible in principle, key requirements are sustainability in funding over the medium-to-long-term, and security and predictability in fund flow. Stops and starts in funding support make energy efficiency resource acquisition programs inefficient and almost unworkable, as these programs require a multiyear focus, in part to align programs to existing business decision making and investment cycles. Utility ratepayer financing has proved a good choice for many states and provinces. The choice between a system benefit charge and financing through overall utility revenues depends on local circumstances; both have been successfully used. If a non-utility is chosen as the savings delivery entity for a ratepayer financed effort, it is easier, but not necessary, to use a system benefit charge. In setting up system benefit charges, it is recommended to include provisions and procedures to allow for periodic adjustments as energy efficiency resource acquisition demands change.

Reporting on use of funds allocated for energy efficiency resource acquisition (in addition to energy savings results) should be detailed and rigorous for utilities and non-utility delivery entities alike. Where used, mechanisms for transfer of funds from utilities to non-utility delivery entities should be efficient, transparent and as secure as possible from appropriation for other uses. Predictability of fund flow is very important for all delivery entities to operate their businesses properly.

Targeting. At the heart of energy efficiency resource acquisition programs, clarity in setting acquisition orders (targets) and rigorous reporting on delivery are essential. The well-established programs include buyer and seller agreement on both a long-term view of acquisition requirements and on a detailed medium term program of targets and budgets (typically three years), against which annual energy efficiency resource delivery is reported and verified. Use of integrated supply and efficiency resource plans are the most elegant foundation for setting savings targets and budgets for utility-supplied energy, but this may not be practical in various cases, such as when utilities and regulators lack the skills or desire to do a solid credible analysis. Definition of percent of energy sales targets is a workable alternative. However, it may be useful to check prevailing percent of sales targets periodically with reviews of cost-effective energy-efficiency potential, including updates in avoided supply costs.

The energy savings product that is being acquired needs to be clearly defined. This includes clarity as to net or gross savings (and calculation methods) and some means to convey preference for persistence in energy savings. Targeting and reporting in net savings terms is especially important for programs where high incidence of 'free riders' or spillover is expected. Supervision entity approval of the planned medium-term acquisition program portfolios of delivery entities is recommended, in addition to targets, for a variety of reasons, including needs to consider savings persistence as a factor. Periodic surveys of the savings persistence of energy savings measures supported in previous years also are suggested, as is possible use of cumulative energy savings target reporting that takes persistence into account.

All programs must balance how much of the benefit of energy efficiency, which accrues largely over the medium and long term, can be afforded with funds that must be paid up front. From the delivery entity perspective, predictability is perhaps the most important point.

Many programs include objectives beyond delivery of as much energy savings as possible with allocated funds. For example, it is common to require some measure of balancing between ratepayer contributions and program incentive and support expenditures between customer classes or geographic areas. Although many of the additional objectives have strong rationale, caution is needed as increasing objectives and performance metrics increasingly compromise the ability of delivery entities to single-mindedly pursue the most cost-effective savings opportunities.

Contracting. Contracting arrangements between supervising entity "buyers" of savings and delivery entity "sellers" also need to be clear. Even though the "contracting" with utility delivery entities is often undertaken as part of larger regulatory proceedings, a strict contractual business approach is still needed. Targets, performance metrics, any performance incentives, detailed budgeting, cost-effectiveness indicators, and other operational topics need to be included and reported on. Non-utility entity contracts need at least as much detail. Experience also has led to longer contract durations (e.g., in Vermont), in the interests of program continuity and to encourage long-term strategic focus in program design and building up in-house capacity. Program continuity is very important, and changes in delivery contractors can prove disruptive, due in part to the importance of trust between particularly industrial customers and energy efficiency delivery contractors.

Supervision entities, such as PUCs, should consider how best to meet sizable supervision demands. If supervision is perfunctory, program quality suffers. A number of PUCs overseeing the programs make arrangements for outside assistance.

Contract performance incentives, resulting in performance-based delivery entity compensation, have proven useful. However, there is an art to design to provide sufficient incentives without increasing compensation excessively. Program administrative costs (including compensation) must be monitored effectively to ensure that the vast majority of ratepayer funds are returned to ratepayers in financial incentives and useful services.

<u>Evaluation, Measurement and Verification (EM&V)</u>. Sound measurement and verification is a critical aspect of energy efficiency resource acquisition schemes, enabling buyers to be reasonably sure that they have purchased the product they ordered. Although delivery entities may undertake the bulk of the work as they complete their savings claims, some type of third party review is also recommended. Nevertheless, delivery entities need as much upfront clarity as possible as to how technicalities of energy savings calculations will be approached, to inform their programming and to maximize verified energy savings delivery. The measurement and verification technical manuals issued periodically in a number of the energy efficiency resource acquisition programs are a good mechanism to guide all of the parties involved.

<u>Preliminary Thoughts on Additional Acquisition Models to Explore.</u>

The prevailing North American model that uses utility ratepayer funds to acquire energy savings with incentives and other services from amongst those same utility ratepayers may or may not blend well in other countries with differing approaches to promoting energy efficiency, or with the utility regulation practices or customer relationships in those countries. Even where the ratepayer financing/utility customer service model is not considered optimal, however, energy efficiency resource acquisition programs can still be developed and applied. The issue is source of funds. As mentioned above, the key requirements for funding are sustainability over quite a few years and security and predictability in fund flow. In principle, a variety of earmarked funding sources can meet these requirements. Assignment of delivery entities, targeting, contracting, and savings verification can then all potentially proceed along similar principles to those that have been successful in North America.

One option that may be worth exploring is use of carbon emission or fossil fuel tax revenues. In this case there also may be potential for development of similar types of "covenants" with consumers used in the U.S. – consumers pay the taxes, but receive their funds back in the form of financial incentives and services.

Energy efficiency resource acquisition programs can be undertaken for certain market segments. Two possibilities include:

- Program application based on customer class: residential energy-users, large buildings (including either commercial buildings, public buildings or both), or small and medium-scale industrial enterprises.
- Blending of energy efficiency resource acquisition with current systems of industrial energy conservation agreements with the government. A delivery entity could provide financial incentives and support to companies with agreements, in exchange for delivery of verified energy savings, perhaps funded with carbon/fossil fuel tax revenues from those companies. Frameworks somewhat akin to this already exist in some European countries.

In exploring development of such programs, perhaps the most valuable experience that North American programs and entities have to offer concern the business aspects of energy efficiency resource acquisition – continual focus on achieving maximum verifiable savings with the limited public funds available.

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RECENT DEVELOPMENTS IN CHP POLICY IN THE UNITED STATES

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ABSTRACT

Combined Heat and Power (CHP), also known as cogeneration, refers to one of several technologies that allow a facility to generate electricity and useful heat simultaneously. It is highly efficient compared to conventional methods of generating heat and power separately. However, various market and policy barriers exist that prevent CHP from being more widely adopted. This paper provides an introduction to CHP and its benefits and an overview of the current CHP market, followed by an assessment of recent developments in CHP policy at the state level across the United States. New trends in CHP policy are highlighted, included an increase in the number of states that include CHP in their energy efficiency standards and the increased attention being paid to CHP's resiliency during times of disaster.

INTRODUCTION

Many different sizes and configurations of CHP equipment are available to allow a wide variety of facilities to use CHP, from small residential systems capable of generating a few kilowatts to medium-sized systems that can power hospitals or hotels to large industrial CHP systems that generate 100 MW or more. Compared to conventional means of generating heat and electricity, CHP can be extremely efficient. A typical coal-fired power plant in the United States is about 33% efficient, meaning that only about 33% of the energy contained in the coal is converted into electricity, while the rest is lost as waste heat. Conventional natural gas plants are, on average, about 42% efficient (1). CHP systems can reach a combined electric and thermal efficiency of 70% or even greater (2).

There are two main types of configurations for CHP systems: topping cycle and bottoming cycle. In a CHP system using the topping cycle, electricity is first generated using a steam turbine. After passing through the turbine, remaining steam is condensed and used for heating. A bottoming cycle CHP system first generates heat for industrial processes, such as a furnace in a manufacturing plant. The waste heat is recovered and is then used to generate electricity. Natural gas is the most common fuel used for CHP systems, but other fuels, such as biomass, can be used as well (3).

There are many benefits to CHP systems. Because they are so efficient, less fuel needs to be consumed to perform the same amount of work compared to a conventional system. Facilities that install CHP systems often experience dramatic reductions in energy expenditures, particularly in regions where electricity rates are high. CHP systems also result in lower emissions of greenhouse gasses and other pollutants, which can help facilities comply with state and federal environmental regulations.

CHP systems also tend to improve reliability of the electric grid. Rather than being large, centrally located plants like traditional power plants, CHP systems are more spread out, generally located on-site where heat and power are needed. CHP systems can help reduce the frequency and duration of interruptions to electricity service. This can be particularly important for places like hospitals or data centers, where even instantaneous power interruptions can result in expensive and time-consuming reboots. This effect is particularly noticeable in the aftermath of a major storm or other natural disaster. After Hurricane Sandy struck New York in 2012 and lower Manhattan was plunged into darkness, a few buildings with CHP systems managed to keep the lights on.

Today there are more than 4,100 CHP sites across the United States, with a generating capacity of about 9 percent of total US capacity. However, there is a great deal of potential for additional CHP capacity in the United States. According to a 2008 study by Oak Ridge National Laboratory, there is potential for 20 percent of generating capacity to come from CHP if pro-CHP policies are implemented at the state and federal level (4).

CHP POLICY SHAPING MARKETS TODAY

CHP has been recognized as a policy priority at the federal level. In August 2012, President Obama signed an executive order encouraging investment in CHP, with a national goal of installing 40 GW of new CHP capacity by 2020 (5). The executive order directs the Federal Government to coordinate policies in support of CHP, such as providing technical assistance, improving data collection, assisting state governments in developing pro-CHP policies, and providing incentives.

In response to the President's Executive Order, the Department of Energy has been convening a series of Regional Dialogue Meetings to give stakeholders across the country the opportunity to discuss CHP policy. These meetings focus on best practice policies and investment models and barriers to CHP, as well as provide public information about the benefits of CHP and existing Federal programs that can be used to support investment in CHP. The most recent meetings occurred in March 2012 in Baltimore, June 2012 in Columbus, Ohio, and January 2013 in Little Rock, Arkansas (6).

At the state level, CHP has become a stated priority in several states. In 2011, Gov. John Kasich of Ohio hosted an energy summit where he expressed support for CHP (7). Today, Ohio's public utility commission is engaged in a pilot project with the Department of Energy, which is intended to address specific barriers to CHP in the state. Through a series of stakeholder meetings and online webinars, the Department of Energy and the public utility commission have identified stand-by tariffs, financing, and education as key barriers. The pilot project is now working to identify a set of best practices (8).

Oregon's recent 10-year energy plan specifically identifies CHP as a critical resource (9), and Massachusetts has long sought to encourage CHP with a specific call-out for CHP within utilities' energy efficiency portfolios (10).

The above examples represent just a few of the ways states are taking the lead in encouraging CHP as an energy resource. Despite the federal goal of 40GW of new CHP by 2020, states still are best positioned to work directly with their utilities to help grow their local CHP markets. As consumer electricity rates rise, more states are giving CHP a new look.

ACEEE SCORECARD

Each year, ACEEE publishes the *State Energy Efficiency Scorecard*, which ranks each state based on its energy efficiency policies (11). CHP policies count for 10% of each state's total score. In the past, scoring CHP policies involved a fairly high amount of subjectivity. The 2012 *Scorecard* aimed to insert more objective assessments of state CHP policies and included a new methodology and scoring system for the CHP section. This new methodology was designed to reduce confusion and more accurately reflect the complete regulatory environment for each state as well as create a more objective system for scoring (12).

States were ranked in seven policy categories, as well as evaluated in two additional policy categories for which no points were awarded. Here we include a brief description and methodology for all of the categories that constituted the CHP chapter of the 2012 *Scorecard*.

Interconnection

Interconnection rules provide guidelines for how CHP systems can connect to the rest of the electric grid. They enable the CHP operator to purchase additional power from the grid when needed, sell excess power back to the grid, and maintain safety and stability standards. Interconnection rules also provide guidelines for the application process a CHP operator must follow in order to connect to the grid.

Not all states have interconnection standards that apply to CHP, so those states received a score of zero in this category. We also wanted to see states that had interconnection standards that included all fuels (instead of only allowing biomass CHP systems, for instance) as well as larger systems over 10 MW. Interconnection standards that had fast-track interconnection processes for smaller systems were also viewed favorably.

Net metering standards

Net metering applies to utility customers that have their own generating capacity, such as a CHP facility or a renewable system such as wind turbines or photovoltaic cells. If a customer with one of these facilities generates more electricity than it consumes, net metering standards allow it to receive retail credit for the electricity that is added to the grid. For the Scorecard, we looked for policies that could be used by all customer classes (i.e., industrial, large commercial, small commercial, and so on), covered all types of CHP technologies and fuels, and covered systems larger than 2 MW. We also considered whether the standards attempted to limit the overall aggregate amount of capacity within a utility system, offered wholesale or retail rates, and if they carried over credit between billing cycles or let credits expire.

Energy Efficiency/Renewable Energy Portfolio Standard Treatment

Many states have established long-term goals for energy savings through Energy Efficiency Resource Standards (EERS) or goals for including renewable energy sources as part of the state's energy mix through Renewable Energy Standards (RES) or Renewable Portfolio Standards (RPS). For this section, we considered whether CHP is included as an eligible technology, how lucrative the portfolio standard is to CHP projects, whether enforceable benchmarks for CHP are part of the portfolio standard, and how CHP is treated relative to other types of energy sources identified in the standard.

Financing Opportunities (Including Loan Programs)

CHP systems can be very expensive to install. Potential CHP operators may see dramatic savings in energy costs in the long run, but still could have trouble obtaining sufficient capital up front. In general, we were looking for states that offered robust programs that allow a wide variety of CHP systems, rather than restricting funding to specific sizes or fuel types. High-scoring states in the *Scorecard* have various programs that assist CHP projects and help owners obtain funding through grants, incentives, or other revenue streams. We looked to see whether incentives and grants specific to CHP exist and how broadly applicable they are. We also looked to see if other revenue streams, such as standard offer programs or feed-in tariffs, are applicable to CHP and are persistent and reliable.

We also examined the availability of other types of financing assistance, including loans, loan guarantees, and interest rate buy-downs. We assessed states based on how widely available these programs are and whether special bonding authorities are being used to fund CHP systems.

Emissions Treatments

CHP has a fairly unique position with respect towards environmental and emissions regulations. On an economy-wide scale, increased adoption of CHP results in lower fuel consumption (and consequently, lower emissions of greenhouse gases and other pollutants) because of the high efficiency of CHP systems. However, CHP systems require operators to consume fuel on-site, which can result in *increased* emissions for the individual operator relative to business as usual. This issue can be particularly challenging when considering CHP systems that use natural gas-fired rather than those that use renewable fuels like biomass.

For the *Scorecard*, we focus in particular on whether emissions standards are developed with an output-based approach. This means that emissions standards take into consideration the efficiency and usable energy output of a system rather than the volume of emissions alone. We also considered whether other environmental regulations are designed to encourage CHP, and whether “fast track” or “standard” permitting is available to certain CHP systems in order to expedite the permitting process.

Additional Supportive Policies

There are some additional policies that benefit CHP, but have not been captured in any of the previous categories. Such policies might include unique technical assistance designed to encourage CHP deployment, educational campaigns designed to increase interest in and knowledge of CHP, or special incentives available to utilities that help encourage CHP deployment.

Unscored Categories

Local Electricity and Gas Rates.

CHP systems tend to make the most economic sense in areas where electric retail prices are relatively high and natural gas retail prices are relatively low. Even states that have policies that are very favorable toward CHP may have a difficult time encouraging projects to get off the ground if local gas and electricity rates are too high or too low. However, the purpose of the *Scorecard* is primarily to consider the impact of state policy rather than other economic factors. We recognize that states cannot directly control the retail price of electricity or gas to customers. We do not score states based on their local electricity and gas rates, but we include this information to more accurately reflect the market in each state.

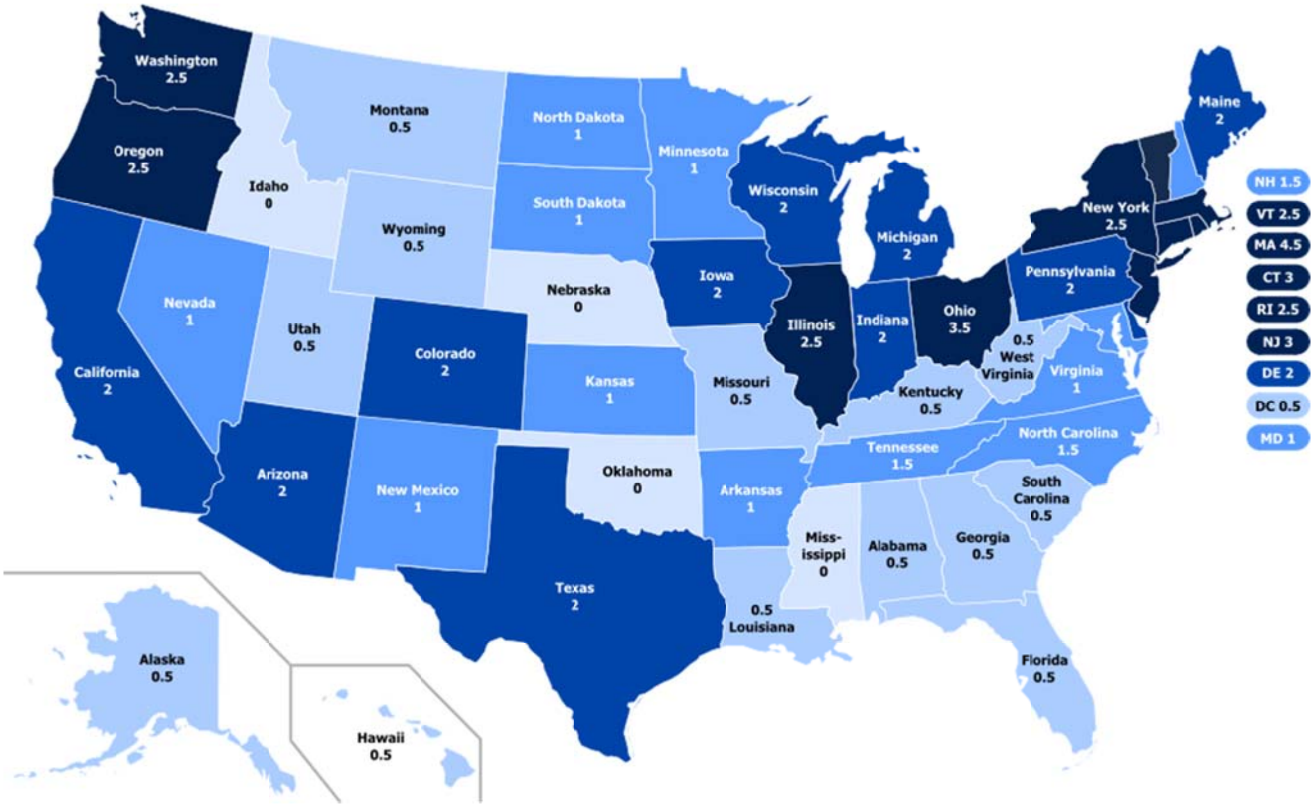
Recent Deployment History

The 2012 *Scorecard* included information about the number of individual CHP systems and the total capacity installed in the previous two years (2010 and 2011). This can be an important indicator of a CHP-friendly environment in any given state. However, we did not include this in our scoring because CHP systems can take a long time to plan and install, so CHP installations within a single year does not necessarily reflect the impact of state policy, and certain economic factors may be more important than policy and regulations in some cases.

Scorecard Results

Using the above criteria, ACEEE gave each state a score, with a maximum possible score of five points. Figure 1 displays a map indicating the scores for all fifty states, plus the District of Columbia. Massachusetts was by far the top-scoring state, with a score of 4.5. All states in the Top Ten for CHP (shaded in darkest blue) obtained scores of at least 2.5. The second tier of ten states all obtained a score of 2, followed by a third tier of states with scores of 1 to 1.5. At the bottom of the list are 14 states that only scored 0.5, followed by four states that scored zero (shaded in palest blue). In general, the lowest-scoring states were most likely to get credit for offering some kind of incentive or financing opportunity for CHP, but restrictions, such as allowing funding only for CHP systems below a certain size or prohibiting natural gas as an eligible fuel, prevent the state from obtaining a full point.

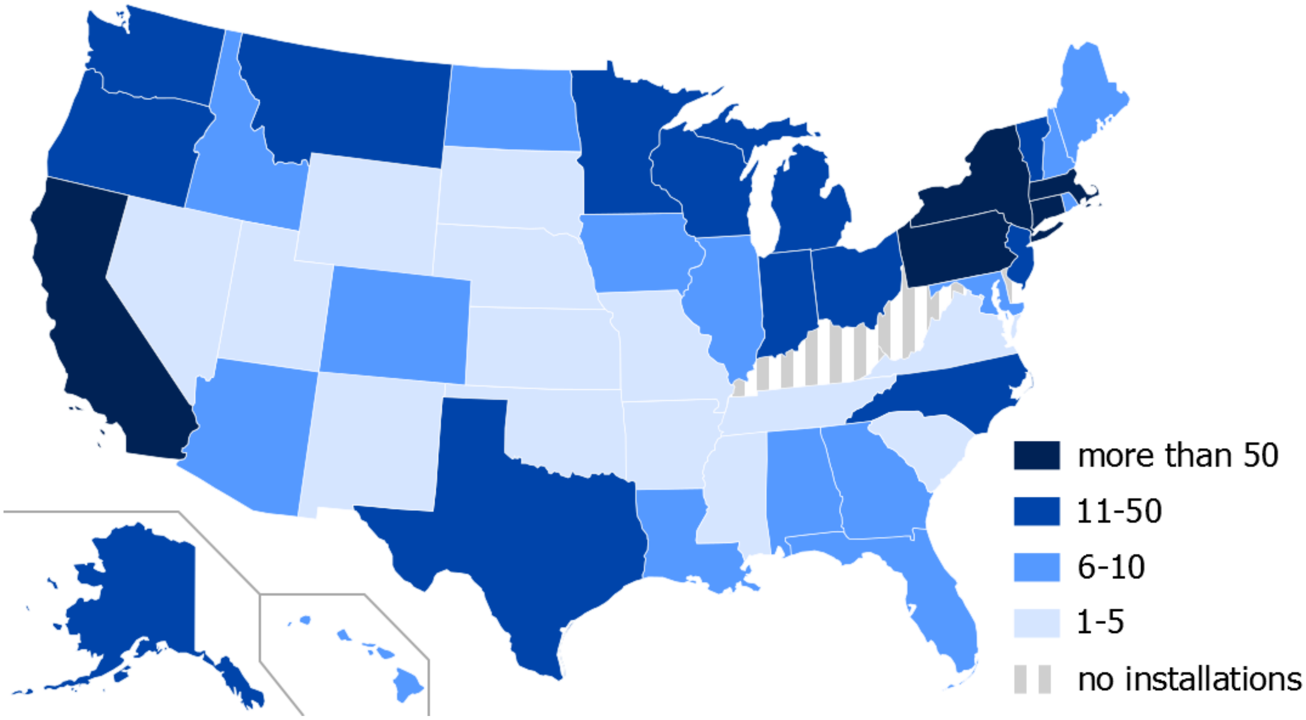
Figure 1. CHP Scores from the ACEEE 2012 Energy Efficiency Scorecard.



The policies reflected in our state rankings for CHP in the 2012 *Scorecard* have a real-world impact. Figure 2 shows a map of the United States with each state shaded based on the number of new CHP sites that have been installed since 2005. A top-tier score for CHP is highly correlated with a large number of new CHP installations. The five states that have installed the most new CHP since 2005—Pennsylvania, Massachusetts, Connecticut, New York, and California—are all ranked in the top two tiers for CHP in the *Scorecard.*

However, the two maps do not perfectly correlate for a few reasons. Firstly, the sheer size of the state has a significant impact. California was in the second tier of ten states for its CHP score in the *Scorecard*, but installed 381 new CHP sites since 2005, which is more than any other state. This can be partially explained by the simple fact that California is the most populous state in the US. Other differences can be explained by differences in utility prices for each state, which can dramatically impact the economics of CHP. Even if a state has policies that are highly favorable to CHP, potential operators are somewhat less likely to choose to install CHP if there is not enough of a financial difference between generating electricity on-site as opposed to purchasing it from the grid. Overall, the correlation is close enough to indicate that state policies can have a significant impact on CHP deployment.

Figure 2. Number of new CHP installations 2005-present



GENERAL TRENDS IN CHP POLICY DEVELOPMENT

Several important trends have begun to emerge at the state level that may prove highly useful to the CHP market. These include:

Growth of CHP Prioritization within Energy Efficiency Standards

This year Ohio officially recognized CHP as a resource within its existing energy efficiency resource standard. This legislative change means that waste heat is now viewed as a renewable energy resource in Ohio, and CHP systems can explicitly count towards utilities' energy efficiency goals (13).

Recognition of CHP as Key to Resiliency

Hurricane Sandy did much to help people realize the importance of on-site generation in strengthening community resilience during times of crises. The storm caused power outages to about 8.5 million customers, but a small number of facilities with CHP systems were able to keep the lights on. These facilities included several universities such as Princeton, College of New Jersey, and parts of NYU, Co-Op City, a middle-income housing development in the Bronx with over 55,000 tenants, and a sewage treatment plant in Bergen County, New Jersey serving 550,000 customers. Perhaps most importantly, several hospitals were able to disconnect from the grid and use CHP to maintain critical systems. At these hospitals, CHP quite literally saved lives (14).

New Jersey, which was hit particularly hard by Hurricane Sandy, has begun to look at CHP as a way to protect against future extreme weather events. In December 2012, the New Jersey Office of Clean Energy hosted a stakeholders meeting with utility officials, energy suppliers, and others with an interest in CHP. The group proposed prioritizing facilities such as hospitals, prisons, and wastewater treatment plants that would be most in need of power in the event of another Sandy-like scenario (15).

Recognizing the benefits of CHP during catastrophic weather events such as hurricanes, both Texas (16) and Louisiana (17) have enacted rules requiring CHP to be considered during construction or major renovation of facilities determined to be critical state infrastructure. Certain facilities must consider the feasibility of CHP and are encouraged to deploy CHP when found to be cost-effective and in the interest of the state.

Specialized CHP Programs

Other states strengthened specific CHP-focused programs in order to help take advantage of the emissions-reducing capabilities of CHP. In California, a new feed-in-tariff program sets specific rates at which excess power from CHP systems will be purchased by the state's regulated utilities. The primary goal of the program is to acquire new energy resources that reduce the state's greenhouse gas emissions, so highly efficient CHP is eligible to help utilities meet their assigned emissions reduction target (18).

Some of the new developments in CHP policy have been in the structure of the tariffs used to charge CHP systems for backup and supplemental power. In New York, Con Edison has developed an offset tariff, which allows the generation from a CHP system to offset the aggregated load of multiple meters in a campus-style arrangement, mitigating the individual peaks of single facilities and thus reducing the demand charges a facility must pay (19).

CONCLUSION

The Federal government as well as individual states are increasingly recognizing the benefits of CHP as a cost-effective means to increase energy efficiency. At the Federal level, President Obama's August 2012 Executive Order has been important in promoting pro-CHP action at the Department of Energy, the Environmental Protection Agency, and other Federal agencies. States are increasingly implementing policies to remove barriers to CHP and provide incentives for investment. Some of the most notable activities in state policy in the past year have been discussions at the state regulatory commission level about how to better engage utilities in the CHP market and an increase in the number of states that view CHP as an energy resource within existing energy efficiency planning and program funding.

Looking forward, we hope to see additional states implement pro-CHP policies. While recent CHP deployment has continued to be below early-2000s levels, the continued low price of natural gas has clearly opened many up to the possibility of CHP again. As states plan to close coal plants and expectations about future federal emissions rules grow again, CHP can continue to position itself as a cleaner, cheaper, and more efficient alternative to traditional centralized energy generation.

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INNOVATIVE ENERGY CONSERVATION THROUGH SCRAP PRE-HEATING IN AN ELECTRIC ARC FURNACE

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ABSTRACT

Objectives:

This paper will present an innovative energy conservation technology for scrap pre-heating in an Electric Arc Furnace that is being implemented in an industrial facility in Ontario. The objective of the paper is to examine the electrical and operational benefits of implementing this technology, as well as the challenges in accurately evaluating the project viability as part of an incentive program.

Highlights of the conservation measure are as follows:

- Recovery of heat from furnace off-gas to pre-heat scrap metal prior to charging in the ladle
- 10% reduction in specific electrical energy (measured in kilowatt-hour per ton of liquid steel)
- Reductions in oxygen, carbon and electrode usage
- Increased production rate due to decreased tap-to-tap time

Methodology and Scope of Research:

1. Similar technologies will be researched for comparison to this newer scrap pre-heating technology with regards to configuration, costs and benefits.
2. The assessment of the new technology's benefits as determined through the technical review process.

Results:

The results of the paper will present the evaluation of the potential benefits based on results from a planned implementation of scrap pre-heating in Electric Arc-Furnaces.

BACKGROUND

With assistance from government incentives, the facility was able to upgrade their electric arc furnace (EAF). In order to acquire the incentive, the facility was required to submit an application and information to support the savings and costs of the project which were required to be accurate to ±10% and ±25% respectively. The project was required to be reviewed for its technical and financial merits to confirm the value of the project to the ratepayers. As a condition of the contract for the incentive, the facility is required to provide measurement and verification (M&V) data to demonstrate the measure's electricity savings for 10 years after the measure is declared to be in service.

Prior to the upgrade, the EAF at Ivaco Rolling Mills 2004 L.P. melted recycled steel scrap for casting into billets that are eventually rolled into steel wire products on site. The scrap melting process at the facility was a batch process. The EAF roof wa periodically opened to load or "charge" the furnace with scrap. Electricity, natural gas, oxygen, carbon, and electrodes were all consumed in the furnace during the melting process. Once the furnace finished melting the scrap, it was "tapped" into a ladle to allow the liquid steel to flow into the next step of the process.

The facility proposed to modify this process with the Consteel^{TM}, or continuous steel, system. This would no longer require the roof to be opened for normal charging as a conveyor carries scrap into the furnace through a tunnel. It is in this tunnel where the off-gas also flows out of the furnace and heat is recovered to preheat the scrap. This pre-heating of scrap is the primary mechanism of reducing electrical input required to melt scrap. Additional benefits associated with this Project are significant, and result from savings in oxygen, carbon, and electrode consumption in the EAF.

BASE CASE

In order to evaluate the accuracy of the potential electricity savings of the project, it was necessary to establish a base case. The base case is the configuration of equipment that will act as the benchmark for calculating the savings. The base case baseline energy is the amount of electricity that the system would have consumed without the installation of the energy conservation measure.

Historical production of liquid steel at the facility has varied between 180,000 and 380,000 short tons of liquid steel (tls) per year. The maximum throughput capacity of the EAF was understood to be 450,000 tls/yr due to limitations of the EAF and other downstream equipment within the mill.

EAF production data from 2011 was provided to determine the electricity consumption and tons of steel throughput of the base case. It was found that 260,000 tls was produced during 2011. Analysis of the heat data for 2011 determined an overall energy intensity of 343 kWh/tls.

The Consteel system allows the batch processing time of the furnace ("tap-to-tap" time) to be reduced. In doing so, the maximum annual production of the facility would increase to 575,000 tls after installation of the Measure. Achieving this level of production also requires upgrades to the caster which turns the liquid steel into billets.

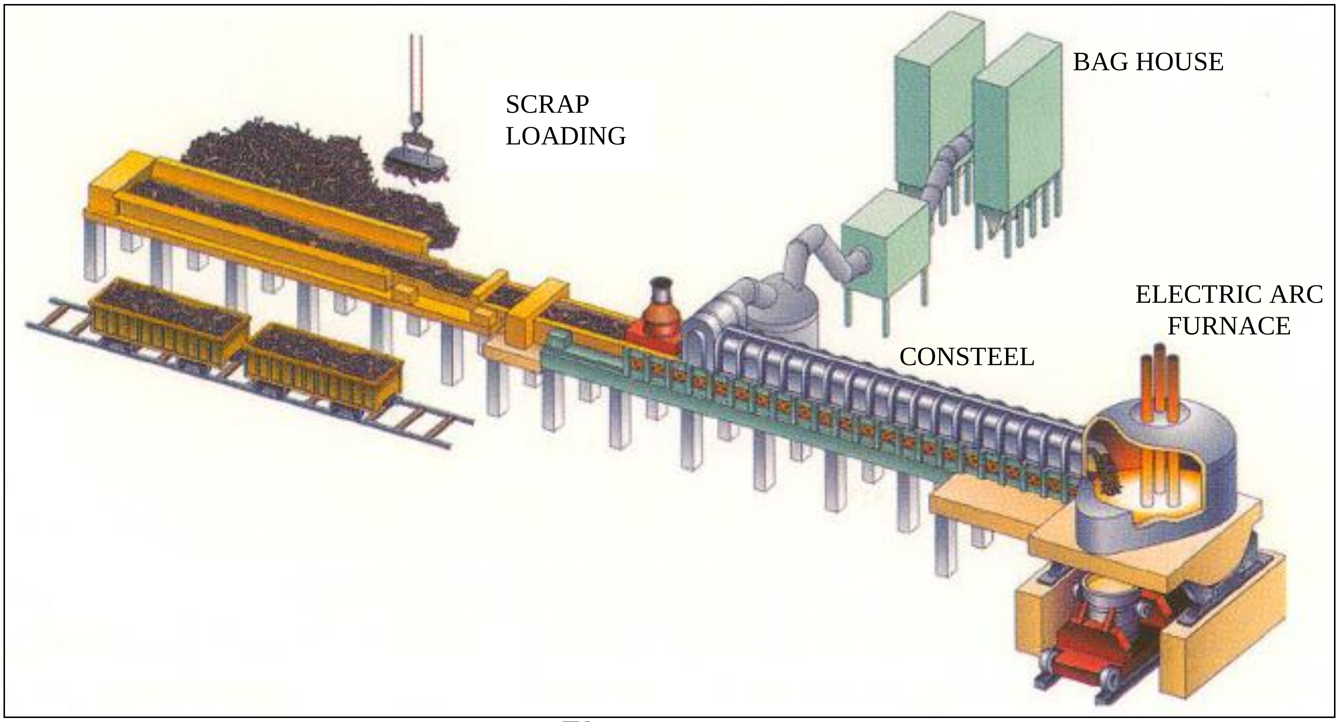

Figure 1. Schematic Depiction of Consteel^{TM} System (2)

The treatment of the above situation for electricity savings and costs is analogous to a new construction scenario where no base case baseline exists. Although this situation is a retrofit of the EAF, the result of the entire mill upgrade will be higher throughput and higher energy use. Therefore, the savings and costs must be calculated incrementally against a base case which was determined to be the least cost upgrade that is available that meets the future production requirements.

The facility provided a least cost alternative to reach a maximum annual production capacity of 575,000 tls. The upgrades include an increase in the size of the transformer, new electrical feeder lines and flicker control. These upgrades would allow the EAF to operate at a higher power and process the scrap into liquid steel at a higher rate. Analysis of the data assessed the energy intensity of the projected base case was 343 kWh/tls for production up to 575,000 tls/yr. This results in a projected base case baseline of 197,000 MWh/yr for every year of the contract assuming production of 575,000 tls/yr.

ELECTRICITY SAVINGS ANALYSIS

Three possible approaches for reviewing the proposed electricity savings were identified: first principles calculation of heat transfer from off-gas to scrap, benchmarking analysis of operational data from a comparable mill with an operating Consteel system, and literature review of published case studies for Consteel installations.

Given the information obtained through from the vendor on the heat and mass balance of the Consteel^{TM} system a comprehensive energy model based on first principles was partially successful. A range of possible savings was estimated using engineering principles and assumptions for the heat recovery portion of the measure. An energy model was developed to calculate the heat absorbed by scrap in Consteel tunnel through the two pre-heating stages: combustion of natural gas and EAF's off-gas. To calculate the transferred heat in each stage, the simplified heat equation was used,

$$Q = m \times c\,(T_2 - T_1)$$

where Q is the transferred heat, m is the total mass of scrap, c is the heat capacity of scrap and T_1 and T_2 are the scrap temperatures before and after the heat transfer process respectively. Assumptions made in developing the heat model include the heat transfer efficiency values and the final temperature of scrap before entering EAF. The final temperature of scrap in the Consteel tunnel could vary from 300°C to 600°C (1,3). Therefore, a sensitivity analysis was performed to determine the change in energy intensity improvement. The results predicted savings ranging from 20 kWh/tls to 60 kWh/tls. The energy model did not consider the effects of other process inputs such as oxygen and carbon.

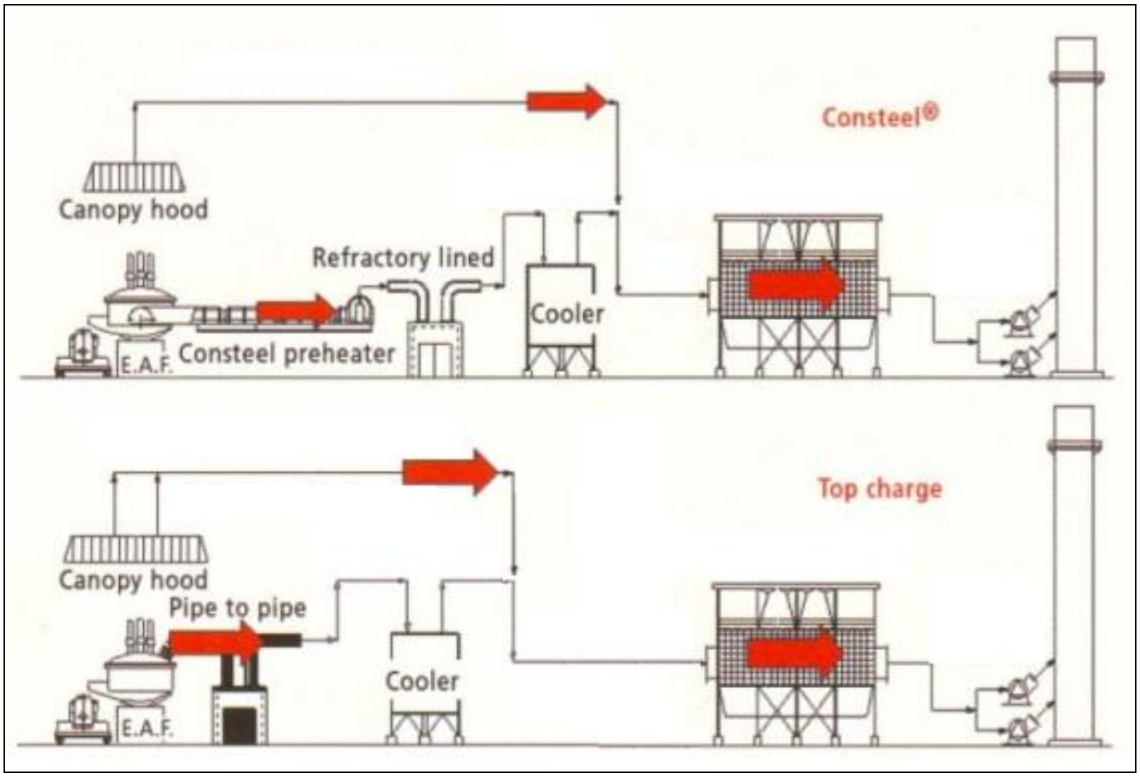

Figure 2. Off-gas treatment in a typical Consteel plant, compared to a conventional EAF (5)

In order to benchmark the measure and the potential electricity savings, operating data obtained independently from a mill of similar size and having a Consteel installation as proposed. However, such data was not available. However, this type of detailed operating information is proprietary, and not available.

In the absence of detailed benchmarking data, the fall-back approach involves comparing the proposed savings against available literature and case studies on EAF scrap pre-heating and Consteel technology. The literature review from multiple sources indicated energy intensity improvements of 45 kWh/tls to 65 kWh/tls (3; 4; 5). Case studies have been published from two plants where Consteel has been implemented. The findings are summarized in Table 1.

One major difference between the proposed Consteel process at the facility and the other two plants is the preheating of scrap by natural gas burners before it enters the Consteel tunnel. This additional stage of preheating makes the proposed energy intensity of 343 kWh/tls more probable.

The facility's application was estimated an energy intensity improvement of 38 kWh/tls. Since the 38 kWh/tls improvement in energy intensity is within the range estimated by our energy model with reasonable operating assumptions and is supported by the literature review findings, it was concluded that the predicted electricity savings are reasonable and achievable.

It was identified that additional connected load would be required for ancillary equipment to support the Consteel™ system which would be netted out from the savings estimate. This equipment is comprised of ancillary pumps and conveying equipment which were estimated to require 900 MWh/yr. Although the ancillary equipment's annualized energy consumption is small compared to the estimated savings that result from the pre-heating and well within the uncertainty range of the analysis. For the assessment of the savings, the ancillary loads were ignored. It was recommended that the consumption of the ancillary loads would be captured through the M&V reporting after the measure is in service.

Based on the expected future production rate of 575,000 tls/yr and 38 kWh/tls Savings it was determined that 21,686 MWh/yr of savings can be achieved.

Additional benefits and costs were identified in the context of the proposed heat and mass balance and changes in the use of consumables (electrodes, oxygen, carbon and natural gas) that were expected through the implementation of the Consteel system. Additional costs would be incurred because of the natural gas would be used in the tunnel section of the Consteel system. Additional savings would result from the reductions in the consumption of electrodes, oxygen and carbon. The facility expects a net benefit of $9.77/tls. Further reductions in operating costs are expected from a reduction in the frequency of EAF relining though these savings were not quantified.

Table 1 - Proposed vs. Case Studies (1,6)

	Ivaco (Proposed), ON	**Ameristeel NC**	**Co-Steel Sayreville, NJ**
Year Consteel Installed	TBD	1990	1994
Year Data Reported	2012	1995	1998
Capacity, MW	35.7	24	35
Capacity, Mt/hour	82.6	54	82
Capacity, Mt/year	521,630	551,268	680,388
Tap to tap time, minutes	50	49	53
Electricity Consumption, kWh/Mt	342	373	390
Electrode Consumption, kg/Mt	1.20	1.7	1.75
Oxygen Consumption, Nm^3/Mt	30.40	22.2	23
Natural Gas Consumption, Nm^3/Mt	9.50	0	not available
Carbon Consumption, kg/Mt	19.60	not available	not available
Simple Payback, year	1.98	2	not available

Note: Mt is "metric tonne" of product

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Technologies to Recover Low--Temperature Waste Energy in Chemical Plants and Refineries

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ABSTRACT

Technologies to economically recover low-temperature waste energy in chemical plants and refineries are the holy grail of industrial energy efficiency. Low temperature waste energy streams were defined by the Texas Industries of the Future Chemical and Refining Sectors Advisory Committee as streams with a temperature below 400°F. Their waste energy streams were also characterized as to state, flow rate, heat content, source and temperature. These criteria were then used to identify potential candidates of waste heat recovery technologies that might have an application in these industries. Four technologies that met the criteria of the Advisory Committee included: organic rankine cycle (ORC), absorption refrigeration and chilling, Kalina cycle, and fuel cell technologies. This paper characterizes each of these technologies, technical specifications, limitations, potential costs / payback and commercialization status as was discussed in the Technology Forum held in Houston, TX in May 2012 (TXIOF 2012).

Introduction

In 2012, the Institute for Industrial Productivity (IIP) and Texas Industries of the Future (TXIOF) at The University of Texas at Austin organized a day-long Technology Forum titled - *Low Temperature Waste Energy Recovery in Chemical Plants and Refineries*. The report and presentations from that workshop are posted at http://texasiof.ces.utexas.edu/. This paper characterizes the opportunities in these two sectors and describes the potential candidate technologies that can turn this low temperature waste energy stream into work or product.

Petroleum refining and chemicals stand out as the sectors with the highest uses of energy, and together have the largest potential for waste energy recovery. These two sectors dwarf all others in energy use; only Forest Products shows a greater potential for energy recovery. Different industries have a different threshold for what they characterize as low temperature. This limits the transferability of technologies from one industry to another. For example, in the glass and metal industries, low temperature is anything below 600°F. In facilities that produce food and beverages, low temperature is below 180°F. Nevertheless, the petroleum refining and chemicals sectors have a similar range (350-400°F) that is defined as low temperature and hence, there is a good overlap for the potential candidate waste energy recovery technologies in those industries. They also share many of the same challenges in executing energy recovery projects; they have been very skilled at recovering high temperature waste energy, and the remaining unrecovered waste energy is low-temperature and distributed across large plant sites.

Another important characterization question is the source of the waste energy stream. Waste energy streams can be from a utility or a process unit. Generally speaking, waste energy recovery from utility streams has been extensively addressed by the U.S. DOE with its

BestPractices software tools. For example, in steam systems - the technology to recover and reuse energy from blowdown, condensate, etc. is well-known and the greatest barrier to implementation is simply the capital cost to retrofit older plants. Since there are several well-known solutions available for energy recovery in utility waste energy streams, these were not considered part of the Technology Forum and will not be covered in this paper. It has to be noted that the authors do not intend to imply that utility energy systems should not be considered for waste energy recovery in industrial plants. Table 1 summarizes the sources of Low Temperature Energy Recovery that were targeted in the Technology Forum.

Table 1. Sources of Low-Temperature Energy

Recovery Applications	**Sources of Low-Temperature Energy**		
	Utilities	**Process**	**Stack Gases**
Thermal to Thermal	**Not** a technological issue. Well understood applications and equipment.	✓	✓
Energy Conversion	**Not** a technological issue. Barrier is capital cost.	✓	✓

Tables 2 and 3 further detail the possible individual unit operations and waste energy streams that were identified by the Advisory Group as potential targets to recover low temperature waste energy from the chemical plants and refineries sector, respectively. It has to be noted that this is a general list that doesn't get into specifics and not every chemical plant and refinery will have all these sources of waste energy streams. There may already be areas where energy recovery and process thermal integration have been completed in the chemical plants and refineries which may reduce the stream temperature compared to what is indicated below.

Table 2. Characterization of Waste Energy Stream Opportunities in Chemical Plants

Type of Stream	**Temperature (°F)**	**Waste Energy (Equipment) Sources**
Stack Gases	350	Thermal oxidizers
	300	Fired heaters
	400	Process heaters
	350-400	Fired furnaces
	400	Pressurized corrosive gases

Source: Attendees of Technology Forum, May 2012

Table 3. Characterization of Waste Energy Stream Opportunities in Refineries

Type of Stream	**Phase**	**Temperature (°F)**	**Waste Energy Sources**
Process	Liquid (L)	180-220	Different cuts that need to be cooled
Process	Gas (G)	150-300	Overhead Condensers
Process	L	350-450	Run-down and product streams
Process	G & L	235	Product/Gas to fin-fans

Process	L	180	Excess quench water
Stack Gases	G	300-450	Fired heaters and cracker units

Source: Attendees of Technology Forum, May 2012

Potential Opportunity

In an effort to understand the potential of recovering low temperature waste energy in the chemical plants and refineries sector, an attempt was made to estimate the amount of equivalent electricity that could be produced from these sources. Table 4 shows the estimates of fuel input, low temperature waste energy recovery opportunity, potential for electricity generation and savings.

Table 4. Annual Electricity Generation Potential and Cost Savings

Sector	Fuel Input (TBtu)	Energy Recovery (TBtu)	Electricity Generation (GWh)	Cost Savings ($Million)
Chemicals	3,451	295	8,600	518
Refining	2,488	360	10,500	633

Source: Prepared for Technology Forum, May 2012 by Texas Industries of the Future

As shown in Table 4, the total potential recovery opportunity from both the sectors is estimated at a total of $1.1 billion annually. The assumptions used to calculate this potential opportunity are as follows:

- The amount of available waste energy for recovery (DOE 2004) was based on a factor of 2.5-10% applied to the fuel input and this factor varied, based on the product or type of process and unit operations.
- A conservative factor of 10% conversion efficiency was applied to calculate the potential electric generation from the available waste energy.
- Cost savings were calculated at a cost of $60/MWh, which was the price paid by the industrial sector for electricity (EIA 2012).

Low Temperature Waste Energy Recovery Technologies

Chemical and refining companies participating on the Technology Forum Advisory Committee defined low temperature waste energy as process or effluent streams (gas or liquid) below 400°F. It was generally agreed by the industry experts that there are widely-known technologies to capture thermal energy above 400°F. The challenge is to recover waste energy from the lower-temperature streams (Tables 2 and 3) cost-effectively. Four technologies (Organic Rankine Cycle, Absorption refrigeration/chilling, Kalina cycle and Fuel cells) were identified by the Advisory Committee as potential candidates for further investigation and implementation for projects related to waste energy recovery in chemical plants and refineries. Each of these technologies was presented in the Technology Forum by their respective manufacturers and technology providers and additional information (presentations) can be downloaded from the website (TXIOF 2012). This paper provides a brief description of these technologies along with their characteristics, specifications, limitations, costs / payback and commercialization potentials.

Organic Rankine Cycle (ORC) Technology

The ORC waste energy to power generation principle is based on the classic Steam Rankine power generation cycle wherein a steam turbine transforms thermal energy into mechanical energy and finally into electric energy through an electric generator. Instead of using steam (water) as the working fluid, as used in steam Rankine cycle, the ORC system vaporizes an organic fluid such as Freons (R134a, R245fa), isopentane, isobutane, etc. This allows the Rankine cycle to operate with significantly lower waste energy temperatures and sometimes as low as 150ºF. The selection of the working fluid to be used in the ORC power generation system will depend mostly on the operating temperature range (waste energy temperature) as the fluids' thermodynamic properties will influence the operation, power generation and efficiency of the ORC system.

A typical setup of an ORC system (Bronicki) for an energy recovery application from a waste energy stream can be summarized as follows:

- Thermal energy in the waste energy stream is transferred to the vaporizer of the ORC either directly or via a heat transfer fluid running through the Heat Recovery Unit (HRU).
- The vaporized organic working fluid drives a turbine that is coupled to the generator.
- The exhaust vapor from the turbine flows through the recuperator for sensible heat exchange.
- The vapors are then condensed in a condenser.
- The working fluid is then pumped back to the vaporizer to complete a closed-loop cycle.

The ORC concept has the potential for a broad diversity of applications. The technology is not particularly new; at least 30 commercial plants worldwide were employing the cycle before 1984 (BCS 2008). From an overall market perspective, ORC technology systems account for 1,600 MW of electricity generation worldwide from waste energy and renewable energy sources. They have been applied in several different industries including, but not limited to, refining, gas processing, pipelines, steel mills, geothermal, biomass and solar thermal power plants.

Waste energy recovery is one of its most useful and popular applications of the ORC power generation technology. The operating temperatures of ORC systems vary depending on the manufacturers' design but typically range between 300-750ºF. The greatest potential application for ORC low-temperature waste energy recovery systems are in the petroleum refining industry and the chemical industry. An ORC market study (Meacher 1981) had indicated that the petroleum and chemical industries constitute almost 95 percent of the available market for application of ORC power generation technology. The same study also indicated that of the technical market found in these two industries, 71 percent was judged to be economically viable.

Currently, from an economics perspective, as the size of the ORC power generation plant increases, the $/kW installed cost reduces exponentially and overall life-cycle cost analysis becomes more attractive with traditional power generation options. Manufacturers of ORC power generation systems are targeting $2,750/kW as installed cost for capacities above 5 MW. Typical simple paybacks for ORC systems seem to lie between 5-6 years.

Absorption Refrigeration and Chilling Technology

Absorption refrigeration and chilling technology can be a very economical and cost-effective means of capturing low temperature waste energy and using it directly to produce refrigeration or chilling for industrial process use. Compared to the ORC technology, absorption refrigeration and chilling eliminates the need to produce electrical power first and then use the electrical power to run a mechanical vapor compression refrigeration or chilling system. In an absorption chilling cycle, the mechanical vapor compressor is replaced by a thermal compressor.

In addition to offsetting the electrical demand of the mechanical vapor compression system, these technologies can be very easily integrated with the industrial processes to improve yield and saleable product such as light ends recovery in petrochemicals and refineries. A variety of waste energy sources can be targeted and these systems are capable of recovering waste energy from temperatures as low as 150ºF.

The use of low temperature waste energy for driving absorption refrigeration and chilling systems has a large potential in petrochemical plants and refineries. In the past, the low cost of fuel and feedstock allowed the petrochemical industry to operate mechanical chillers affordably. But with current feedstock prices and higher value-added saleable products, absorption systems can be very cost-effective and offer very attractive paybacks when compared to the traditional mechanical vapor compression systems. The waste energy streams mentioned in Tables 2 and 3 can all be used to drive absorption refrigeration and chilling systems.

As a simple example, a process will benefit from absorption chilling if it can operate more efficiently with cooling water supplied at temperatures colder than that obtained from a cooling tower. In a refinery, chilling the lean oil and un-stabilized naphtha, propane, butane, and propylene can significantly increase recovery rates and debottleneck units especially during the hotter summer months.

The working fluid in an absorption system is a mixture of a refrigerant and absorbent. As a result of this, the working fluid has a unique property known as “temperature glide” which means that the boiling (or condensing) point of the working fluid continues to increase (or decrease) as the concentration (ratio of amount of refrigerant to absorbent) of the solution changes. This temperature glide allows for very efficient waste energy recovery in industrial applications and custom designs of refrigerant and absorbent working pairs and concentrations can be developed to optimize these absorption systems.

There are several different configurations of absorption refrigeration and chiller systems. Most times they are identified as half-effect, single effect and double-effect. An effect typically represents the ratio of the amount of cooling provided to the amount of heat required. A typical setup of a single-effect absorption system can be summarized as follows:

- Thermal energy in the waste energy stream is transferred to the generator of the absorption system directly or via a heat transfer fluid.
- This boils off the refrigerant which then travels to the condenser and is condensed as refrigerant liquid there.
- The refrigerant depleted solution from the generator is returned to the absorber via a Solution Heat eXchanger (SHX).
- The condensed refrigerant liquid provides the chilling or refrigerant effect in the evaporator and the vapors travel to the absorber.

- The refrigerant vapors and the refrigerant depleted solution combine in the absorber to form a refrigerant-rich solution.
- The refrigerant-rich solution is then pumped back to the generator via the SHX to complete the closed-loop cycle.

One major difference across absorption refrigeration and chiller systems is the working fluid pair that is used in these systems. The two most commonly used refrigerant/absorbent mixtures are ammonia / water and water / lithium bromide. Absorption refrigeration and chilling technologies using both of these working fluid pairs are described in detail below.

Ammonia / Water absorption refrigeration and chilling technology. In the ammonia / water pair working mixture, ammonia is the refrigerant while water is the absorbent. As a result of ammonia being the refrigerant, it has the ability to provide refrigeration as low as -50°F and/or water chilling, for process cooling at the required temperature. Due to this inherent ability, these technologies are mostly found in refrigeration applications with low evaporation temperatures.

These systems have the ability to pick up waste energy from temperatures as low as 180°F up to a maximum of 850°F. The operating pressure levels in the ammonia / water absorption system are usually above atmospheric pressure and this helps to keep the overall footprint of the system to a very compact size. Most ammonia / water absorption systems are half-effect or single-effect. The double effect is seldom seen in ammonia / water systems as it may pose safety problems due to its high operating pressure and temperature (European Commission 2001).

There have been significant costs saving advances in the ammonia / water absorption technology such as more efficient thermodynamic cycles and better heat exchanger and rectification designs. Technology providers have been able to custom design ammonia / water absorption refrigeration and chilling systems for a wide cooling capacity ranging from 10-2,000 RT (0.12-24 MMBtu/hr). There have been several installations in petrochemical plants and refineries and typical paybacks are expected in the 2-3 years timeframe. From a specific cost perspective, it is difficult to provide a figure ($ per RT) because it is a function of the refrigeration temperature required. Nevertheless, it would suffice to say that this technology has capital cost parity with mechanical vapor compression systems as the systems get larger (>500 RT) and the refrigeration temperature required reduces (<20°F).

Water / Lithium Bromide absorption chilling technology. In the water / lithium bromide pair working mixture, water is the refrigerant while the salt, lithium bromide, is the absorbent. As a result of water being the refrigerant, this technology has the ability to provide cooling only as low as 40°F. Due to this limitation, these technologies are mostly found in water chiller applications or process cooling with evaporation temperatures above 40°F.

The waste-energy-fired water / lithium bromide absorption chillers are typically single-effect machines and require waste energy temperatures between 190-250°F. Double-effect systems will need at least 350°F as the waste energy temperature. The only difference with the double effect machines is that it incorporates two generator-condenser blocks that are staged in order to utilize the energy supplied twice. The water / lithium bromide systems operate under partial/deep vacuum conditions to allow for water to act as the refrigerant and provide the chilling effect.

Most major manufacturers of water-cooled chillers offer water / lithium bromide absorption chillers as a standard catalogue product. Water / lithium bromide absorption chillers are very commonly found in utility central plants that generate their own steam as a utility and are used in parallel with centrifugal chillers to reduce peak demand. Manufacturers estimate that the capital cost of water / lithium bromide absorption chillers is approximately twice the cost of electric motor-driven chillers. A typical large plant cost using water / lithium bromide absorption chillers can be estimated to be ~$1,000/RT. These units can be adapted with special requirements to provide a source of chilled water for use in ethylene units and naphtha crackers.

Kalina Cycle Technology

The Kalina cycle technology is a proven thermal energy recovery cycle that can be used for conversion of thermal energy to electrical power. In the most simple form, it is a combination of the principles of the Rankine (power generation) cycle and ammonia absorption refrigeration. Nevertheless, there are some significant inherent advantages of combining these technologies wherein the system design permits customization to maximize the potential waste energy recovery opportunity. The biggest advantage of the Kalina cycle is the choice of its working fluid – ammonia / water. As mentioned in the **Absorption Refrigeration and Chilling Technology** discussion, ammonia-water mixtures (binary fluids) exhibit a temperature glide in their boiling point at constant pressure. This non-isothermal boiling with variable ammonia-water compositions can be configured to provide an ideal match with the thermal characteristics of a waste energy recovery source. As a result, more energy recovery can be achieved from the energy source without a detriment to the overall process efficiency. Similar considerations apply at the condensing end of the power cycle. With these characteristics, the Kalina cycle technology can generate electrical power from low temperature waste energy sources in chemical plants and refineries. Efficiency improvements above conventional power generation plants of up to 50% are claimed for these types of applications (Mirolli 2012).

A typical setup of a Kalina cycle technology system that provides electrical power from a waste energy stream can be summarized as follows:

- Thermal energy from the waste energy stream is transferred to a rich mixture of ammonia-water in an evaporator either directly or via a heat transfer fluid.
- The ammonia-water mixture is boiled and becomes superheated vapor.
- This superheated vapor is expanded through a turbine that is coupled to an electric generator and produces the electrical power.
- The turbine exhaust vapor is cooled through a recuperator for sensible heat exchange and maybe diluted with separator bottoms depending on the overall cycle arrangement.
- The ammonia-water vapors are then condensed in a condenser.
- The working fluid is then pumped back to the evaporator to form a closed-loop cycle.

Some of the major cost advantages of the Kalina cycle technology can be the use of carbon-steel-based, standard commercially available mechanical equipment such as steam turbines, centrifugal pumps and shell & tube heat exchangers. The Kalina cycle technology can be custom designed over a wide operating range and can recover waste energy at temperatures as low as 200ºF. The maximum temperature cited for applications of these technologies is cited to be 1,000ºF. In comparison to ORC technology, the Kalina cycle technology is claimed to have a

15-25% higher power generation efficiency (EPA 2012). Worldwide, several plants are now operating successfully using a variety of energy sources, and all have seen gains in efficiency relative to a conventional Rankine Cycle (Mirolli 2012).

Fuel Cell Systems Technology

Fuel cell systems have come a long way and have become an important technology in distributed electric power generation and combined heat and power systems. They are considered to be very attractive power generation systems due to their more efficient power generation capability, potential high-temperature thermal energy availability and low environmental impact. Fuel cells are used for many applications. They range from small fuel cells in portable devices for mobile applications to heat and power generators in stationary applications for the residential and industrial sectors. There are several different types of fuel cells commercially available such as Phosphoric acid (PAFC), Proton Exchange Membrane (PEMFC), Molten Carbonate (MCFC), Solid Oxide (SOFC), etc. The main distinguishing characteristics of these fuel cells are the electrolyte, catalyst and the operating temperatures. Depending on the type of the fuel cell, operating temperatures range from ~200-1,800°F with an electrical generating efficiency of about 47% (FCE 2012). A typical setup of a fuel cell system can be summarized as follows:

- They are made up of three adjacent segments: anode, electrolyte and cathode.
- Chemical reactions occur at the interfaces between these segments.
- At the anode, a catalyst oxidizes the fuel (hydrogen), turning the fuel into a positively charged ion and a negatively charged electron.
- The freed electrons travel through an electrical circuit creating the electrical power.
- The hydrogen ions travel through the electrolyte to the cathode and are reunited with the electrons.
- Thermal energy is recovered to be used as process heat.

From a perspective of fuel cell operations and applications, the key is the source of hydrogen fuel. Hydrogen can come from a variety of sources but the most economical currently is steam reformation of hydrocarbons (a thermally activated chemical process that strips the hydrogen from both the hydrocarbon and the steam).

In the petrochemicals and refineries sector, there have been very interesting advances and emerging opportunities in the applications of fuel cell systems wherein manufacturers have taken a wholistic approach of taking a hydrocarbon fuel (methane), petrochemical off-gas (inherent waste stream containing C1-C4) and a molten carbonate fuel cell to be able to produce electrical power, thermal energy (at temperatures ~1000°F) and generation of hydrogen simultaneously. Some of the innovations in this technology include a solid state hydrogen separator and a solid state hydrogen compressor (FCE 2012).

In some other interesting applications of fuel cells in petrochemical refineries, the Fluid Catalytic Cracking Unit (FCCU) that potentially emits SOx and NOx deserves a mention. These emissions are hydrotreated to yield H_2S (process waste stream). There is significant energy in H_2S and it can be captured effectively. The process involves first converting H_2S to hydrogen in a Na-S type cell. The generated hydrogen can then be fed to a fuel cell for both power and thermal energy capture (Viswanathan, Davies and Holbery 2005).

Fuel cell technology applications in petrochemicals and refinery sectors provide fuel flexibility, hydrogen balance and possible recovery of high-value commodities. These technologies have yet to be commercialized and the market penetration is currently limited. The manufacturers seem committed to work with the petrochemicals and refinery sectors to capture this large available potential of Combined Heat, Hydrogen and Power (CHHP).

Industry Feedback at Technology Forum

The main purpose of the Technology Forum was to accelerate the adoption of waste energy recovery technologies in chemical plants and refineries by:

- Educating end-users on available technologies for low temperature waste energy recovery
- Educating technology developers on the potential market and needs.

There were ~40 invited participants at the Technology Forum and each of them represented a major petrochemicals manufacturer or a refinery. Their backgrounds represented Technology Leaders, Energy Efficiency Coordinators, Site Optimization Leaders, etc. The feedback from the Technology Forum helped to understand the specific interests of these industrial companies and their reaction to these low temperature waste energy recovery technologies. Table 5 presents a summary of the survey of the Technology Forum attendees (end-users) who were interested in following up on the technologies presented.

Table 5. Survey of Attendees who will follow up on Technologies Presented

Technology Presented	Percent of Attendees
ORC	53.9
Absorption Refrigeration (Ammonia / Water)	30.8
Absorption Chilling (Water / Lithium Bromide)	15.4
Kalina Cycle	0.0
Fuel Cells	53.9
Will not follow up on any technology	15.4

It was also very important to understand the high priority areas for these industries and barriers for implementing some of these waste energy recovery technologies in their operations. With these objectives in mind the Technology Forum was set up to collect feedback from the industry group on the high priority items. These priorities are based on attendee votes and are presented below in the different categories.

- Tools and Analysis
    - A better guide to know which technology to apply in each application
- Improving the Economics
    - Capital costs need to be reduced to make recovery economical especially for retrofits
- Policy
    - Environmental laws can be an impediment to project execution
- Research
    - Further develop hydrogen purification and delivery process
    - Support application development for CHHP for petrochemical industry

- Integrate to develop hybrid systems such as ORC + fuel cell for higher benefits
- Identify best solution for large mass flows of waste-water at <200°F
- Identifying Opportunities
    - Increase site awareness of energy opportunities

However, it was also reported that at current natural gas prices in the U.S., there was not a major economic driver for low temperature waste energy recovery to generate power.

Conclusions

In 2012, the IIP and TXIOF at The University of Texas at Austin organized a day-long Technology Forum titled - *Low Temperature Waste Energy Recovery in Chemical Plants and Refineries*. This paper characterized the potential opportunities in these two sectors and briefly described the potential candidate technologies that can turn this low temperature waste energy stream into work or product. It was estimated that the potential total annual cost savings for the chemicals and refinery sector could be ~$1.1 billion.

Low temperature waste energy streams were defined by the TXIOF Chemical and Refining Sectors Advisory Committee as streams with a temperature below 400°F. Four technologies that met the criteria of the Advisory Committee included: Organic Rankine Cycle (ORC), Absorption refrigeration and chilling, Kalina cycle and Fuel cell technologies. This paper characterized each of these technologies, technical specifications, limitations, potential costs / payback and commercialization status as was discussed in the Technology Forum held in Houston, TX in May 2012.

The Technology Forum attendees also provided valuable feedback to IIP and TXIOF on the low temperature waste energy recovery technologies. It was found that more than 50% of the attendees surveyed would follow up on the ORC and the Fuel cell technologies for potential applications in their industries. About 46% of the attendees would also pursue technologies related to Absorption refrigeration and chilling. Finally, the Technology Forum presented an opportunity to develop a list of high priority items which can help to eliminate the potential barriers that limit the recovery of low temperature waste energy in the chemical plants and refineries.

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DRIVING WATER AND WASTEWATER UTILITIES TO MORE SUSTAINABLE ENERGY MANAGEMENT

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ABSTRACT

The Water Environment Federation (WEF) and industry leaders have identified the need for an energy roadmap to guide utilities of all sizes down the road to sustainable energy management through increased renewable energy production, energy conservation and focus on overall energy management. This roadmap leverages the framework developed in the electric power sector to move to "smart grid" technology: the smart grid maturity model (SGMM). The basis of this material originated at a workshop of water and power industry leaders convened by WEF in North Carolina, in March 2012. Case studies were analyzed from successful utilities in Austria, Holland, Australia, and the United States. High level, strategic best practices were identified and organized into topic areas, which define the level of progression (enable, integrate and optimize) towards achieving energy sustainability.

The WEF energy roadmap is intended to guide utilities of all sizes as they progress towards becoming the treatment plants of the future. While it is not practical for all wastewater treatment plants to become energy positive or neutral, all can take steps towards increasing energy sustainability.

Financial viability for energy management sustainability is crucial for success. Finding alternative financial models such as Energy Services Performance Contracts (ESPC) is a good option to accomplish energy management goals in a timely and financially responsible method.

INTRODUCTION

Energy and water have a well-known relationship that is interconnected and interdependent. While water production, processing, distribution, and end-use all require energy, electric utilities rely on a steady flow of water for essential functions, particularly cooling.

"wastewater treatment plants are not waste disposal facilities but are water resource recovery facilities that produce clean water, recover nutrients (such as phosphorus and nitrogen), and have the potential to reduce the nation's dependence on fossil fuels through the production and use of renewable energy and the implementation of energy conservation." (WEF renewable energy position statement)

ENERGY AT WATER FACILITIES

On average, the energy content of wastewater (chemical, hydraulic and thermal) is greater than the energy required to treat it. However, becoming net energy positive is not the only goal. Treating wastewater to higher standards is often more energy intensive. Similarly, using biogas as a transportation fuel reduces onsite power production. More energy is required to further process biosolids to maximize reuse potential and to recover nutrients and minerals.

The balance between energy efficiency and resource recovery involves tradeoffs and can best be achieved through holistic process planning. The more resources that are recovered, the less energy is available for generation or the more energy that is consumed. These tradeoffs must be understood and managed to achieve your utility's particular sustainability goals. There is no one model.

WEF's Energy Roadmap is a series of steps to help wastewater utilities plan and implement a wastewater energy program. The road map is applicable whether plants choose simply to increase energy efficiency or to build a full-scale cogeneration system. Steps will be arranged under various topics, from technical needs to managerial aspects, and will be applicable to small, medium, and large facilities. The steps are arranged under six topics. Under the six topics, the steps are organized into levels of progression. The first set of steps enables the organization. The second set integrates energy efficiency and generation into the organization's structure, culture, communications strategy, and technology. The last set of steps involves optimizing current processes and procedures. The topics, shown in more detail in Annex A, are as follows:

- **Strategic Management:** High-level management policies and practices that lay the foundation for sustainable energy management
- **Organizational Culture:** Implementation of an energy vision to create an organizational culture that values energy efficiency at all levels and

supports an energy champion and cross-functional energy team

- **Communication and Outreach:** Tools for effective two-way communication with key stakeholders around energy management
- **Demand Side Management:** Methods to assess and reduce energy use and energy costs
- **Energy Generation:** Tools for utilities to evaluate whether and how to increase onsite renewable energy production and/or investments
- **Innovating for the Future:** Guidance for utilities of all sizes to leverage existing research, further in-house innovation and manage risk associated with these ventures

Water and wastewater facilities represent about 3-4% of U.S. energy consumption. According to the Department of Energy, they are the third largest energy consumers, using more than 55 billion kilowatt hours per year. On the reverse side, it takes between 3,000 and 6,000 gallons of water to power one 60-W incandescent bulb for 12 hours per day over the course of a year, according to EPA.

However, there are many opportunities to improve energy efficiency at treatment facilities, from technology improvements to more efficient system design. Energy generation at wastewater facilities is already a reality. In fact, some plants are generating enough energy for onsite use and selling electricity back to the grid.

East Bay Municipal Utility District (EBMUD; Oakland, Calif.) is a forerunner in energy generation. EBMUD produces more than 100% of its energy through renewable technologies. EBMUD's energy portfolio includes biogas production of more than 55,000 MWh/year.

Saving money drove energy generation for EBMUD, as energy prices were increasing in the early 2000s, and the utility needed to control rates to customers. The other aspect of EBMUD's operational success was process optimization. This is implementing opportunities to reduce energy use while producing process benefits, such as reducing aeration demand.

The Sheboygan Wastewater Treatment Plant (Sheboygan Wisconsin) began by becoming energy efficient first, reducing the plants energy use by 20% of its 2003 baseline. The plant accomplished the energy reduction by combining energy saving changes with regular maintenance and equipment replacement. New motors and variable Speed Drives helped the plant reduce energy use by 157,000 kWh/year with an annual savings of $5,300. Replacing blowers saved the plant another $63,889 in 2009. Now, the plant produces 70% to 90% of its own energy.

According to the Water Environment Research Foundation (WERF; Alexandria, Va.), wastewater and biosolids contain 10 times more energy than is required for treatment. Yet, roadblocks remain to capturing this energy and becoming energy-neutral. The roadblocks include funding as well as existing codes and regulations.

Producing energy also imposes new operation and maintenance challenges. To produce more biogas, EBMUD expanded its organic-waste acceptance program to supplement its municipal wastewater. Some of the organic material came from dairies, olive waste, and even poultry farms.

Another challenge is developing organizational commitment. Energy programs require the support of all departments. The Roadmap encourages developing an interdepartmental energy implementation team to build support at all levels.

An organizational commitment was instrumental to the success of the Gloversville–Johnstown (New York) Joint Wastewater Treatment Facility. In 2003, the plant began accepting 90,850 to 113,560 L (24,000 to 30,000 gallons) of dairy whey per week for codigestion. Since then, dairy feedstocks have increased. The utility now generates more than 90% of its own energy through a combined heat and power process. Reduced electrical costs saved the utility about $500,000 per year in 2009 and 2010, and accepting dairy wastes resulted in additional revenue of $750,000 annually.

Utilities also have to confront economic and regulatory barriers. For example, not all states include biosolids in their renewable energy portfolios. Further, navigating metering laws and accepting low prices for wastewater generated energy can discourage utilities from feeding energy back into the grid.

The most common generation method is anaerobic digestion, which is used to create biogas. Anaerobic digestion is used at about 1,238 water resource recovery facilities (WRRFs) in the U.S. It is a process by which bacteria break down organic material without oxygen. As a result, the bacteria produce carbon dioxide and methane, also known as biogas, which can be used to generate energy. Only about 292 facilities generate electricity, while many others flare the biogas without a way to harness its potential. In the U.S., WRRFs that do generate large quantities of energy generally do not do so with municipal waste alone. Cooperation with food or agricultural entities is often an important source of organic material. However, there are utilities in Europe and Canada that are energy neutral and use only municipal waste.

A major facet in energy resource recovery from wastewater is the generation of biogas from anaerobic digestion. The following graphic shows the current state of anaerobic digestion in the U.S.

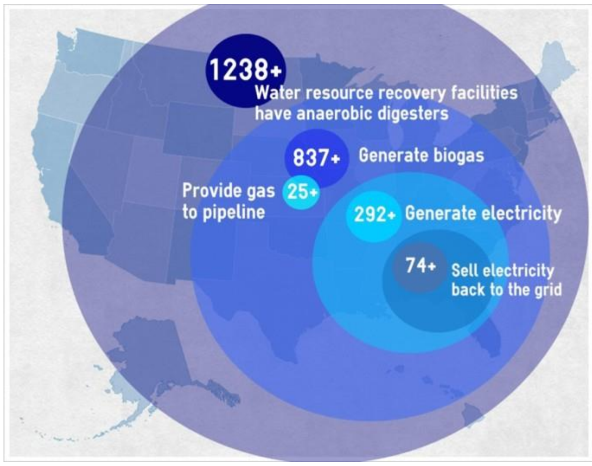

Figure 1. Biogas from Water Resource Recovery Facilities (http://www.biogasdata.org)

WATER REUSE AT POWER PLANTS

A key component of the WEF Energy Roadmap is collaboration between the water wastewater utilities and electric utilities**.** The impending regional freshwater shortages and increasing electricity demand in the United States have encouraged the reuse of municipal wastewater in electric utilities. Treated by municipal wastewater plants, this reclaimed water can safely meet the water needs of the power producing process while conserving freshwater for other uses.

Successful projects incorporating municipal wastewater reuse into electric utilities have launched in areas that experience regular freshwater shortages or have regulations that favor such approaches, such as Florida, Arizona, California, and Texas. However, these projects typically take a long time to develop, and in some regions, are not even under consideration. Projects must offer a reliable supply of reclaimed water of consistent quality at a reasonable price, overcome public and political perceptions about the reuse of municipal wastewater, and be technically and logistically feasible. These requirements pose significant challenges to municipal wastewater treatment plants and electric utilities that make it difficult for either to launch new reclaimed water projects on their own

The American Society of Mechanical Engineers (ASME) and the Water Environment Federation (WEF) jointly sponsored a workshop to address this challenge. Held May 21–22, 2012 at the ASME Washington, DC office, the Municipal Wastewater Reuse by Electric Utilities: Best Practices and Future Directions workshop brought together leading experts from municipal wastewater plants and electric utilities to identify best practices and potential paths forward for increasing the use of municipal wastewater in electric utilities across the nation. Through a series of highly interactive discussions led by professional facilitators, workshop participants defined the following:

- Characteristics of successful municipal wastewater reuse projects at electric utilities
- Common barriers to successful municipal wastewater reuse projects at electric utilities
- Potential steps needed to overcome the barriers and launch new projects

Past municipal wastewater projects at electric utilities share common characteristics that can help formulate best practices for collaborative projects. In the broadest sense, successful projects offer a reliable supply of reclaimed water of consistent quality at a reasonable price. The following are the most critical components to successful projects, as determined by the workshop participants:

- Active collaboration and agreement between wastewater treatment plants and electric utilities
- Clearly defined water quality and flow rates
- Optimal and adaptable system design
- Compliance with all regulations
- Ongoing education and outreach efforts

Identifying common barriers to municipal wastewater projects at electric utilities can help those implementing similar projects proactively address potential issues. The following are the most critical to overcome in order to launch successful wastewater reuse projects at electric utilities, as determined by the workshop participants.

- Absence of a dedicated regulatory framework
- Lack of information sharing and best practices
- Risk aversion and resistance to change
- Inability of stakeholders to work cooperatively and establish long-term contracts

FINANCIAL VIABILITY

Identifying funding options to assist with a sustainable energy management strategy is key for municipalities. Cash flow to sustain water and wastewater infrastructure has dwindled to a trickle as financial woes grip local, state and federal government agencies. The need for unemployment, educational, public safety, and other services has left precious few funds for water and wastewater infrastructure maintenance and upgrades. Very few funds are available to implement an energy management strategy for the future sustainability of a plant. Changing weather patterns, unsustainable rate structures and fluctuating industry and residential populations are trends also negatively impacting our nation's water and wastewater financial viability. The complexity and gravity of the situation is further enhanced by aged infrastructure, more stringent environmental regulations and increased demand for treated water. Financial strategies are needed to support energy audits and to fund resulting projects to have a successful energy management program.

Municipalities implementing energy management strategies must understand electric utility rates and structures. Maximizing off-peak demand as well as load monitoring and shifting opportunities could provide needed funds. Investigating utility rebates, as well as federal and state grants for energy efficient operations, could also secure additional funds. At the same time, it's crucial to establish an energy usage baseline.

Budgeting for success of the program to obtain net zero energy usage depends on establishment of the baseline to enable measurement of performance indicators and milestones for the strategy. In addition, lifecycle analysis is used for decision-making and energy use is considered on all capital project design and in operating budgeting decisions and standard operating practices.

Energy or production savings are used to invest for the future. A municipality's energy initiative should generate sufficient revenue to invest in other utility priorities and reduce upward pressure on rates. Energy arbitrage opportunities are also leveraged to reduce costs or increase revenue.

With that baseline established, the four-step energy efficiency lifecycle begins. The next two steps are implementation of passive and active energy efficiency measures. Passive energy efficiency measures are those that are easy to implement without automation. Conversely, active energy efficiency measures require automation and optimization of processes. The final step is metering and monitoring to establish future efficiency goals and key performance indicators, thus making energy efficiency an ongoing process. Figure 2 is a diagram of the Energy Efficiency Lifecycle.

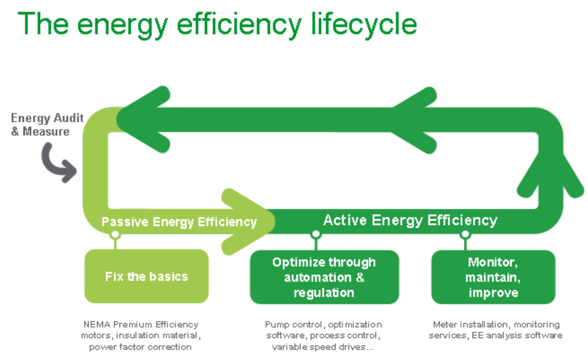

Figure 2. The Energy Efficiency Lifecycle

ENERGY SERVICES PERFORMANCE CONTRACTS (ESPC)

Energy Savings Performance Contracts for the water and wastewater market are a financial alternative for completing energy management strategies. An ESPC is a turnkey service that incorporates system design, construction and commissioning that provides comprehensive energy conservation measures to include energy efficiency, renewable energy and distributed generation opportunities that result in a guaranteed energy savings.

The resulting savings for energy ultimately funds the improvements with guaranteed performance. In the event the savings are not achieved, the company providing the ESPC, an ESCO, will pay the difference. In addition, the ESCO arranges the financing and finds the most flexible options for the municipality. ESCOs must be experienced and financially strong to execute a successful project. See Figure 3 for a block diagram of an ESPC.

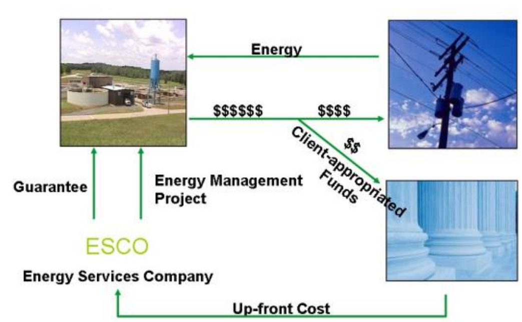

Figure 3. Block Diagram of an Energy Savings Performance Contract

The EPA defines an ESCO as a company that provides energy efficiency related services with energy savings performance contracting as a central part of its business. ESCOs can offer other services beyond energy efficiency offerings such as engineering, design, construction or manufacturing. However, they are only considered an ESCO if they offer energy efficiency as a major service offering and implement projects while assuming some performance risk during the economic life of the project. In addition, the EPA excludes companies in the ESCO definition that only provide on site or renewable energy services without including energy efficiency services.

Experience in environmental engineering and working with environmental consultant firms is a must. Further, the ability to cross national and global markets are beneficial in understanding the complete market and allows ESCOs to understand the global and national water sustainability issues. To keep the cash flowing for energy and water sustainability, implementing ESPCs with the right ESCO is critical for water and energy needs for future generations.

CONCLUSION

An energy roadmap to guide utilities of all sizes down the road to sustainable energy management through increased renewable energy production, energy conservation and focus on overall energy management is critical for the sustainability of energy and water. The roadmap gives utilities the steps for energy independence. Implementation of the roadmap will assist all size of utilities to get closer to their goal of net zero energy. Financial viability is also critical to the success of any energy management program. As an industry, let’s start making taking the steps to obtain energy sustainability together.

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ANNEX A

WEF ENERGY ROADMAP TOPIC AREAS AND THEMES

STRATEGIC MANAGEMENT

	Enable	Integrate	Optimize
Strategic Direction	SET GOALS • Energy goals and key performance indicators are established for both conservation (see Demand Side Management) and production (see Energy Generation)	GATHER SUPPORT • Utility incorporates energy goals and key performance indicators into strategic plan • Governing board establishes energy/sustainability committee	PRIORITIZE & IMPLEMENT • Energy management program initiatives are prioritized using tools such as: ○ Strategic Planning ○ Effective Utility Management (EUM) ○ Environmental Management Systems (EMS) • Energy generation is an integral part of utility's suite of services • Utility utilizes triple bottom line approach for sustainability project decision-making
Financial Viability	IDENTIFY FUNDING OPTIONS • Financial strategy developed to support energy audit and to fund resulting projects	BUDGET FOR SUCCESS • Lifecycle analysis used for decision-making on energy projects • Energy use is considered on all capital project design and in operating budgeting decisions and standard operating practices	INVEST IN FUTURE • Utility's energy initiatives generate sufficient revenue to invest in other utility priorities/reduce upward pressure on rates • Energy arbitrage opportunities are leveraged
Collaborative Partnerships	EVALUATE OPPORTUNITIES • Opportunities for collaboration on energy projects (e.g., Energy Services Company - ESCO, joint venture, public-public/private partnership) are analyzed • Diverse markets for energy products are identified	ESTABLISH CONNECTIONS • Contracts with partners are in place and implemented to facilitate data exchange and planning with water, energy and gas utilities • Utility planning efforts are integrated with other agencies regarding multiple resources (e.g., water, stormwater, etc.)	LEVERAGE RESOURCES • Utility uses partnerships to maximize energy sales revenues and/or reduce demand (e.g., selling power or biogas to adjacent facility, working with a feedstock provider for co-digestion)
Towards Carbon Neutrality	PLAN CARBON FOOTPRINT ANALYSIS • Approach to carbon footprint analysis/GHG inventory is established	INVENTORY GHG EMISSIONS • Carbon footprint/greenhouse gas (GHG) inventory is developed	RECOVER RESOURCES • Additional resources are recovered or realized (e.g., carbon credits) as utility moves towards carbon neutrality • Comprehensive carbon footprint/GHG inventory is maintained, including fugitive emissions and embodied energy of major inputs (e.g., chemicals)

ORGANIZATIONAL CULTURE

	Enable	Integrate	Optimize
Energy Vision	DEVELOP VISION • Leadership Group develops Energy Vision • Governing body adopts Energy Vision as policy • Leadership Group communicates Energy Vision to workforce	COMMUNICATE INTERNALLY • Leadership Group links Energy Vision to staff performance plans • Leadership Group incorporates energy goals/key performance indicators into strategic plan	COMMUNICATE EXTERNALLY • Utility shares Energy Vision with external stakeholders and the industry • Plans are in place to embrace external market changes
Energy Team	FORM TEAM • Utility establishes cross-functional Energy Team • Leadership Group establishes clear charge and authority for Energy Team with defined roles for members	TAKE ACTION AND TRACK • Energy Team drives implementation of recommendations • Energy Team systematically reports on progress and future actions	EMPOWER TEAM • Energy Team provided significant budget authority to implement improvements • Energy Team interfaces directly with governing body to get direction and report on energy program status
Staff Development and Alignment	SET TRAINING PLAN • Employee performance plans include energy program-related activities to support Energy Vision • Training needs for utility leadership and staff are identified	TRAIN AND SUPPORT STAFF • Staff are trained in demand side management and energy generation • Staff maintains knowledge of emerging technologies through information sharing events	EMPOWER STAFF • Leadership Group establishes incentives for energy conservation results • Leadership Group empowers staff to make changes for energy savings

COMMUNICATION AND OUTREACH

	DEVELOP STRATEGY	DEVELOP MESSAGE	CONTINUOUSLY EVOLVE EFFORTS
Customers and Community	• Customer outreach and education strategy is tailored to project needs and customer expectations • Community groups are identified for outreach to gain program support	• Proactive customer outreach program (e.g., bill inserts, tours, fact sheets, website) that focuses on environmental benefits and cost-effectiveness is established	• Utility engages customers in helping to achieve energy programs goals (e.g., local grease collection)
Regulatory and Legislative	• Key regulators are identified and effective working relationships are established (e.g., regulations pertaining to air and solids) • Legislative strategy is developed to enhance opportunities and minimize hurdles for energy program	• Key regulators are educated on holistic energy/water relationship Utility advocates for unified regulations that address cross-media issues • Regional collaboration with other agencies occurs (e.g., for funding or policy changes)	• Utility works with industry associations to influence regulators/legislature to create incentives to encourage efficient energy use and increase renewable energy production • Utility influences funding agencies to prioritize energy projects in the water sector • Regulators and utility work together to resolve cross-media issues
Media Outreach	• Media outlets are identified and strategies are developed	• Media kit is developed (e.g., video, sound-bites, pictures and press releases)	• Dedicated utility staff work on messaging with media
Environmental Advocacy Groups	• Outreach strategy is developed to support energy projects • Appropriate partnerships are identified	• Utility shares energy program activities (e.g., tours, fact sheets, etc.)	• Joint programs and outreach that support the goals of both organizations are implemented
Water Sector	• Key energy staff network at local/regional industry events and information sharing groups	• Successes, failures, and lessons learned are shared at industry events	• Energy staff leads industry initiatives to support sector advancements in sustainability

DEMAND SIDE MANAGEMENT

	Enable	Integrate	Optimize

Electricity Costs and Billing	GET ORGANIZED
	• Historical electricity bills are analyzed (2+ years of data is preferred)
		UNDERSTAND THE DETAILS
		• Rate structure and billing details are understood:
		  ○ Demand charges
		  ○ Billing period
		  ○ Unit costs and time of use
			IMPLEMENT CHANGES
			• Modifications are made to billing and/or operations to reduce costs:
			  ○ Consider/select new rate structure
			  ○ Shift loads to reduce peak demand charges or unit costs

Power Measurement and Control	GET THE BIG PICTURE • Baseline energy use and benchmarks are determined • Energy sub-metering needs are identified • SCADA systems and power monitoring capabilities are identified	DETERMINE USE BY KEY PROCESS • Energy use by each major unit process area is determined • Energy use is benchmarked against similar size/type plants to identify target areas for energy reductions • Load management (shedding/switching) is in place	MONITOR FOR REAL TIME CONTROL • Electricity use by major load center is monitored in real time • Real-time control is in place (e.g., SCADA) to measure equipment energy use and efficiency with a user-friendly display (i.e., “energy dashboard”) • Excess power generation is wheeled to other assets or entity
Energy Management	INITIATE AUDIT • Energy Team performs Energy Audit • Goals are set for reducing energy use and costs	IMPLEMENT RECOMMENDATIONS • Cost-effective recommendations from audit are implemented • Energy Team tracks actual versus planned results	PLAN FOR THE FUTURE • Energy savings is incorporated in the design of all future capital projects and new operating strategies
Source Control	UNDERSTAND INFLUENT • Loads (Industrial, water use, infiltration & inflow) are understood and evaluated for energy requirements and production potential	MANAGE LOADING • Methods are in place to manage influent loading to reduce energy usage (e.g., industrial surcharge optimization, I/I reduction program, etc.)	ENHANCE ENVIRONMENT • Sources are managed to reduce energy use and maximize energy potential (e.g., appropriate incentives for trucking high-strength waste)

ENERGY GENERATION

	Enable	Integrate	Optimize
Strategy	SET PRODUCTION GOAL • Measurable energy generation goal is established • Energy generation plan is coordinated with utility strategic plan • Energy Team understands regulatory and permit limitations (e.g., air emissions) with regard to generation	OBTAIN SUPPORT • Governing body approves capital budget for energy generation projects • Regulatory issues have been addressed and satisfactorily resolved	GROW PROGRAM • Infrastructure for energy generation is proactively maintained, renewed, and upgraded • Holistic evaluation methodologies (e.g., triple bottom line) are used to evaluate energy generation opportunities

Energy from Water and Wastewater	EVALUATE INTEGRAL ENERGY SOURCES
	• Available energy resources are quantified, such as:
	  ○ Biogas
	  ○ Hydropower
	  ○ Heat
		IMPLEMENT GENERATION SYSTEMS
		• Energy generation facilities are operating and producing power/heat for utility use
		  ○ Electricity/heat
		  ○ Fuel (natural gas, pellets, etc.)
			OPTIMIZE PRODUCTION
			• Energy production is optimized to maximize the value of generation (e.g., biogas storage to offset power purchases during “on-peak” hours)

Supplemental Energy Sources	IDENTIFY SUPPLEMENTAL ENERGY SOURCES
	• Available non-wastewater/water derived energy sources are quantified, including:
	  ○ Co-digestion
	  ○ Solar
	  ○ Wind
	• Feedstock market evaluation is performed
		IMPLEMENT GENERATION SYSTEMS
		• Energy generation facilities are operating and producing power/heat or fuel
		• Quantity and quality of feedstock meets capacity
			MAXIMIZE PRODUCTION
			• Onsite electricity generation from all sources approaches or exceeds onsite electricity demand
			• High-strength organic waste (e.g., food, FOG, etc.) is integrated into feedstock supply to increase generation potential

Renewable Energy Certificates (REC)	PLAN FOR RECs • Staff gain understanding of State regulations for Renewable Portfolio Standard (RPS), as well as production and sales of RECs	UTILIZE RECs • Utility produces, sells and/or purchases RECs, as appropriate	MAXIMIZE VALUE OF RECs • Sales and purchases of RECs are optimized to maximize value of resources, potentially using automation.

INNOVATING FOR THE FUTURE

	Enable	Integrate	Optimize
Research and Development	PREPARE FOR R&D • Staff well versed in existing technologies • Opportunities are identified by survey of emerging technologies	PERFORM R&D • Utility budget includes R&D funding • Utility actively participates in water innovation partnerships (e.g., Water Innovation Centers, research foundations, university partnerships, etc.)	EXPAND R&D • Site visits to facilities utilizing innovative technologies occur regularly • Completed trials and research projects provide the foundation for further advancement within the industry
Risk Management	IDENTIFY AND PRIORITIZE RISKS • Risk of innovation is identified • Strategy for risk mitigation is developed • Planning includes measures for climate change adaptation (e.g., extreme events)	MITIGATE RISKS • Risk is reduced through collaborative research and information sharing • Leadership Group recognizes and rewards innovative approaches	LEVERAGE INNOVATION • Organization can successfully trial and implement innovative projects and is adaptable to emerging opportunities • Patents are obtained to protect utility and water sector
Alternative Technologies	EVALUATE TECHNOLOGIES • Technologies that reduce energy use or increase generation are identified	INITIATE TRIALS • Advanced low-energy treatment technologies and energy production technologies are demonstrated	IMPLEMENT FULL SCALE SOLUTION • Lower energy consuming processes replace energy-intensive secondary treatment
Alternative Management Approaches	IDENTIFY ALTERNATIVES • Decentralized treatment options are considered • Planning is performed on a watershed basis	IMPLEMENT ALTERNATIVES • Green Infrastructure projects are implemented where appropriate • Enhanced regionalization (e.g., biosolids processing) has been considered and implemented where appropriate	EXPAND INTEGRATION • Alternative management approaches (e.g., decentralization, regionalization, etc.) are used, where appropriate, to maximize overall, region-wide benefit

Image Recognition System for Automated Lighting Retrofit Assessment

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Abstract—**Buildings are responsible for approximately 40% of all US energy use and carbon emissions. Lighting technologies continue to evolve, leading to potential energy savings through retrofits of lighting systems. Building lighting systems is typically the first item evaluated by commercial and industrial energy auditors. This paper presents the first phase of a project to develop unmanned aerial and ground vehicles capable of conducting autonomous energy audits of commercial buildings.**

The paper presents a prototype system that can enumerate and classify the lighting in a building using an optical camera, accelerometer, spectrometer, and distance sensor. As the aerial vehicle navigates throughout a room, the prototype system captures images and collects frequency data of lighting. The system employs image recognition techniques to quantify lighting in each room. Using the unique frequency spectrum of each lighting type, the prototype system classifies the different types of lighting with the spectrometer. An accompanying software program then analyzes the quantity and type of lighting to recommend economical alternatives, or lighting retrofits.

INTRODUCTION

Energy usage in commercial and industrial buildings constitutes a dominant portion of the energy usage both inside and outside of the United States (5). Over 30% usage in these buildings is derived from lighting and HVAC systems. Lighting alone accounted for roughly 275 billion kWh or 21% of electrical consumption in 2011 (6). In global energy usage, lighting composed 19% of the total electricity consumption in 2005 (3). Consequently, industrial lighting presents one of the greatest opportunities for energy efficiency improvements. Some of the biggest contributing factors to energy inefficiency are excess heat generation due to inefficient types of lighting, incorrect level of lighting for a given task, ineffective use of available daylight, and lights being left on when not needed.

While great strides are being made in the construction of energy efficient buildings, significant cost savings can be realized by upgrading existing buildings with cost-effective, energy efficient alternatives. This process, often termed continuous commissioning, is performed by expert energy auditors and can result in significant cost savings for participants (6). However, due to the necessary training and expertise of energy auditors, combined with the labor-intensive nature of the auditing techniques, the expense of continuous commissioning limits the implementation of energy audits in many buildings. A team of autonomous aerial vehicles is proposed as a less expensive alternative that can produce consistent and reliable energy audits.

The aerial vehicles will navigate buildings and perform energy audits in reduced time with lower capital costs than current expert energy auditors. The team of vehicles would automatically assess entire facilities and produce reports of cost savings for the consumer. These audits, which have shown measurable benefits in cost and energy savings, have the potential to be performed on a much larger scale through use of autonomous vehicles. They can produce significant and sustainable energy efficiency improvements, promoting a sustainable energy portfolio.

As a first step in creating autonomous energy auditing tools, a sensor payload has been designed that is capable of automatically classifying and quantifying industrial lighting. This system is capable of providing its customers with a detailed lighting retrofitting report that details opportunities for cost savings and increased energy efficiency.

METHODS

In industrial lighting applications, the auditors must enumerate and classify all lighting in a facility. With knowledge of current lighting used and usage patterns in the facility, total energy usage and associated monetary costs can be calculated. Additionally, recommendations can be given to improve energy efficiency, such as updating outdated units or adjusting the number of lighting units to satisfy recommended lighting levels.

In development of the sensor payload, the auditing process is divided into two main areas of focus: enumeration of lighting in a facility and classification of lighting type. In accomplishing these areas of focus, the following four sensors were selected and used: a spectrometer, an optical camera, a distance sensor, and an accelerometer. The sensors collect and record data as the aerial vehicle navigates through a facility. All data collection is stored onboard during the auditing process. Once the audit is complete, the onboard storage device is removed from the sensor package and connected to a computer with greater processing power. The post processing program first parses the data and then processes all assessment data through a software program to quantify and classify lighting and generate a recommendation report.

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After initially parsing the data, the program sends the parsed data matrix to the image processing portion of the program. This program quantifies and dimensions the bulbs within a facility and passes a matrix containing this information to the classification portion of the program. The program then analyzes the spectral power curve data associated with each identified bulb. Following the spectral curve analysis, the report generation portion of the program receives the resulting matrix and analyzes the lighting for energy efficiency recommendations. These recommendations are then compiled into a final recommendation report. A summary of this processing sequence is shown in Figure 1.

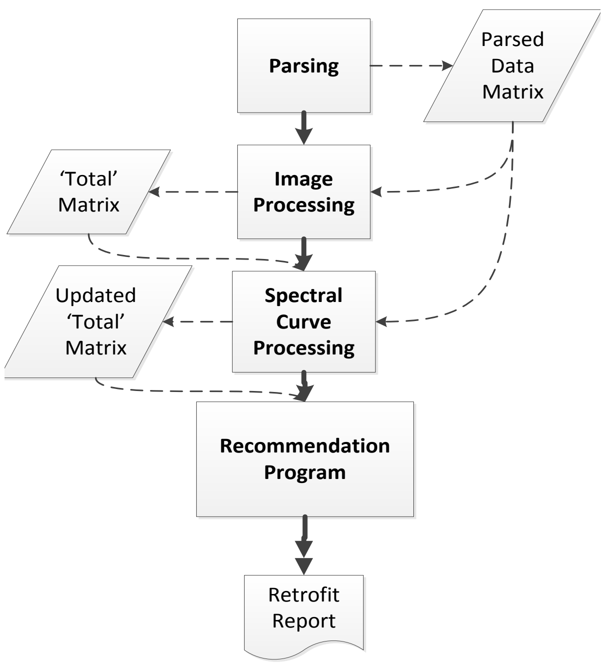


Figure 1. Post Processing Sequence of Sensor Package

Quantify Lighting

The sensor package employs optical techniques to quantifying the bulbs in the facility. In a traditional audit, the trained auditor manually counts the number of bulbs present in the facility. In the sensor package, the process is performed similarly through an optical camera paired with an image processing program. The camera is mounted on the sensor package facing the ceiling. Dividing the ceiling into a grid, the camera records an image in each rectangular sector of the grid, so that the total ceiling area is recorded. The images from each sector are then paired with onboard distance sensor data and stored onboard the package for the duration of the flight for post-processing.

The post-processing program uses the Computer Vision System Toolbox (4) and the Machine Vision Toolbox (1), image recognition tools provided through MATLAB®, to determine both the presence and quantity of bulbs. The program converts individual images into grayscale images and filters them. Bulbs are then identified as objects, and the program counts the total number of valid objects in the image.

Objects are also isolated and dimensioned by pixel. The parallel line of sight of the camera and distance sensor allows the program to scale the size of each pixel to the corresponding area on the ceiling. This information is used to scale the dimensions of each identified object. The identified objects are additionally categorized by shape. The total quantity of bulbs for each sector, paired with dimension values and shapes, is then passed to the classification program for further analysis.

Dimensioning each object not only quantifies the size of the bulb, but also assists in bulb classification. Using the reference database, bulbs with unique shapes can be identified through image processing, providing a shortcut to classifying bulbs. For example, fluorescent lights (and replacement LED tubes) are the only types of lighting in the shape of elongated cylindrical tubes. Knowledge of common bulb shapes and dimensions can assist and validate the results obtained from the classification program.

Classify Lighting

Of the four onboard sensors, the spectrometer is exclusively used to classify lighting. A spectrometer collects and records the frequency spectrum of incoming light. This spectrum, often termed a spectral power curve, displays the intensity of light at different wavelengths and is unique for every type of light (2). In the sensor package, the spectrometer is mounted onto the frame with a 400 micron optical fiber protruding out the top of the structure as the data collection point. Light entering the aperture of the optical fiber is collected and guided to a photodetector. Photons striking the photodetector are used to produce the spectral power curve. Figure 2, Figure 3, Figure 4, and Figure 5 demonstrate the spectral signatures of fluorescent, incandescent, halogen, and LED bulbs respectively.

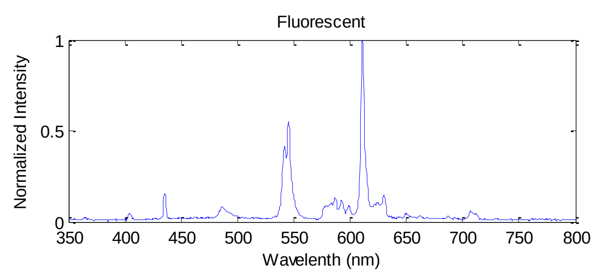


Figure 2. Spectral power curve for fluorescent bulbs

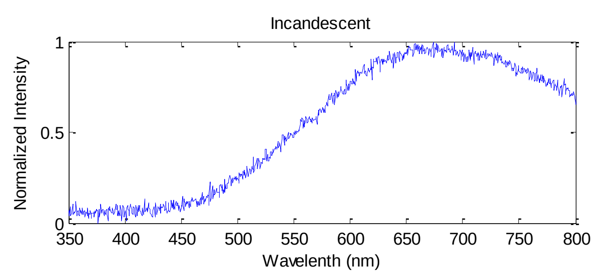


Figure 3. Spectral power curve for incandescent bulbs

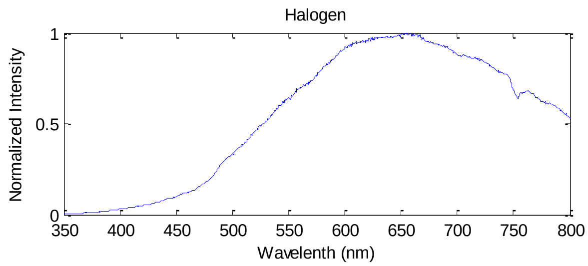


Figure 4. Spectral power curve for halogen bulbs

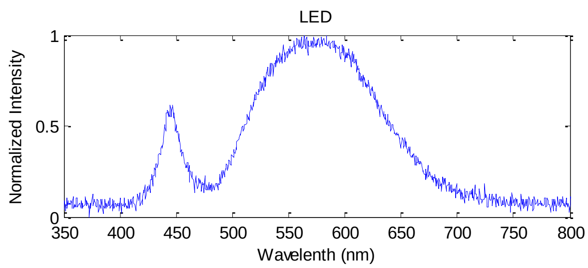


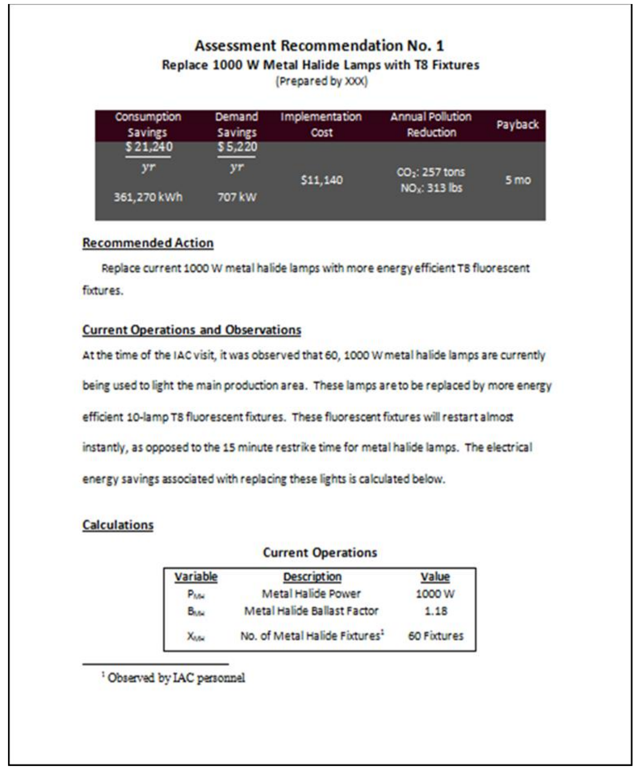
Figure 5. Spectral power curves for LED bulbs

Since the viewing angle of the spectrometer is small, the optical fiber is attached to a servo motor, enabling the spectrometer to collect data over the entire surface area of a sector. The viewing angle of the spectrometer with the servo motor covers a sinusoidal path over each sector. The frequency of oscillation of the servo motor is timed with the speed of the sensor package to ensure all lighting units are analyzed. Portions of the sector left 'un-scanned' are not large enough to contain a bulb.

The spectral data from the spectrometer corresponding to each optical image is stored onboard until post processing. During post processing, each light is classified using several methods. The program initially compares the sensor spectral power curve to the reference curves using a mean-squared error approach. The program then identifies spectral peaks and compares them to the reference database. Finally, the general curve characteristics, such as the slope of the spectral power curve in certain wavelength ranges, are compared to the reference database. Using these criteria, the incoming signal is classified to whichever reference it most closely resembles. Information on bulb type is stored with the quantification data by sector and passed to the report generation program.

Report Generation

The main objective of the lighting audit is to calculate current energy costs and to give recommendations for energy and cost savings. The processed data is passed to the report generation program to analyze lighting for energy efficient recommendations that will produce cost savings. The recommendation report includes inventory of all bulbs present in the facility, calculations on current energy use, potential savings, implementation costs, and payback periods for all recommendations. An excerpt from a sample report used by energy auditors is displayed in Figure 6. Expertise from personnel at the Industrial Assessment Center at Texas A&M University has been used in developing the database of potential recommendations from the collected data. Recommendations with regards to lighting include replacement of lighting type to more energy-efficient lighting, installation of occupancy sensors, and removal of lamps to achieve correct lighting levels.



Assessment Recommendation No. 1

Replace 1000 W Metal Halide Lamps with T8 Fixtures

(Prepared by XXX)

Consumption Savings	Demand Savings	Implementation Cost	Annual Pollution Reduction	Payback
$\frac{\$21,240}{yr}$ 361,270 kWh	$\frac{\$5,220}{yr}$ 707 kW	$11,140	CO_2: 257 tons NO_x: 313 lbs	5 mo

Recommended Action

Replace current 1000 W metal halide lamps with more energy efficient T8 fluorescent fixtures.

Current Operations and Observations

At the time of the IAC visit, it was observed that 60, 1000 W metal halide lamps are currently being used to light the main production area. These lamps are to be replaced by more energy efficient 10-lamp T8 fluorescent fixtures. These fluorescent fixtures will restart almost instantly, as opposed to the 15 minute restrike time for metal halide lamps. The electrical energy savings associated with replacing these lights is calculated below.

Calculations

Current Operations

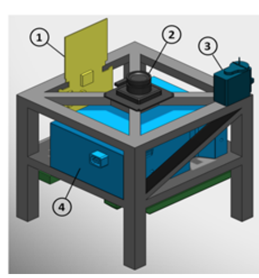
Variable	Description	Value
P_{MH}	Metal Halide Power	1000 W
B_{MH}	Metal Halide Ballast Factor	1.18
X_{MH}	No. of Metal Halide Fixtures[1]	60 Fixtures

[1] Observed by IAC personnel

Figure 6: An excerpt of a sample recommendation report used at the Industrial Assessment Center at Texas A&M University.

Support Structure

All portions of the package are contained in a structure mounted on the aerial vehicle. The compact platform structure is based on a two-tiered system of parallel surfaces. The flat surface on the top of the structure allows for the vertical alignment of sensors. This alignment is necessary to accurately quantify and classify lighting in the auditing process. An overview of the structure, along with a layout of sensor placement, is given in Figures 7 and 8. As illustrated in Figure 7, the camera, distance sensor, and spectrometer probe are aligned vertically in order to gain consistent results. Moreover, the lower tier provides protection to supporting components, such as the microcontrollers, accelerometer, and on-board processor. This can be seen in Figure 8.



Part Reference Key:
1 – Distance Sensor
2 – Camera
3 – Spectrometer & Swivel Motor
4 – Spectrometer Base

Figure 7. Isometric view of the package design

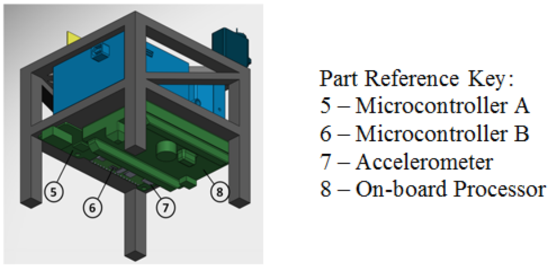


Figure 8. Isometric view of the underside of the package design

The support structure containing all sensors is mounted on an aerial vehicle for data collection. In selecting an aerial vehicle, a hexcopter was selected for its stability and hovering capability during flight. The chosen hexcopter for this project is shown in Figure 9. The platform is mounted to the hexcopter with a series of clamps so that that the platform may be removed during development and testing.

Figure 9. Picture of the hexcopter selected for mounting all sensors.

Integration of Components

When integrating the quantification and classification portions of the program, a BeagleBoard, a low-power single-board computer, is used as the central processor to control and coordinate all sensors. The spectrometer, distance sensor, and accelerometer all directly communicate with the central processor. The camera is interfaced with an Arduino Nano microcontroller, so that captured images may be temporarily stored on the microcontroller prior to transferring information back to the central processor. This central processing computer stores all information from all sensors during the flight for post processing. The layout of these sensors is displayed in Figure 10.

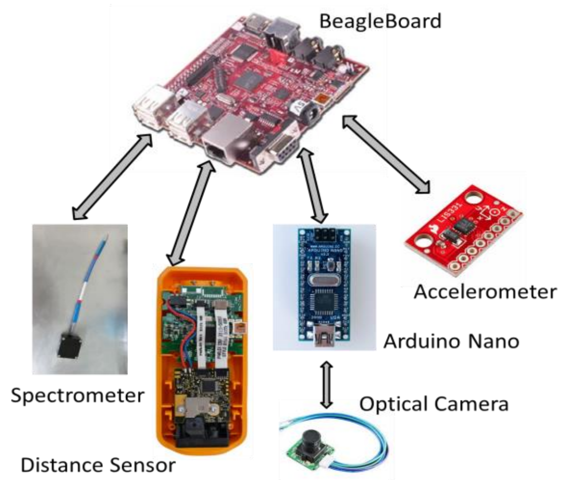


Figure 10. Layout of the sensors and microcontrollers in the sensor package.

RESULTS

Quantify Lighting

When initially testing the image processing program, the lighting level of the room was often too high for the camera's aperture and consequently saturated the image. To rectify this issue, images were taken after applying thin films to the camera's lens. For a specific view of a sector, images were taken with different numbers of films in order to achieve the optimal number of films to accurately enumerate lighting. A sample of the transition of images with additional films is displayed in Figure 11. Testing the program across multiple sectors and films led to the optimal number of films for future testing. The results are summarized in Table 1. As seen in the table, using 3 films was optimal for the given conditions, as the program correctly identified the number of bulbs contained in a sector over 90% of the time.

Figure 11. The transition of images taken in with the addition of thin films – the left image has no film, the middle image has one layer of film, and the third image has two film layers

TABLE I. RATE OF SUCCESS OF IMAGES BY NUMBER OF FILMS USED

Number of Films Used	Images Taken	Total Number of Objects	Correctly Quantified
0	50	140	36%
1	15	42	67%
2	10	28	70%
3	45	108	94%
4	25	70	88%

In quantifying lighting, the image recognition program converts the image to a grayscale image and establishes a threshold cutoff value based on the brightest pixels in an image. Pixels above that threshold are retained, with the remaining pixels discarded. Each group of retained pixels is termed an object. The program then finds objects that are within a certain distance and groups those objects together to eliminate false gaps in lighting. These grouped objects are counted as the number of lights in an image. Figure 12 highlights the main stages of a successful identification. Figure 13 demonstrates the transition from an unsuccessful iteration to a successful one through the addition of an improved threshold value.

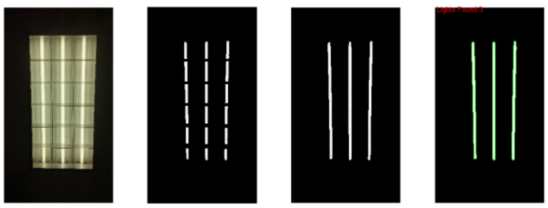


Figure 12. The stages of the image processing software in a successful trial – from left to right: initial image, grayscale conversion and filter, removal of false gaps, final image

Figure 13. The transition from an unsuccessful iteration to a successful one - from left to right: initial image, unsuccessful iteration, successful iteration

The program then dimensions images in terms of pixels. When coupled with distance sensor data, the pixels can be scaled to equivalent dimensions. Initial testing of pixel scaling had large deviations from expected values. These deviations likely resulted from measurement error in measuring the viewing angle of the camera, distance between the camera and the light fixture, and hand measurement of the bulb. Successful dimensioning is anticipated with more reliable measurements of necessary parameters. In obtaining these parameters, camera attributes can be adjusted through programming and triggering software. These programs specifically allow for manipulation of the images though timing, focal length, resolution, and the viewing angle of the lens.

Classify Lighting

The basic recognizable features of the spectral curves were determined for several types of lighting and tabulated in Table 2. Multiple samples were tested for each type of light, and the locations of different wavelength peaks were recorded and averaged. For a given lighting type, the standard deviation for any sample away from the average wavelength peak locations was approximately 2nm. In addition to noting specific peaks, the general shape of each curve provides a noticeable distinction between lighting types. The various features of the spectral power curve were incorporated in the software analysis for lighting type. The primary features include location of wavelength peaks, slopes of the curve in certain wavelength ranges, and the relative intensity of peaks.

TABLE II. AVERAGE PEAK WAVELENGTHS AND CURVE TRENDS FOR VARIOUS LIGHTING TYPES

Light Type	**Spectral Curve Descriptor**	
	Wavelength Peaks [nm]	***Curve Type***
Incandescent	650-670	Smooth
Halogen	640-660	Smooth
Flourescent, CFL	436, 546, 612	Spectrum Spikes
HID (Metal Halide)	819, 671	Spectrum Spikes
HID (High Pressure Sodium)	819,569	Spectrum Spikes
LED	456, 548-565	Smooth, Dual Peak

Tests on LED, halogen, incandescent, and fluorescent bulbs were performed to gauge the flexibility of the developed code in classifying lighting types. Data was collected via the fiber optic cable in the presence of ambient lighting at four different distances, ranging from approximately 60 to 200 inches, from the light. This range incorporates all expected distances during an actual audit. 20 repetitions were performed for each lighting sample at different distances and with different operators. The program correctly classified the lighting type in all cases except for two tests using incandescent bulbs. In these cases, the program incorrectly identified the incandescent bulbs as halogen lighting. Due to the similarity in the spectral curves of halogen and incandescent lighting, their distinction is currently the most difficult to compare. Logical curve characteristic checking is being implemented along with mathematical signal comparison to further increase accuracy. The results for identifying bulbs are summarized in Table 3.

TABLE III. LIGHT IDENTIFICATION WITH THE SPECTROMETER AT VARYING DISTANCES

Light Type	**Number of Correct Classifications**	**Number of Tests**
Incandescent	18	20
Compact Flourescent	20	20
LED	20	20
Halogen	20	20

In initial testing, the only lighting type significantly affected by varying distance of the spectrometer from the lighting source was the incandescent type. With knowledge of this sensitivity to distance, additional logic and comparison to reference curves have been included to improve future accuracy. Additionally, the high sampling rate of the spectrometer as it sweeps from side to side provides multiple spectral power curves for each identified bulb to check the accuracy of the classification of lighting. Due to the sweeping nature of the optic fiber during data acquisition, the quantifying data from each sector will be processed prior to integrating the spectrometer data. This will determine how many lights are to be classified and which spectrometer readings correspond to which light.

Report Generation

The software program receives the matrix containing the bulb count and type and produces a report of potential energy savings recommendations. Currently, the program correctly calculates total energy use and cost with a reference electricity cost for a sample matrix. Development of autonomous recommendations for energy efficiency measures are presently being pursued based on recommendations currently used by energy auditors at the Texas A&M University Industrial Assessment Center.

Auditing Time Comparison

The estimated movement of the aerial vehicle and payload depends on the triggering speed of the onboard camera. With an estimated sector size of 6ft x 6ft, the auditing rate is currently 2,160 ft^2 per minute without accounting for turns, which is approximately 10 seconds per 360 ft^2. Anticipated delays by aerial vehicle motion in turning, take-off, and landing procedures add an estimated 3 minutes to the total auditing time.

The resulting recommendation report is produced from data processing. The total time is dependent on the total number of samples and the processing power of the computer. The average processing time for each image currently is 0.6 seconds. With anticipated parsing time, the total processing time of the image processing software is 5.8 seconds per 360 ft^2. In terms of auditing time, the current classification program is capable of processing and classifying an individual spectral signal in approximately 2 milliseconds. At a sampling frequency of 1.3 Hz, the average processing time is 320 milliseconds per 360 ft^2. The average running time of the report generation program is 0.2 seconds per 360 ft^2. These results are summarized in Table 4

The human auditing time was generated by observing actual energy auditors perform audits on lighting in an industrial facility. This time assumes the report is generated automatically once the human auditor inputs the number of bulbs and types of lighting in a facility into a report generation program. If the report is manually created, additional time will be required from the human auditor.

The results are summarized in Table 4. As shown, the current estimated time for auditing with the aerial vehicle is significantly slower than a human auditor. The time for the sensor package to audit a facility is expected to decrease as software programs and calibration are refined. Additionally, an operator of aerial vehicles could manage a team of aerial vehicles, allowing multiple vehicles to simultaneously audit a facility, decreasing the overall time to perform a lighting audit on a facility.

TABLE IV. AUDITING TIME COMPARISON BETWEEN THE CURRENT SENSOR PACKAGE AND A HUMAN AUDITOR

Process	**Time Required for Initialization (seconds)**	**Average Process Time per 360 ft^2 (seconds)**
Initial Flight	180	10
Quantifying	30	5.8
Classification	0	0.3
Report Generation	0	0.2
Total	**210**	**16.3**
Human Auditor	**30**	**8.2**

Although desirable for automated auditing to compete with human auditors in time required to perform an audit, there are still several advantages of autonomous auditing despite slower operating times. To start, the aerial vehicles are able to accomplish tasks current energy auditors can't do. For example, an aerial vehicle can easily take repeated measurements to record occupancy patterns and light usage on regularly scheduled intervals. Additional capabilities of the aerial vehicle are also anticipated in the future that will expand the number of assessment recommendations possible by the sensor package, compensating for the extended time in enumerating and classifying lighting. The cost for these additional capabilities in human auditing is significant, but aerial vehicles can incorporate additional sensors with minimal additional time requirements. Finally, the cost of operating a team of aerial vehicles consists of the capital cost of the equipment along with the cost for a technician. In human auditing, many years of training and auditing experience are required to become a certified energy auditor. This results in a high cost for certified energy auditors to perform audits. Through economies of scale and with less required expertise, the cost to perform an audit can be reduced through use of automated aerial vehicles.

Conclusions and Future Work

The developed sensor payload concept design is able to classify and quantify industrial lighting individually, but is still in the initial prototyping stages. The enumeration and classification concepts have been proven feasible, but improvements and robustness of these systems are under development. Each element in the sensor package and associated programs is being refined through improved calibration and additional testing. The processing times of all software programs are expected to decrease as development continues and calibration is improved. Wifi or Bluetooth technologies can enable streaming data between the sensor package and the processing computer, further reducing total auditing time.

As the individual elements are refined, the sensors will be integrated into a single sensor package capable of quantifying and classifying lighting simultaneously. Once integration of the individual elements is complete, field tests will demonstrate the capability of the sensor package to perform a lighting audit under flight conditions. Additionally, the software program will accurately determine reasonable energy efficient recommendations for the given lighting type and count. By the conference, the team aims to complete a field test with the integrated sensor package.

Additional capabilities for the sensor package will be explored to expand the scope of potential recommendations. For example, using light intensity data, lighting levels in a facility can be analyzed for potential overlighting and consequent delamping opportunities. Also, maps of lighting levels throughout the facility can be used to determine schedules for automated lighting. These and other avenues will be explored to increase the capabilities of the autonomous auditing vehicles.

ACKNOWLEDGMENTS

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Identifying Efficiency Degrading Faults in Split Air Conditioning Systems

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***Abstract*—Studies estimate that as much as 50% of packaged air conditioning systems operate in faulty conditions that degrade system efficiency. Common faults include: under- and over-charged systems (too much or too little refrigerant), faulty expansions valves (stuck valves, valve hunting, poorly tuned valve controllers), and fouled evaporators and condensers. Furthermore, air conditioning systems can often be adjusted to improve efficiency while continuing to meet cooling loads (adjusting system pressures, decreasing superheat setpoints). This study presents the design of a low cost device that can non-invasively measure system operating conditions, diagnose faults, estimate potential energy savings, and provide recommendations on how the system should be adjusted or repaired. Using eight external temperature measurements, the device potentially can detect and diagnose up to ten faults commonly found in HVAC systems. Steady state temperatures are compared to threshold values obtained from literature and HVAC manufacturers to detect and determine the severity of faults and subsequent reductions in coefficient of performance. Preliminary tests reveal the potential for the device to detect and diagnose common efficiency-degrading faults in HVAC systems.**

INTRODUCTION

Background

In 2010, building energy use made up about 40% of total energy use in America (19). Studies estimate that as much as 50% of packaged air conditioning systems operate inefficiently, costing the building owner money and consequently the United States in energy and carbon emissions (5). Industrial Assessment Centers (IACs) perform free energy audits to determine ways an industrial facility can reduce its energy usage, producing cost and energy savings (20). Currently, the IAC at Texas A&M University (TAMU IAC) does not perform analysis on air-conditioning (A/C) systems. Therefore, to increase the scope of these energy assessments, the purpose of this design project is to produce a device that is capable of detecting and diagnosing common faults found in A/C systems, subject to the following constraints:

- Operate without extensive training or expensive equipment.
- Focus on small to medium-sized split and packaged A/C systems.
- Attach all sensors noninvasively, cutting no deeper than insulation when required.
- Collect and analyze data in less than one hour.
- Keep the footprint of the system small enough that it may be easily transported and installed by one person.

Currently, there are a limited number of commercial systems for AC fault detection and diagnosis. One such system is the *ClimaCheck Performance Analyser* (4). This system uses seven temperature, two pressure, and four electrical measurements to detect and diagnose faults. The output results include heating and cooling capacity, electrical power input, coefficient of performance, and compressor efficiency. Due to the strict time constraints on IAC personnel during an energy assessment, as well as the device's reliance on the presence of pressure taps, this device has limited practicality during energy assessments. The purpose of this paper is to present the results of a device that can effectively detect and diagnose common faults in A/C systems while meeting all the constraints of the TAMU IAC.

Overview of Air-conditioning systems

An air-conditioning system operates on a thermodynamic vapor-compression refrigeration cycle, consisting of four basic processes for the working fluid: compression in a compressor, heat rejection in a condenser, throttling in an expansion device, and heat absorption in an evaporator (2). Figure 1 represents the cycle in its simplest form. The components of a typical air conditioner are described below:

- **Compressor** – Increases the pressure and temperature of the refrigerant vapor and consumes the majority of the power in an A/C unit.
- **Condenser** - Transfers heat from the refrigerant to the ambient air, cooling the superheated refrigerant to a saturated liquid.
- **Expansion Valve** - Lowers the pressure of the liquid refrigerant, allowing it to expanding into a liquid-vapor mixture at a low temperature.
- **Evaporator** - Transfers heat from the indoor air to the refrigerant, heating the refrigerant from a liquid-vapor mixture to a saturated vapor.

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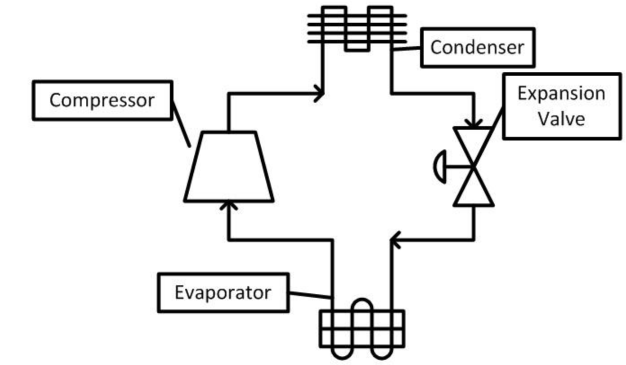

Figure 1. Basic elements of a vapor-compression refrigeration cycle.

Common faults in A/C systems

The most common faults which reduce the efficiency of A/C units are given below, sorted by malfunctioning component.

Compressor

Valve leakage (3): This fault occurs when refrigerant vapor leaks between the valves within the compressor. This is usually caused by general usage wear on the compressor. Valve leakage leads to a reduced amount of refrigerant compression, decreasing the amount of superheat in the vapor and thus reducing the available heat for heat transfer to the environment.

Condenser

Fouling (3): Fouling on the condenser unit is characterized by anything that reduces air flow across the condenser coils, inhibiting heat transfer.

Expansion valve

Thermal expansion valve (TXV) setting too high (13): This fault typically occurs when an A/C technician errors in setting up the unit. This fault reduces the amount of refrigerant allowed into the evaporator coils, increasing the temperatures of the superheat above the recommended level.

TXV hunting (13): When a TXV is oversized for an A/C unit, the valve alternates between allowing too much and too little refrigerant into the evaporator coils.

Liquid line restriction (3): The restrictions in the line are typically caused by a dirty filter or drier in the line. This fault causes a pressure drop in the refrigerant line between the condenser outlet and the expansion valve inlet.

Evaporator

Fouling (3): Very similar to condenser fouling, this fault occurs when air flow across the evaporator coils is restricted. Evaporator fouling hinders heat transfer from the air to the refrigerant.

System-wide faults

Refrigerant over-charge (10): This fault typically is caused by technician error when the system is initially charged. Refrigerant over-charge leads to decreased energy transfer at the condenser and evaporator.

Refrigerant under-charge (10): The opposite problem from refrigerant over-charge; this fault reduces flow speed through the system. Refrigerant under-charge usually occurs from either technician error when charging the system or refrigerant leakage.

Non-condensable gas (3): This fault occurs when a non-condensable gas, such as atmospheric air, is entrained in the system with the refrigerant. These gases decrease the compressibility of the refrigerant, thereby limiting heat transfer to the environment.

METHODS

Fault Detection and Diagnostic Method

Fault detection and diagnosis (FDD) has been used in aerospace, automotive, manufacturing, and other industries for several decades, but it has only recently been pursued in the heating, ventilation, and air-conditioning (HVAC) industry within the past twenty years, making it relatively new in HVAC (6). There are several common branches pursued in FDD as summarized below in Figure 2. For the given constraints and requirements, a rule based qualitative diagnostics method was selected for this project. The rule based method contains models consisting of qualitative relationships derived from knowledge of underlying physics (6). The advantages of the rule based method include using expert knowledge to create if-then-else rules to draw conclusions, suitability for data-rich environments, and simplicity in application. Also, since the method relies on cause-effect relationships, it helps provide explanations for the suggested diagnoses (6).

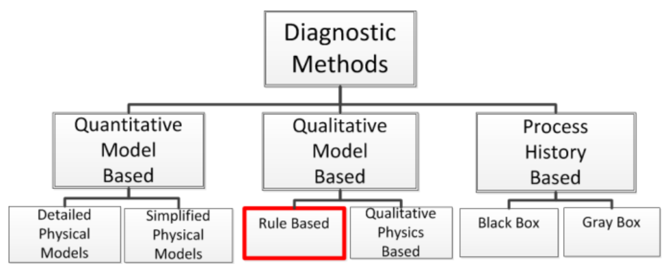

Figure 2: This is a chart of available diagnostic methods. The chosen method (Rule Based) is highlighted (6).

The rule based method for detecting and diagnosing faults depends on steady state temperature and pressure values of the refrigerant and air at various points throughout the system. As data are collected, a moving window average algorithm is used to determine steady state of the A/C unit. Once steady state is reached, the system analyzes temperature readings, pressure values, and temperature differences at different points of the system. These values are used in if-then-else rules to determine the presence and severity of faults in A/C systems. Once the severity of the faults is classified, the resulting efficiency loss and potential energy and cost savings are calculated. This process is summarized in Figure 3.

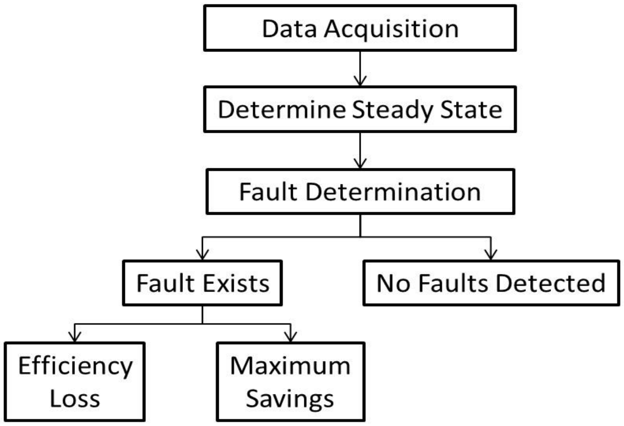

Figure 3. Programming flow chart for detecting and diagnosing faults in A/C systems.

In determining rules for detection of faults, literature sources were the primary resource to determine relationships between a fault and the corresponding temperature difference. Once the underlying relationships were established, specific threshold values were researched to establish an initial correlation between a given temperature difference and a fault. When threshold values couldn't be obtained from literature, HVAC manufacturers were contacted to find general rule-of-thumb relations. The results for these initial threshold values are given in Table 1. The values for the tables were obtained from references (1), (3), (7-10), and (12-18).

TABLE I: INITIAL TEMPERATURE DIFFERENCE RELATIONS AND THRESHOLD VALUES FOR FAULT DETECTION AND DIAGNOSIS (1), (3), (7-10), AND (12-18).

Fault	Temperature 1	Temperature 2	Threshold
Compressor Leakage	Evaporator Inlet	Inside Air	< 31 °F
Condenser Fouling	Condenser Inlet	Outside Air	> 21 °F
TXV Setting Too High	Evaporator Inlet	Evaporator Outlet	> 12 °F
TXV Hunting	Evaporator Inlet	Evaporator Outlet	Changes Rapidly
Liquid Line Restriction	Condenser Outlet	TXV Inlet	> 3 °F
Evaporator Fouling	Evaporator Inlet	Inside Air	> 34 °F
Refrigerant Under-/Over-Charge	Evaporator Inlet/Outlet	Condenser Inlet/Outlet	Based on (10)
Refrigerant Leakage	Evaporator Inlet	Evaporator Outlet	< 12 °F
Non-Condensable Gas	Evaporator Inlet	Evaporator Outlet	> 15 °F

System Setup and Data Acquisition

To diagnose the most common faults found in A/C systems, the fault detection and diagnostic device must take temperature data at 8 different points in the system and pressure readings at 2 points in the system. In order to analyze both split and packaged A/C systems, the design setup includes several wireless sensors. The base station is located outdoors near the condenser and compressor, and all wired sensors feed into that station. All sensors located at the evaporator communicate data wirelessly to the base station. A summary of the type and location of sensors used in the device is found in Table 2.

TABLE II: LOCATION AND TYPE OF SENSORS USED IN THE FAULT DETECTION AND DIAGNOSTIC DEVICE

Type of Sensor	Location of Sensor	Type of Transmission
Temperature	Compressor Outlet	Wired
Temperature	Condenser Coil	Wired
Temperature	Expansion Valve	Wired
Temperature	Evaporator Inlet	Wireless
Temperature	Evaporator Coil	Wireless
Temperature	Evaporator Outlet	Wireless
Temperature	Indoor Wet Bulb	Wireless
Temperature	Outdoor Ambient Air	Wired
Pressure	Compressor Suction Line	Wired
Pressure	Compressor Discharge Line	Wired

In order to forgo the need for pressure taps, pressure measurements can be derived from available temperature data. Li has performed work on using virtual sensors to derive pressure information from temperature readings (11). A saturated liquid-vapor mixture at a specified temperature will have a fixed pressure. Knowledge of the temperatures during evaporation and condensation in the evaporator and condenser, respectively, will reveal the pressures of the refrigerant at these points in the system. With known relations for the pressure drop between these components and the compressor, the compressor suction and discharge pressure can be determined. Li's work has shown that this method is effective in determining accurate values for the pressure in the system at a given time, eliminating the need to install pressure taps to obtain necessary pressure readings (11). Pressure sensors will be used for the prototype to verify this relationship, but the final design will not include pressure sensors.

Economic analysis and cost savings estimates

In the rule based method, the amount which a reading exceeds the specified threshold indicates the degree which a fault is present. Based on the work of Chen (3), the severity of each fault can be related to a change in coefficient of performance (COP) for the system. From the change in COP for each identified fault, it is simple to calculate the overall efficiency of the system by multiplying the fault efficiencies together. After estimating the COP reduction due to each fault present in the system, coupled with knowledge of the cost of electricity, the cost savings of repairing the unit can be estimated with the following equation.

$$Potential\ Cost\ Savings = \left(\frac{\mathrm{COP}_R}{1-\mathrm{COP}_R}\right)(\mathrm{P_n})\,(\mathrm{C_{elec}})(\mathrm{H_{op}}) \qquad (1)$$

where $\mathrm{COP_R}$ is the reduction in COP of the unit, $\mathrm{P_n}$ is the nominal power of the unit in kW, $\mathrm{C_{elec}}$ is the cost of electrical power in \$/kW-hr, and $\mathrm{H_{op}}$ is the operating hours of the unit

For example, if a liquid line restriction is responsible for a 15% decrease in COP, then the overall efficiency of the system due to this fault is 85 %. Based on this calculation, the system can be said to use 1/85%=118% of the power required by a fault-free system. The excess 18% power consumption can be eliminated by fixing the liquid line restriction fault. Chen has determined COP reductions in efficiency for several different faults at different levels of severity (3). Linear interpolation between these severities gives a method for estimating COP loss for each of these faults.

RESULTS

Establishing a baseline system

One of the principal difficulties in development of the fault detection and diagnostic device lies in validation of the device for different faults. In order to validate the device, a laboratory split system has been set up with variable speed fans, compressor, and a controllable TXV valve to artificially simulate faults in the system. Figure 4 displays the laboratory setup of the split system. By installing multiple pressure transducers, thermocouples, and current clamps throughout the system, data have been collected for simulated faults of valve blockage, compressor leakage, evaporator fouling, and condenser fouling. In simulating a fault, the system was initially operated normally. After steady state was reached, the fault was artificially introduced into the system. Figure 5 shows refrigerant temperature measurements at various points in the system for one of these induced faults. As can be seen in the figure, the temperatures of the refrigerant change when the fault is introduced around 200 seconds.

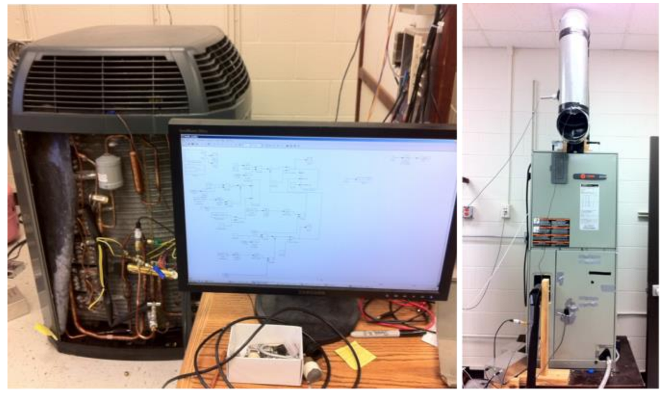

Figure 4: Setup of the laboratory split system to artificially induce faults in the system.

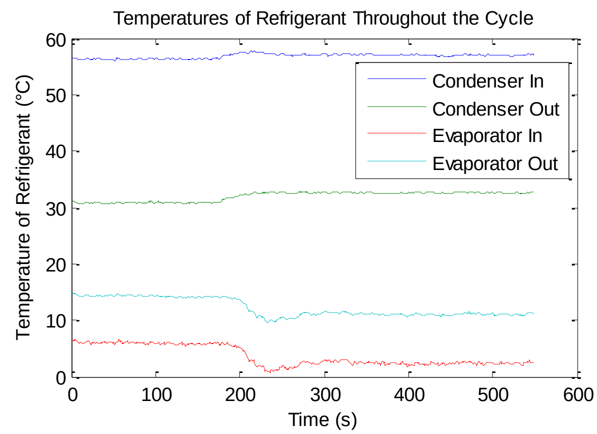

Figure 5: Temperature data of refrigerant during a test when a fault is artificially induced in the system.

Preliminary fault detection

In initially testing the programming logic and threshold values for the fault detection and diagnostic device, the artificially simulated fault data were used to determine if the device can detect the presence of a known fault. These preliminary tests show the potential of the device to detect faults. Results from testing the program with an artificial fault of compressor leakage are shown in Figure 6. As can be seen in the figure, the program correctly predicted the presence of this fault using established threshold values. Correlation of the severity of the fault and subsequent reduction in COP is currently under progress. Additional calibration of threshold values is also being performed due to the presence of some false positives when testing the simulated fault data for other faults.

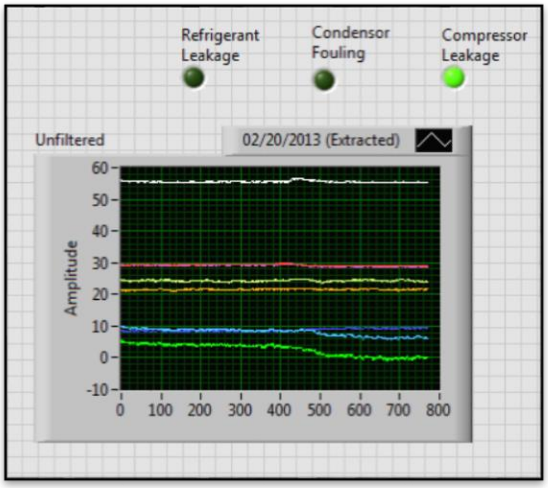

Figure 6: Results of testing the fault detection threshold values for an artificially induced fault of compressor leakage.

Initial field tests

In addition to testing the threshold values on simulated faults, initial field tests have been performed to demonstrate the effectiveness of the device in setup and collection of data. In order to accurately detect and diagnose faults, steady state must be reached and detected by the system. A moving window average filter has been developed to determine steady state. Moving window average filters require an error cutoff value and a slope cutoff value. The moving window average has been used in precedent with Kim's work with refrigerant charges (10). An example of a moving window average is given in Figure 7. This figure contains four ranges of data that consider an equal number of data points. The minimum and maximum values in each range are determined to calculate the spread of the temperature data, and this difference is compared to the prescribed cutoff value. A linear interpolation is also performed on the data in the time range, and the slope is compared to a second cutoff value. If the data in this range pass both criteria, the data are considered steady state and are passed to the fault diagnostic functions. If the data are not in steady state, the earliest data point is discarded and the next data point is added for consideration.

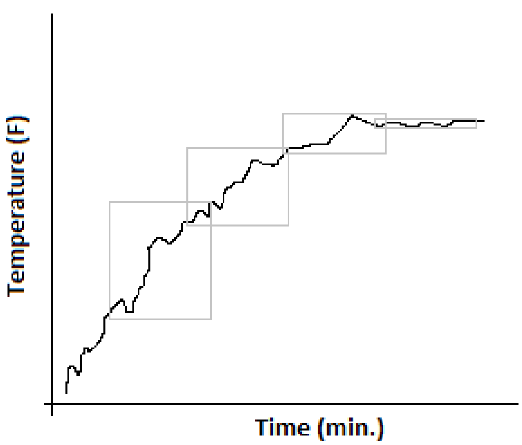

Figure 7. Example of moving window average filter

The system has successfully been installed and data have been collected for several split A/C systems within the required constraints of the TAMU IAC. Additionally, determination of steady state from raw sensor data using the moving window average filter has been demonstrated. An example of data collection and the steady state filter of an actual field test are displayed in Figure 8.

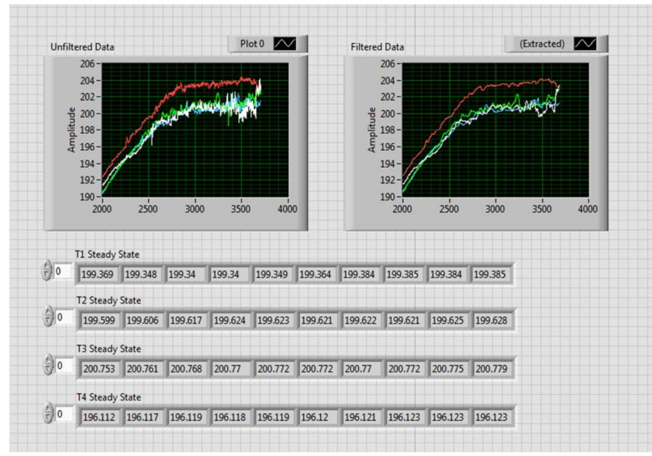

Figure 8: Data collection from a field test along with the working moving window average filter.

Conclusions and Future Work

The fault detection and diagnostic device currently is capable of meeting all of the TAMU IAC constraints in setup and data collection on split and packaged A/C units. Additionally, the obtained threshold values for the rule based method in determining faults have shown preliminary success in detecting simulated faults in a laboratory A/C system.

Further validation and refinement of threshold values is necessary to eliminate false positives and missed faults in tested artificial simulated faults. This refinement will be assisted with additional simulated faults in the laboratory system. Additionally, the laboratory system will be run at different operating conditions, e.g. different outside air temperatures, to give robustness in the refined threshold values.

In addition to refinement of threshold values, the power usage of the compressor will be monitored to further validate detected faults. The rated load amperage (RLA) of a compressor represents the manufacturer's anticipated current draw when the system is running normally (8). The RLA for the compressor is an important figure because it identifies the expected current draw by the compressor during fault-free operation. When certain faults are present, the compressor must draw a higher current in order to operate. The difference between RLA and steady state compressor current draw is representative of the amount of extra energy consumed by the system. Measuring the power draw of the compressor will aid in determining the severity of known faults as well as validate the existence of faults in a system.

Additional methods of fault detection will also be researched to further improve fault detection and diagnosis. Other methods proposed by Katipamula as well as analysis of transients in the A/C units will be explored (6).

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Automated Part Tracking and Metrology Applied to a Manufacturing Process

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***Abstract*— This paper presents a case study in the design of an automated part tracking and metrology systems for an industrial manufacturing system. A major productivity challenge of this facility is managing each batch of parts as it is formed, treated, and processed. Currently this is handled with paper forms that are transferred manually with each batch, resulting in scheduling problems, lost parts, and a general lack of ability to track orders through the production process. Problems in quality control also lead to significant waste. Required part measurements are taken and recorded manually, and are not considered reliable by plant management. The prototype design is an automated part tracking and quality control system to enhance productivity. The system uses RFID technology to identify parts and associate them with a particular order, giving management real-time information on the location of any product batch in the plant. In addition, part measurement quality control is enhanced with digitized calipers and scales, thus increases reliability of part measurement accuracy through human error reduction.**

I. Introduction

Industrial applications benefit from greater process control that leads to enhanced efficiency, increased part quality, and increased productivity. This paper presents a case study in enhancing manufacturing operational processes through automated part tracking and metrology. The facility transforms metal powder into precision-hardened, tungsten carbide drill parts on a large scale. Their current method for tracking orders involves a manual barcode scanning system linked to a software program. Each order has paperwork with a printed barcode that follows it around the plant as it goes through every step of manufacturing at different stations. These include (in the order listed):

(1) Order Receiving
(2) Tooling
(3) Powder Selection
(4) Press Queue
(5) Pressing
(6) Heat Treatment
(7) Sorting
(8) Inspection/Grinding Queue
(9) Post-furnace Inspection
(10) Inspection/Grinding Queue
(11) Grinding
(12) Tumbling
(13) Final Inspection
(14) Packaging

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A representation of these steps is shown in Fig. 1. Rectangles are manufacturing steps while diamonds are quality control steps. The dashed line represents a potential design solution, discussed in the Metrology section.

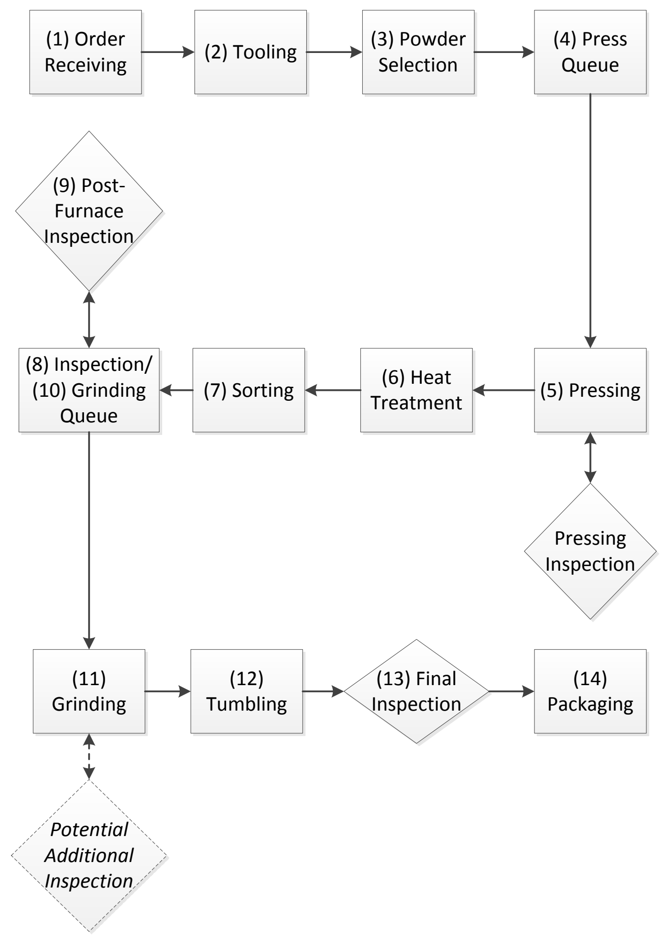

FIGURE. 1. Manufacturing process flow diagram.

At every station, the barcode must be manually scanned by an employee. This relays information to the software and allows the company to know which step of the process an order has reached. In addition, due to the company's specific software setup, a second barcode scan is required at every station for labor charging.

In addition to product tracking, the company implements quality control part measurements. At each step, measurements are taken on a set number of parts and are recorded on the order paperwork in addition to a log kept at each station.

Several concerns arise from current operational methodology. One concern is the ease with which the manual barcode scan can be overlooked. Often, an employee will scan one barcode but forget to do the second required scan at a station. This makes it necessary for managers to go through the software system, searching for and correcting the errors. In addition, the manufacturing process can be halted for orders missing tracking data, verifying parts have gone through the necessary processing. According to management, approximately 30 hours of manager time per week is wasted correcting these errors. Another concern is the nature of the current metrology system. Operators must record part dimensions and weights by hand, inviting human input error from repetitive data recording. The facility would like to eliminate data recording errors and streamline data analysis, currently unrealizable through manual, paper based means. The goal is to improve production efficiency by implementing a system that is easy to use, relative to the current system, reduces human error by taking advantage of automation, and is financially appropriate when considering cost vs. value.

II. Metrology

Throughout the manufacturing process, several steps are taken to help ensure the quality of produced parts. The first quality check is performed after pressing. After every 25th part is pressed, the machine will stop; the operator must measure the height and weight of the part before proceeding. Only the height and weight are measured and used to predict the shrinkage behavior of the part in the furnace. The next quality check is performed after heat treatment. One part from every order is removed and set aside for destructive and metallurgical testing. The order cannot be shipped until these tests are performed. In addition, three parts from every order are dimensionally checked. Several dimensions are checked on each part to ensure that it is within specified tolerances. Once completed, these three parts are returned to the order at which point the order can proceed. Next, during grinding, approximately every 50th piece has its diameter checked. During the grinding of non-threaded nozzles, the parts make several passes through the grinder; each pass takes a specified amount off of the outer diameter. The machines cannot reduce the diameter too much in one pass without incurring damage. So, after each pass, the outer diameter is checked of every 50th part to protect part quality

A. *Design Concepts*

The two steps in the process where quality control was deemed to have room for improvement were at the pressing station and at the grinder. The concepts must have the ability to take weight, height, or outer diameter measurements. The concepts can be broken down into two categories: those that automate both the measurement taking and recording processes and those that only automate the measurement recording process. The concepts that automate both measurement and recording are as follows: automated scale (conveyor belt), single-axis diameter gauge, and a full-featured automatic measurement system. The automated scale would be installed near the pressing station and would check the weight of every part before allowing it to move on in the process. Implementing this technology is estimated to cost at least fifty thousand dollars. The single-axis diameter gauge would be installed at the grinding station and would automate both the recording and measurement of the outside diameter of the parts [4]. Implementing this technology is estimated to cost twenty-one thousand dollars. The full-feature automatic measurement system could be installed at either the pressing station or the grinding station. This technology has the ability to take measurements in all three dimensions [5]. Implementing this technology will cost approximately fifty thousand dollars.

The concepts that only automate the recording of the measurement are as follows: a standard scale able to output measurements to computer via universal serial bus (USB) and a digital caliper able to output measurements to a computer via USB. Both require the user to press a button that outputs the measurement to the computer; the output is recognized by the computer. The digital caliper could be implemented at the pressing station or at the grinding station. The standard scale would only be implemented at the pressing station. If implemented at the pressing station, each press would have its own scale and caliper. Equipping each pressing station with a caliper and scale would cost approximately eight thousand dollars total [3,4].

B. *Concept Evaluation*

The concepts were evaluated on the following criteria: commercial availability, digital interface capability, automated recording, and automated measuring. Commercial availability was deemed important because the products must be easily maintained, serviced, and replaced throughout their life cycle. Automated recording was deemed important because it speeds up the quality control process and eliminates errors. Automated measurement was deemed important because it would allow more measurements to be taken, therefore reducing the probability that a bad part makes it through to the next production stage.

The automated scale, single-axis diameter gauge, and full-featured measurement system meet all functional requirements. The automated scale can weigh between 80 to 400 parts per minute [3]. The single-axis diameter gauge has the ability to take 1,200 measurements per second [4]. Both technologies could take measurements faster than parts supplied for inspection.

The digital scale and digital caliper meet all functional requirements except automated measurement. Based on the functional requirements an automated scale (conveyor belt) and full-featured automatic measurement system would be installed at the pressing station and a single-axis diameter gauge would be installed at the grinding station. However, the concepts must also be considered economically viable.

C. *Economic Analysis*

The first step in determining if the concepts are economically viable is determining the amount of money that is lost each year from bad parts continuing through the production process. A cost model was created based on assumptions made by the design team and is presented in Fig. 2. The cost model divides the cost to produce a part into four sections: labor costs, material costs, operating costs, and overhead costs.

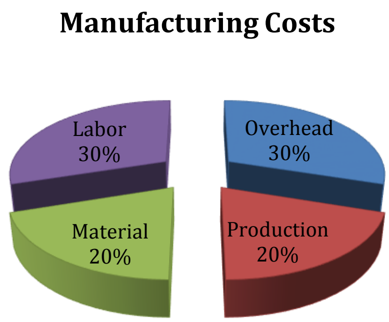

FIGURE. 2. Cost breakdown of manufacturing process.

The labor cost relates simply to the total amount of money paid to all employees who work directly on the parts in the facility. Material cost is only the money spent on buying the material used to create the pressed parts. In order to power the entire process a great deal of electricity is used. The operating cost covers the cost of electricity as well as other utilities. Finally, the overhead cost encompasses management and all other aspects of the process, such as rent for the facility.

The cost model then took into account what percent of the labor and production had already been put into the part after the pressing and grinding stations as shown in Table 1.

TABLE. 1. Labor and production cost split for grind and press.

	Labor		Production	
	Completed	***Remaining***	***Completed***	***Remaining***
After Press	45%	55%	16.7%	83.3%
After Grind	90%	10%	83.3%	16.7%

There are cost savings opportunities that exist after the press due to early part forming. Such a large percentage of the production cost remains because after the press, the parts have not been heat-treated. The furnace accounts for a large portion of the production cost. After the grinding station, the cost savings opportunity is smaller since only tumbling, final inspection, and packaging remain. Wasted material is estimated to lose fifty percent of its original value because it can be shipped back to the powder facility and reprocessed. Overhead cost cannot be saved regardless of where the bad part is caught. All these values can be combined into a single percentage to show what percentage of the part cost can be saved if bad parts are identified after the press and after the grinding station, shown below in Fig. 3.

The cost model then took into account how often bad parts continue through the production process before they are caught. With all this information the model can then determine what the cost savings are for identifying bad parts at the pressing and grinding stations. This information along with the cost to implement the technologies can be used to determine if the concepts are economically viable.

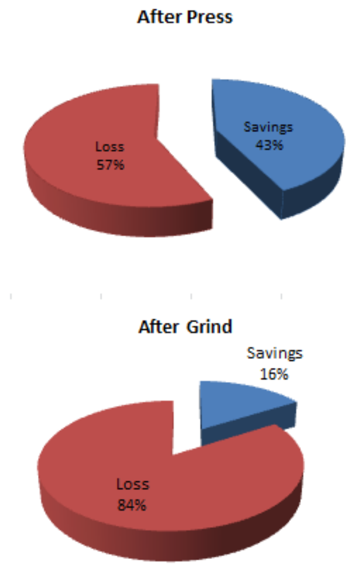

FIGURE. 3. Manufacturing cost model before and after press and grind.

In order for a concept to even be considered, it must be economically viable if it is perfect and catches all bad parts. The concepts will be judged on three factors: internal rate of return, net present value, and payback. Concepts will be determined to be economically viable if they have an internal rate of return (IRR) of 15%, a positive net present value (NPV), and a payback of less than two years. Table 2 presents these values for each design concept.

TABLE. 2. Economic analysis for metrology design concepts.

	IRR	NPV	Payback (yr)
Caliper and Scale at Press	180%	$26,495	0.5
Full Feature Measurement System at Press	-5%	-$15,504	3.3
Automatic Scale at Press	-5%	-$15,504	3.3
Laser OD at Grind	-7%	-$6,041	3.5
Caliper at Grind	133%	$7,871	0.7

The automatic scale, full-featured measurement system, and single-axis diameter gauge are eliminated from consideration due to having a negative rate of return and a negative net present value. The next step is to consider the situation where the remaining metrology concepts catch some but not all bad parts. For this situation it was assumed that the digital caliper and scale increase the current detection of faulty parts by 30%.

The digital caliper and scale are economically viable; therefore, they are selected for the final design based on the model assumptions. They meet all of the functional requirements except automated measurement. The key benefit that they provide is the reduction of human reading or recording errors.

TABLE. 3. Detailed economic analysis at 30% increase in faulty part detection.

	IRR	NPV	Payback (yr)
Caliper and Scale at Press	32%	$2,348	1.8
Caliper at Grind	14%	-$73	2.3

III. Part Tracking Design Concepts

Once a customer places an order, a work order is created and all necessary paperwork is printed and brought together. This paper follows the parts throughout the facility and provides the most basic level of tracking. Once the parts are pressed, graphite trays with cutout numbers provide a simple tracking method through the furnace. The tray number is recorded on the paperwork which is stored on a ring outside of the furnace during sintering. After the furnace, the parts are transferred to numbered wooden boxes. These numbers are recorded and the parts are kept in these boxes between machining stations until shipping. The current tracking method is a set of two barcodes which must be scanned at every step in the process in order for the known part location to be accurate. Inevitably, mistakes occur in recording numbers or scanning barcodes. According to management, it costs approximately 30 hours of manager time per week to correct the mistakes.

A. *Design Concepts*

Various signal types that could be tracked by an automated system were considered. These consisted of audio, visual, and radio communication signals that can track the part's progress through the manufacturing process or track the physical location of the part.

Radio communication signals considered included Global Positioning System (GPS) and Radio Frequency Identification (RFID). Both are commonly used tracking systems based on non-visible and non-acoustic signals which do not require a direct line of sight to function. Visual concepts consisted of utilizing barcode and QR technology. QR technology is similar to a barcode, but two-dimensional, meaning more information can be stored. Blinking Light-Emitting Diodes (LED) were also considered; the frequency/pattern of blinking would characterize identification to a visual sensor. Audio ideas were limited to audible or high-frequency sounds identified through pitch, frequency, type of sound, etc.

B. *Eliminating Concepts*

For a concept to be considered, it must be able to function correctly in the manufacturing environment. It should not require manual input of part information because of the likelihood of human input errors. The concept should be commercially available and provide customer support. The best concepts provide real-time updates on a part's progress. Finally, the initial investment and recurring costs need to be as low as possible.

Visual tracking may prove challenging in light of the gray powder used to produce the tungsten-carbide parts. Direct line of sight may also prove difficult when the part carts are next to each other. Audio concepts also are difficult to implement. Audio signal receivers would receive considerable interference due to various sources of plant noises. Both visual and audio concepts are not typically used for tracking, which requires a unique design and provide no customer support.

QR or barcode technology is a visual concept that is available commercially. It is inexpensive to implement but does not provide real-time updates on part location.

GPS and RFID are both automated systems which could provide real-time updates and do not require manual input. The difference between these concepts is the affordability of RFID. GPS is far too expensive for the added benefit of tracking exact location. RFID is the most practical option for this manufacturing process. Even though RFID does not provide the exact location of a part, it provides real-time updates whenever a part passes specifically placed RFID antennas. Both of these are more expensive than QR or barcode, important factor for the customer. The most viable options appear to be either RFID or barcode/QR technology.

C. *RFID Technology*

RFID technology uses radio waves to transmit a unique identifier from an RFID tag to a reader without requiring line-of-site. There are two types, passive and active. The advantage of passive tags is their minimal cost [6]. However, they cannot store information. An active tag, on average, costs approximately ten times more but can store information and can be located within two centimeters in some cases [6]. Due to their increased range, they require power to operate. The RFID tag range depends on a number of factors including: environment, tags, reader, and antenna. In general, the range is between two and ten feet. [6]

RFID technology would allow for the use of either tags or labels in tracking parts. Labels are stickers embedded with passive tags which can be printed from an RFID printer. These would be stuck to existing paperwork which would allow the parts to be tracked as long as the paper stayed with the parts. In addition, more durable tags can be attached to the wooden boxes that transport the parts. Using both tags and labels would benefit part and paperwork separation. Both of these identifiers could be associated through software to order number, part number(s), client, order date, due date, etc.

Stationary RFID readers would be placed throughout the plant at specific points where parts need to be tracked. When the RFID tag comes within range, the reader would store the information, such as time and order number, in the software package. Additionally, this design concept would allow for employees to wear RFID tags and indicate who performed each step of the order process. While not specifically part of the customer's need, tracking labor for each part is an added benefit. Handheld RFID readers could also be added to provide information without the need of a computer station.

The advantage of RFID is that it automates part tracking and mitigates human error. The primary disadvantage is the initial capital investment. The improvements in process management through RFID are difficult to quantify, making it difficult to determine a cost benefit.

D. QR and Barcode Technology

Another concept using scanning technology is QR or barcodes. Currently, two separate barcodes are scanned; one to track parts, the other to record labor time per part. The improvement in using this concept is that both the part tracking and labor tracking information require one scan. In this concept the current barcodes can be continued or a QR code can be implemented, but only one scan would be required at each station.

The advantage of switching to QR codes from barcodes is that QR codes allow for more information to be stored within the code itself. Information such as order number, part numbers, client, order date, due date, and part specification could all be stored in the code. The station at which the QR was scanned and the time it was scanned would be stored and tracked in the software.

The disadvantage of this concept is it still leaves the part tracking in human hands because the code must be manually scanned. However, by eliminating the need for a second scan, it theoretically has the potential to reduce errors by at least 50%.

E. Final Selection

The design selected as the best match for the given parameters is to use passive RFID tags and labels on all of the boxes and papers as well as to place readers and antennas throughout the plant. Although costly at first, this will greatly improve plant productivity because of the ability to complete parts in order based on order date, customer, or any other desired metric. Although QR codes are much cheaper to implement, they still require workers to scan the QR code, which takes more time and offer little improvement in stored information. RFID meets all functional requirements while limiting the cost in comparison to location-based tracking such as GPS.

IV. RFID Implementation

In order to fully track order progress through the facility, the RFID system must sense the presence of orders at every step in the manufacturing process. RFID is extremely sensitive to specific application environments. As a result, the design must be detailed and adaptive, so that it is clear exactly how the RFID system will be implemented in this specific facility. The design must be able to account for several metals present at the RFID sensing locations. The proposed RFID solution must capture all of the following steps in the manufacturing process. For reference, see Fig. 1.

Each step in the manufacturing process presents a different set of challenges toward implementation of an RFID tracking system. As a result, each step must be looked at individually. Passive and printable RFID tags will be used to follow orders throughout the facility, and RFID readers and antennas will be used to track the movement of these RFID tags. For part tracking applications, UFD (Ultra High Frequency) readers will be used. Depending on the reader model, one or more antennas can be attached, providing greater reader operating range. Both single antenna and multiple antenna readers will be used as part of the design. The range of the reader will be determined by each specific step in the manufacturing process. Several stations will require an antenna with very low range because all tags will be placed directly adjacent to the antenna with no interference other than the order paperwork. A facility map is presented in Fig. 4. Each step in the manufacturing process is shown along with the approximate placement of RFID antennas.

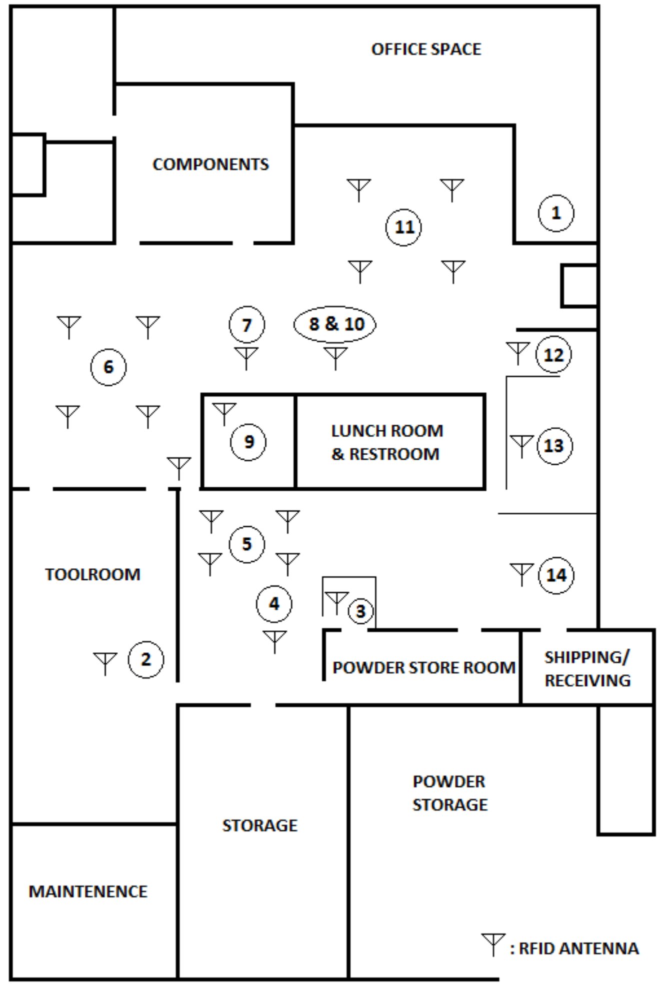

FIGURE. 4. Facility map with process steps and antennas locations.

After an order is placed with the facility, appropriate paperwork is printed to initiate an order. Along with the creation of paperwork, a printed RFID label will be attached to each order's paperwork. Once printed, the RFID label designates the order as initiated, allowing it to begin the manufacturing process. The paperwork then travels to the tool room where the station worker places it on a centrally-located desk. A single-antenna reader will be placed directly next to this location; the necessary range will be small. The paperwork then travels to the desk at the powder selection station. Another single-antenna reader will be used at this location. After, the specific powder for the order and the order paperwork are taken to the press queue waiting area. The open space of the waiting area presents a challenge in light of its poorly defined boundaries and sensing area is quite large for an RFID antenna. A checkpoint demarcation with a single-antenna reader will be placed. Operators must pass this checkpoint with the order paperwork before proceeding to place the order in the press queue.

The next step in the production process is pressing. Fig. 5 shows a partial view of one row of presses.

FIGURE. 5. Row of presses during operation.

Four pressing machines are shown on each side of the aisle. At this station, a reader with multiple output antennas will be placed. One low-range antenna can be used at each station such that the operator does not have to alter his/her current behavior to ensure the paperwork is in range. Four antennas are shown in Fig 4, but in full implementation, more antennas will be used to account for every pressing station. This same convention is used for other stations with multiple antennas.

After pressing, the parts and paperwork are placed on graphite trays, which are placed on large metal carts. On the way to heat treatment, the paperwork and the batches of pressed nozzles pass through a doorway. A high-powered reader will be placed at this doorway to ensure that all tags are read regardless of metallic interference. Each cart then waits to be taken to a specific furnace for sintering. During the heat treatment, several sets of order paperwork for parts sintering in the furnace are placed on a hanging ring on the side of the furnace. A multiple-antenna reader will be used, with one antenna at each reader, placed next to the ring.

Once the parts have finished sintering and have cooled, a sorter is used to move the parts from the graphite plates to wooden trays: paperwork is set aside in a specific position, shown in Fig. 6. For reference, several wooden trays can be seen in Fig. 7 on a cart. A single-antenna reader will be used here to track each order through the sorter.

After each order is sorted, it is placed on a cart in a waiting area according to the outer diameter size. Fig. 7 shows one of the carts used in this area. This area presents a challenge similar to the press queue waiting area. The same type of solution will be used here, with a single-antenna reader at a checkpoint, through which all orders must pass. At this point, the paperwork and three parts for each order are taken to a separate room for an inspection. Another single-antenna reader will be placed around the doorway of the inspection room. After, the paperwork and three parts are returned to the trays.

FIGURE. 6. Placement of order paperwork during sorting process.

FIGURE. 7. Example of a cart used to transport orders in trays.

Depending on due date, a grinding operator will bring an entire cart from the waiting area to a grinding station, where each part of every order is ground. There are several grinding stations, similar to pressing stations. A multiple-antenna reader will be used here, with one antenna placed at the workstation of each grinding station. As each order is ground, the paperwork is placed on the workstation. After grinding, some parts are placed in a tumbler. At this station, the paperwork is placed in a specific location. A single-antenna reader will be placed directly adjacent to it. After tumbling, all parts are completed and then placed on a rolling surface. All remaining steps are performed along this surface until the part is ready for shipping.

V. CONCLUSION

Part tracking and metrology have the potential to increase productivity and quality control for any industrial facility. While there are several methods employed to accomplish these tasks, economic viability is at the heart of implementation. The use of a digital calipers and scale has been shown to be a viable means of recording part data, reducing user prone error and further realizing trend data analysis while minimizing implementation costs. Similarly, part tracking across various production stages can minimize lost part and reduce wasted employee time. The use of an RFID system capable of locating parts while reducing implementation cost affords managerial staff greater control over production operations. Although the system will be able to locate part orders at any point throughout the production process, the system has the potential to make possible part production optimization, manipulating part staging to effect variables such as order timing and optimal equipment use.

VI. ACKNOWLEDGMENTS

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Industrial **G**eospatial **A**nalysis **T**ool for **E**nergy **E**valuation- **IGATE-E**

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ABSTRACT

IGATE-E is an industrial energy analysis tool. The tool is intended to be a decision support and planning tool to a wide spectrum of energy analysts, engineers, researchers, government organizations, private consultants, industry partners, and alike. The tool applies statistical modeling to multiple datasets and provides information at the geospatial resolution of zip code using bottom up approaches. Within each zip code, the current version of the tool estimates electrical energy consumption of manufacturing industries based on each type of industries using information from DOE's Industrial Assessment Center database (IAC-DB) and DOE's Energy Information Administration Manufacturing Energy Consumption Survey database (EIA-MECS DB), in addition to commercially available databases such as the Manufacturing News database (MNI, Inc.). Ongoing and future work include adding modules for the predictions of fuel energy consumption streams, manufacturing process steps energy consumption, major energy intensive processes (EIPs) within each industry type among other metrics of interest. The tool utilizes the DOE EIA-MECS energy survey data to validate bottom-up estimates and permits several statistical examinations.

INTRODUCTION

Energy professionals and researchers are often challenged with initiating projects or performing analyses that are the basis for project approval with limited and/or unreliable information. In manufacturing industry related projects, the challenge is compounded (compared to residential and commercial sectors) since end-use attributes in commercial and residential sectors are more uniform than in the industrial sector. In addition, data on some driving factors are more accessible, like temperature, population densities, or other parameters that are typically used for residential and commercial energy estimation models. Industrial energy consumption is heavily dependent on the type of manufacturing process, production volume, plant size, location, operational parameters, and other variables that are usually proprietary for each manufacturing facility.

This paper discusses the development of an analytical tool "IGATE-E" (Industrial Geospatial Analysis Tool for Energy Evaluation) that provides multi-layer industrial energy information including; manufacturing plant level, industrial subsector level, zip code level, county level, balancing authority level, state level, and national level. IGATE-E was developed utilizing MATLAB platform as the existence of numerous tool libraries provides good opportunities for analysis expansion. It utilizes statistical analysis of multiple databases to estimate manufacturing plants energy consumption for over 300,000 manufacturers across the U.S. and provides geospatial interlinking to Google Earth using MATLAB based mapping tools. We used the "bottom up approach" in the development of this tool where the analyses were performed at the granular level of a manufacturing facility and results were aggregated up to zip code and regional values. The current version of the tool is only capable of estimation of electrical energy consumption; however, future versions of this tool will include estimation of fuel energy streams at the plant level as well as other parameters of interest such as Energy Intensive Processes per SIC, Load Curves per Process Step per SIC, Load Factor per type of Manufacturing Plant. Future versions can also be linked with other DOE tools such as LIGHTEnUP tool [1] to provide the impact of implementing emerging energy efficiency (EE) technologies in industrial sector. The following sections describe the tool development methodology, initial results of the analysis, and brief introduction to the tool and its visualization capabilities.

TOOL DEVELOPMENT METHODOLOGY

Development of the current of version of the IGATE-E tool consisted of collecting and querying multiple datasets for industrial related information, data filtering, statistical modeling, computations, and validating the results against published DOE's EIA-MECS data [2]. The tool performs multi-layer analysis and provides geospatial representations of different manufacturing sectors across the U.S as shown in Figure 1. The following subsections describe this functional flow diagram in details.

average peak demand, electrical energy consumption, and product sales. The SIC codes (NAICS codes) classify establishments by their primary activity [4]. Although, IGATE-E is an SIC based tool, linking old data on an SIC basis to new data on a NAICS basis is currently underway. As a matter of fact, data for more than two-thirds of all 4-digit SICs will be derivable from the NAICS system, either because the industry is not being changed (other than in code), or because new industries are being defined as subdivisions of old ones.

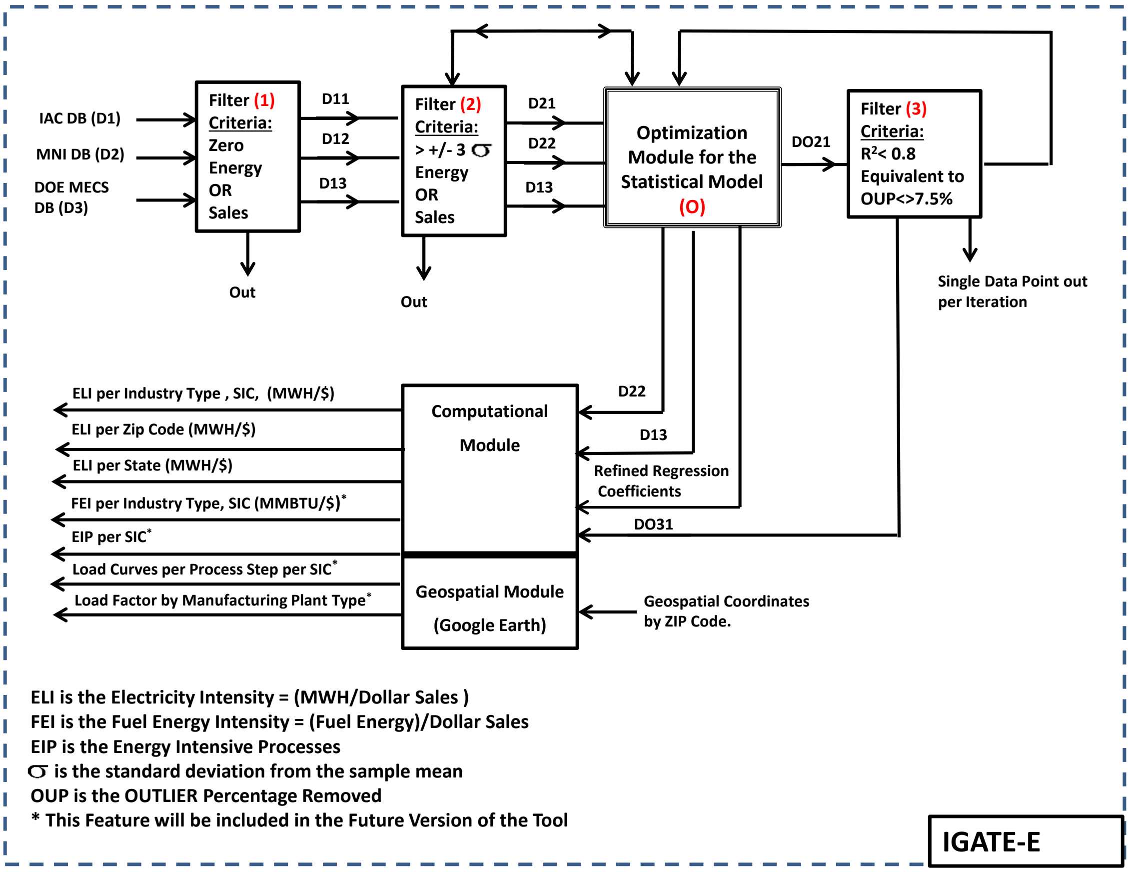

Figure 1. IGATE-E Flow Diagram

DATABASE QUERYING

As shown in Figure 1, the manufacturing plants energy information (mainly small to medium and large size plants) datasets from previous industrial assessments were pulled using publicly available IAC database [3] and Energy Saving Assessments data (ESA). Plant level energy information included industry types based on SIC (Standard Industrial Classification) and/or NAICS (North American Industry Classification System), energy systems, size of the plants in terms of square footage, number of staff employed, number of operating hours,

Table 1 shows major industry groups within both classification systems. The IAC Database is a collection of publicly available assessments and energy saving recommendations performed by student engineers seeking graduate degrees under supervision of tenured faculty professors at selective number of US universities. Currently, there are 24 IACs located at accredited Universities across the US. These IACs are funded by the US Department of Energy as a means to promote industrial energy efficiency.

Table 1. SIC and NAICS for Major Manufacturing Industry Groups [4]

SIC	Major Industry Group	NAICS	Major Industry Subsector
20	Food And Kindred Products	311	Food
21	Tobacco Products	3122	Tobacco
22	Textile Mill Products	314	Textile Product Mills
23	Apparel And Other Finished Products Made From Fabrics And Similar Materials	315	Apparel
24	Lumber And Wood Products, Except Furniture	316	Leather and Allied Products
25	Furniture And Fixtures	321	Wood Products
26	Paper And Allied Products	322	Paper
27	Printing, Publishing, And Allied Industries	323	Printing and Related Support
28	Chemicals And Allied Products	324	Petroleum and Coal Products
29	Petroleum Refining And Related Industries	325	Chemicals
30	Rubber And Miscellaneous Plastics Products	326	Plastics and Rubber Products
31	Leather And Leather Products	327	Nonmetallic Mineral Products
32	Stone, Clay, Glass, And Concrete Products	331	Primary Metals
33	Primary Metal Industries	332	Fabricated Metal Products
34	Fabricated Metal Products, Except Machinery And Transportation Equipment	333	Machinery
35	Industrial And Commercial Machinery And Computer Equipment	334	Computer and Electronic Products
36	Electronic And Other Electrical Equipment And Components, Except Computer Equipment	335	Electrical Equip., Appliances, and Components
37	Transportation Equipment	336	Transportation Equipment
38	Measuring, Analyzing, And Controlling Instruments.	337	Furniture and Related Products
39	Miscellaneous Manufacturing Industries	339	Miscellaneous

The information contained within these assessments includes size, industry, energy usage, etc. in addition to details of energy saving opportunities (recommendations) such as type, energy and cost savings, and payback period. As of February, 2013, the IAC database contained 15,803 industrial energy assessments and 118,719 recommendations identified in various energy system areas such as HVAC, Steam, Process Heating, and Motor Driven systems [IAC]. The information of particular interest within the IAC Database consisted of reported plant annual electrical energy consumption, plant average peak demand, product sales, and the industry code. Figure 2 shows the represented industrial sectors captured by the IAC assessments. This chart provides an indication of the potential accuracy in the regression analysis. It is worth mentioning that the IAC-DB is regularly updated as new assessments are completed and added to the IAC-DB. Certainly, this should enhance the quality of regressions and curve fit for some industrial sectors in the future.

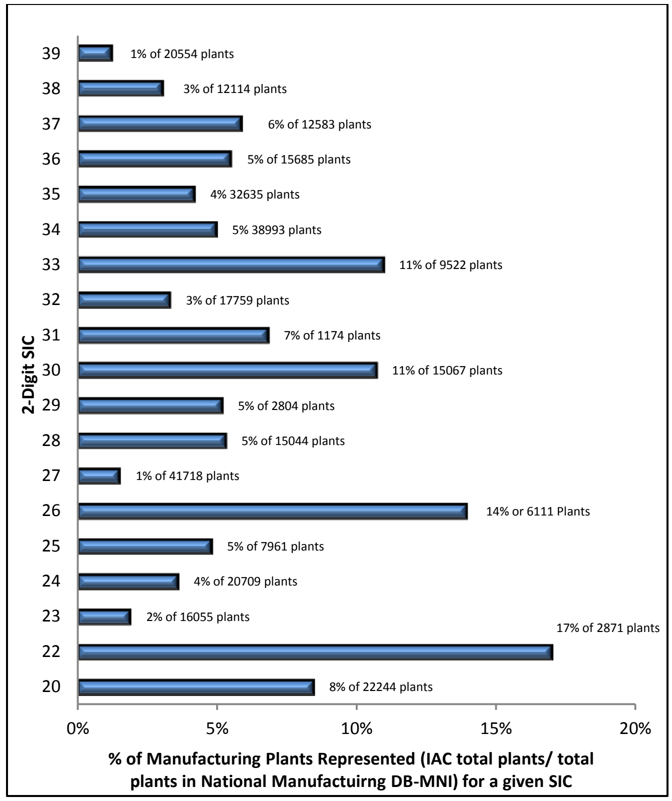

Figure 2. Percent of IAC Plants Modeled at the 2-Digit SIC Level

Manufacturing News, Inc Database (MNI) is a commercially available database which houses over 300,000 manufacturing plants entries [5] and matches the official count by the US Census Bureau. The MNI database contains information on specific companies such as SIC (NAICS), plant name, type of products, product sales figures, zip code, mailing address, and company contacts. This information was gathered by MNI through phone calls and direct interviews with plants and companies personnel. EIA's 2006 Manufacturing Energy Consumption Survey (MECS - 2006) is a publicly available data on industry energy consumption. EIA's MECS 2006 data contain estimates of the number of establishments, average energy consumption by industry code and average energy costs by key industry code [2].

DATA FILTERING PROCESS

Rigorous filtering processes of the data streams from the 3 primary databases used (IAC, MNI, and EIA-MECS) were performed to eliminate potential outliers and enable regression models that are more representative of the actual data as shown in Figure 1. It should be mentioned that data streams to IAC, MNI, and EIA-MECS were designated by 3 symbols; D1, D2, and D3. Figure 1 shows three filters involved in this process as follows: 1) unreported energy and or sales removal filter, 2) standard deviation filter, and 3) outlier data point removal filter (OUP). Upon exiting each filter, data streams were associated by the given filter number to indicate whether or not a refinement process was applied to a given data stream. For example, data stream D13, denotes data sets that were only refined by Filter (1) with no further refinements required afterwards. We started with Filter (1) where all SICs that contain unreported energy or sales information were automatically removed and revised data streams (D11, D12, and D13) were ready to enter Filter 2 which is the Standard Deviation Filter. In this case, we applied a (+/-) nσ of sales and electrical energy consumption, where nσ is the number of standard deviations as expressed by the following equations:

$$std\_lim \geq (y(i) - \overline{y})/std(y) \qquad \text{Equation (1)}$$
$$S(i) \geq 0 \qquad \text{Equation (2)}$$
$$E(i) \geq 0 \qquad \text{Equation (3)}$$

Where, *E* represents energy in MWh, *S* is the sales in dollars, and *y* is the data value (either sales or energy). An optimization module helped determining the value of the variable n to be 3. This represents the optimum number of standard deviation where least error deviation occurs as shown in Figure 3.

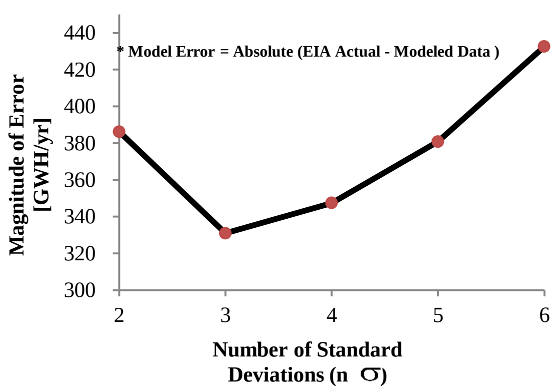

Figure 3. Magnitude of Model Error as a Function of Number of Standard Deviations from the Sample Mean

The optimization module is an iterative computational algorithm that optimizes the model accuracy by comparing the aggregate actual industrial electrical energy consumption in 50 states using published data from EIA-MECS DB (EIA Actual) with the aggregated modeled industrial energy consumption in the same states using IAC and MNI databases to filter out data points that generate higher error. As shown, model error is at its lowest when n = 3.

Filter (3) was applied to remove certain percentage of problematic data that may affect the goodness of the model fit as represented by the R^2 value (The coefficient of determination), Figure 4.

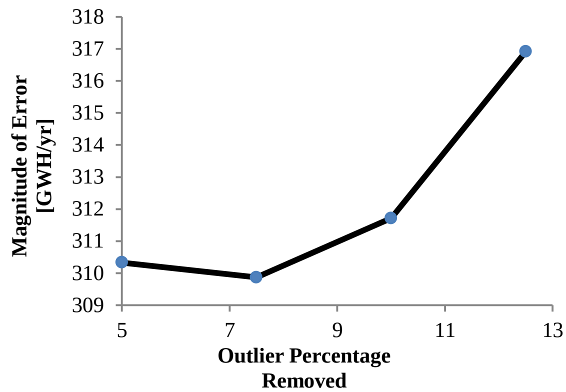

Figure 4. Magnitude of Model Error as a Function of the Outliers Removed (Percent of the Total Number of Data Points)

The outlier data points (OUP) were examined for removal. The strategy for this technique involved iteratively performing the linear regression with a single data point removed, examining the impact on R^2 value and taking the resulting highest R^2 value. For this analysis, we considered a threshold limit for R^2 of 0.8 or higher as acceptable (Reference). Then, a correlation between R^2 values and percentage of outlier data points removed (OUP) was established. Using the same optimization module explained above, it was found that at 7.2% of removed OUP, the model error is minimized.

It should be mentioned that the absolute magnitude of deviation in GWH/yr shown in Figure 3 and 4 is attributed to several factors including the number of represented industries in the EIA-MECS database as many industries may opt out of reporting their electrical energy consumption, hence some gaps in the data may exist. In addition, the quality of regressions may be impacted by shortage of data points in certain industrial sectors as shown in Figure 2. In this case these data points were eliminated yielding to loosing certain representation of these sectors in the analysis. Nevertheless, the data presented in this study remains the most comprehensive and publicly available information at this point.

STATISTICAL MODEL DEVELOPMENT

Linear regression was used to develop relationships between sales and electrical energy consumption of different manufacturing industries at the 4-Digit SIC. Correlations were examined between electrical energy consumption and square footage, number of employees, number of operating hours but gaps in the available datasets limited predictive power. Linear regression is an approach for modeling the relationship between a scalar dependent variable *y* and one or more explanatory variables denoted x. The equation for this relationship is given as [6]:

$$y = \beta_0 + \beta_1 x + \varepsilon \qquad \text{Equation (4)}$$

Where, β_1 represents the slope of the regression line (MWH/Sales), β_0 is the intercept and ε the error associated with the observations. In many cases, the error between the data and linear relationship is minimized through the sum of the squared residuals or least squares. The regression coefficients are solved directly using the following equations:

$$\beta_1 = \left(\sum xy - \left(\sum x \sum y / n1\right)\right) / \left(\sum x^2 - \left(\sum x\right)^2 / n1\right) \qquad \text{Equation (5)}$$

And

$$\beta_0 = \left(\sum y / n1 - \beta_1 \sum x / n1\right) \qquad \text{Equation (6)}$$

Where n1 represents number of data points. In some cases, outliers can exist and can cause the regression coefficients (β_1 and β_0) to have misleading values. The coefficient of determination known as R^2 can be used to provide a measure of how well future outcomes are likely to be predicted by the model. R^2 values range between 0 and 1, where 1 shows the best prediction capability. The R^2 value can be calculated as follows:

$$R^2 = 1 - \left(\sum (y_i - f_i)^2\right) / \left(\sum (y_i - \overline{y})^2\right) \qquad \text{Equation (7)}$$

Where, f_i represents the linear regression solution. The available information including sales and electrical energy consumption were obtained mainly from the IAC DB. This information was applied to the linear regression equation to derive relevant coefficient of regressions:

$$E(SIC) = \beta S(SIC) + S_0(SIC) \qquad \text{Equation (8)}$$

Where, *E* represents electrical energy of a given industry type in MWh, *S* is the product sales in a given industry type in dollars, and S_0 a constant determined by the regression analysis [7,8]. Higher resulting values of β indicate industries where electricity is important in the manufacturing of a given product. This will be explained in details in the results section of this paper. An example of the linear regression performed for the glass industry (SIC 3211) is shown in Figure 5.

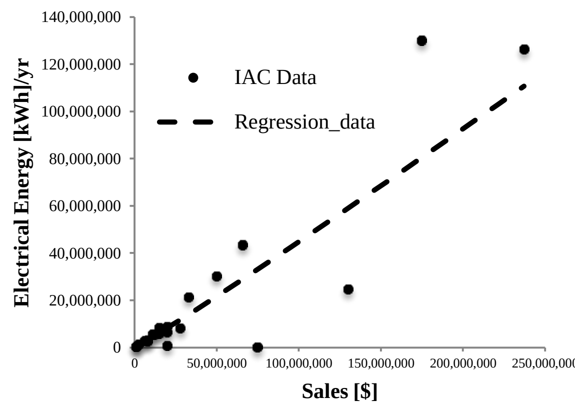

Figure 5. Regression Analysis on SIC 3211.

The derived coefficients of regression for each type of industry as represented by SIC code (captured from IAC DB) were applied to the corresponding SIC in the MNI database where the sales information of each manufacturing plant is utilized to predict the plant level electrical energy consumption associated with this given SIC across the U.S. industrial sector.

ELECTRICITY INTENSITY (ELI)

The statistical model developed resulted in a metric that we will be using from this point forward. This metric is the Electricity Intensity (ELI). ELI is defined as electrical energy use in MWh per product sales in dollar, MWh/$. Product sales represent the value added to a given manufacturing facility. The greater the value of the ELI the more important the electricity as an energy stream to a given industrial sector.

USER INTERFACE

The IGATE-E was developed in a MATLAB platform and provides user-friendly interfaces to examine the various results of the statistical models. The current version of the tool consists of two main modules; electrical energy analysis module and geospatial linking module. The details of one of the computational modules are shown in Figure 6. The Geospatial button enables the user to geospatially plot individual industries across the U.S. at zip code level and predicted electrical energy consumption

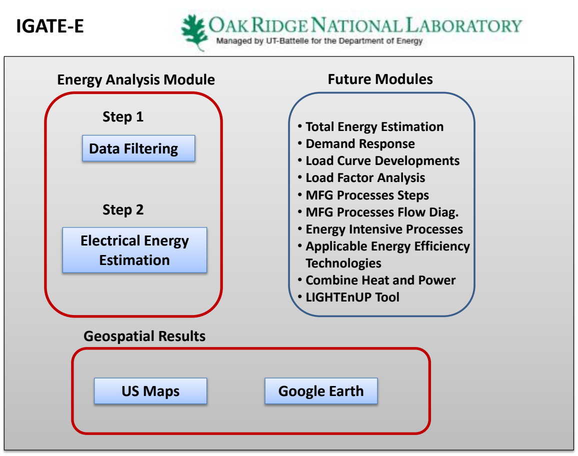

Figure 6. IGATE-E Main User Interface

The regression engine interface is shown in Figure 7. The stars represent actual data points of data stream D1 (IAC datasets), triangles represent the outliers, and the line represents the regression model for this data. Industries at both 2-digit SIC and 4-digit SIC are selectable for regression analysis.

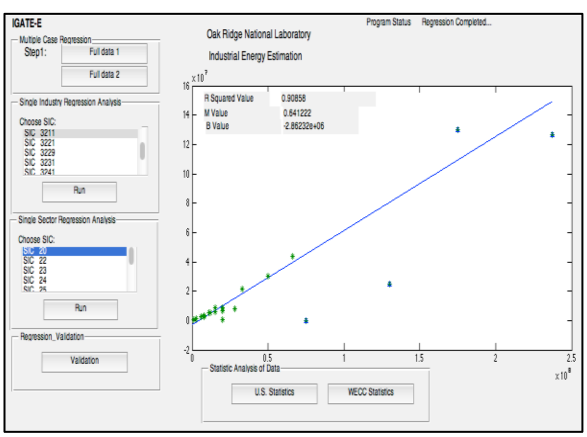

Figure 7. Regression Engine Interface

Selecting 'Validation' provides the comparison against the statistics of industrial electricity consumption provided by the EIA-MECS DB. Selecting 'U.S. Statistics' undertake a deeper examination of the information across the U.S. including industry count by state and estimated electrical energy consumption by sector for each state.

ANALYSIS OF PRELIMINARY RESULTS

Current version of the tool provides multi-layer industrial energy information at different levels of granularity including; manufacturing plant level, zip code level, county level, regional level, state level, and national level. In the following, we will present few examples and a case study.

LAYER 1 – INDUSTRIAL ENERGY INFORMATION BY MAJOR INDUSTRY GROUP (2-DIGIT SIC)

The industrial sector is highly heterogeneous, with nine major industry groups (also referred to as sectors) representing over 400 types of manufacturing industries within the four-digit SIC system [9]. To determine major industry groups where electricity is significant in the manufacturing of products, the 2-digit SIC major industrial groups were first examined

Figure 8 shows the electricity intensity (ELI) in kWh per product sales in dollars for the 9 major industry groups and the electricity consumption as a function of product sales respectively.

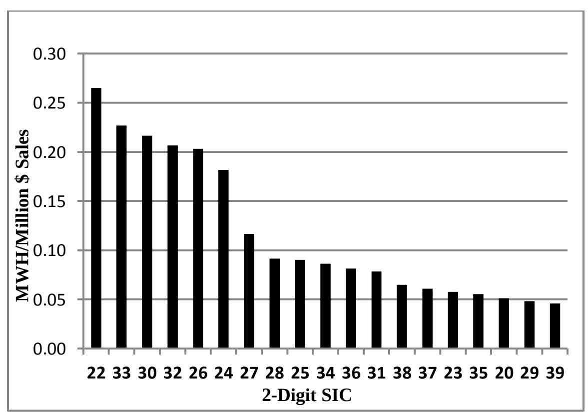

Figure 8. IGATE-E Model Results for All Manufacturing Sectors (SIC 20-39) Electricity Intensity (ELI)

The highest electricity intensities within these major industry groups are also represented by the highest bars as shown in Figure 8 and highest slopes as shown in Figure 9, below. The top three electricity intensive industrial sectors were Textile Mill Products (SIC 22), Primary Metal Industries (SIC 33) and Rubber and

Miscellaneous Plastics Products (SIC 30). In Textile industry, electricity is a common power source for machinery such as winding/spinning, weaving, water pumps, dryers, cooling and temperature control systems. Primary metal industry (iron, steel, and non-ferrous metals) is in top three because of the intensive use of electric arc furnaces, induction furnaces, electrolysis, etc. Rubber and Plastic, mixing, extruders, and mills are electricity intensive equipment in tire manufacturing. Mixing, laminating, injection molding, blow molding, extrusion molding, all these operations consume significant amounts of electricity.

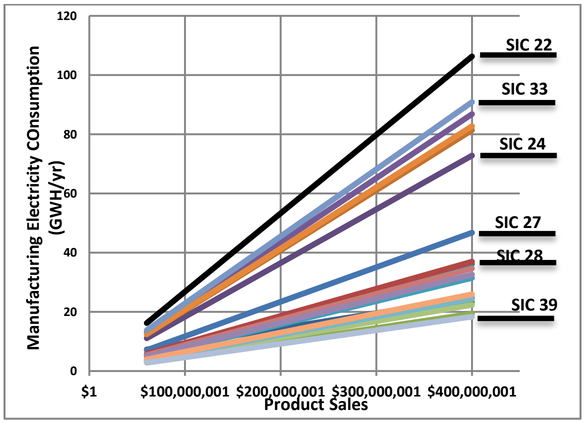

Figure 9. Electricity Consumption versus product sales in Dollar

Interestingly enough, known electricity intensive industries such as Computer and Electronics (SIC 36) didn't make it for the above top list. The reason is that the focus in this analysis is on the combined effect of electricity consumption and product sales. It appears that in the case of textile, the product sales value are not as significant compared to Computer and Electronics product sales value. This can also give an idea on the importance of electricity to industries like Textile, Primary Metals, and Rubber. The above chart suggests that a slight change in sales can have a major impact on ELI.

LAYER 2 – INDUSTRIAL ENERGY INFORMATION BY SPECIFIC INDUSTRY (4-DIGIT SIC)

Layer 1 of the analysis provided good information on the major industry sectors where the combined effect of electricity and product sales is significant. However, the energy analyst may need to get more information on specific type of industries within these sectors to perform more detailed analysis at the process level within each of these industries. Layer 2 of the analysis returns this important information. Figure 10 suggests that the top 3 electricity intensive industries in the Textile Sector are SIC 2284; Thread Mills, SIC 2210; Broad woven Fabric Mills, Cotton, and SIC 2298; Cordage and Twine (hemp rope made in spinning mills).

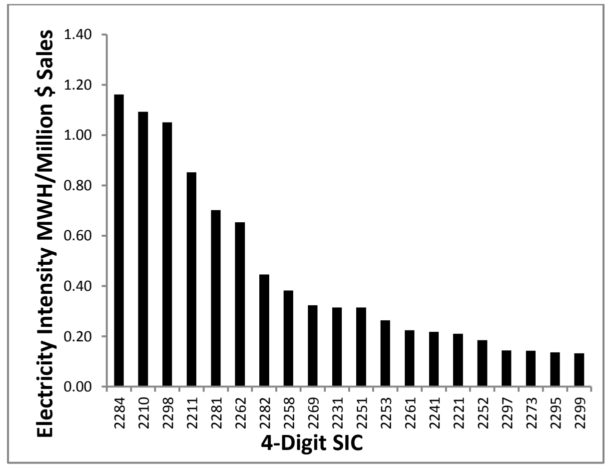

Figure 10. SIC 2210-2299 (All Textile Mill Industries) Electrical Energy Intensity.

This analysis is important in spotting industries that are more likely to play a role in energy efficiency measures and demand response programs as reducing the cost of electricity plays a significant role in profits. This also provides plant managers the ability to gauge their plants performance within their SIC bracket. Figure 11 shows representative sample of textile industries, due to limited space in this chart, we didn't include the full textile industries.

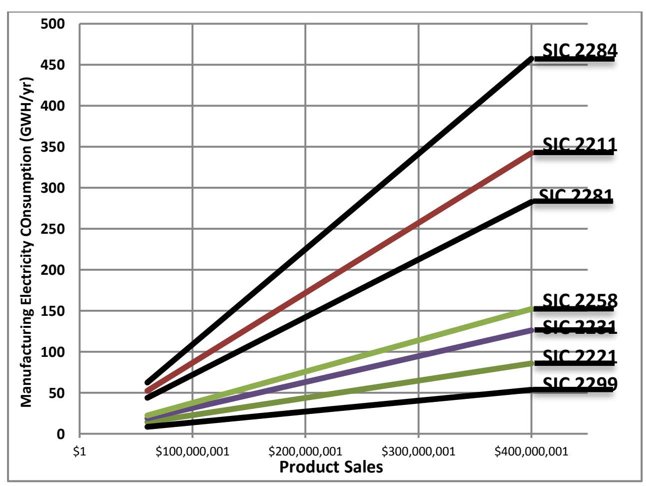

Figure 11. SIC 2210-2299 (Sample Textile Mill Industries) Electrical Energy Consumption as a Function of Products Sales.

The slope in this chart represents the electricity intensity in MWH per product sales. Steep slopes reflect electricity intensive industries in a given sector.

CASE STUDY

Let's examine IGATE-E using a case study where the modeled industrial electrical energy consumptions at the state level were compared to those published by DOE's EIA-MECS. Then, we will examine the graphical interface of the tool by demonstrating the geospatial linking of some manufacturing plants (represented by SICs) using appropriate Zip code to GPS coordinates at each manufacturing plant's location in the US.

a. Validation against DOE's EIA-MECS Published Data

IGATE-E statistical module was used to apply data from IAC DB to the population of manufacturing plants (300,000+) in the MNI DB and compared with the industrial electricity consumption state level data from the DOE's EIA-MECS as shown in Figure 12.

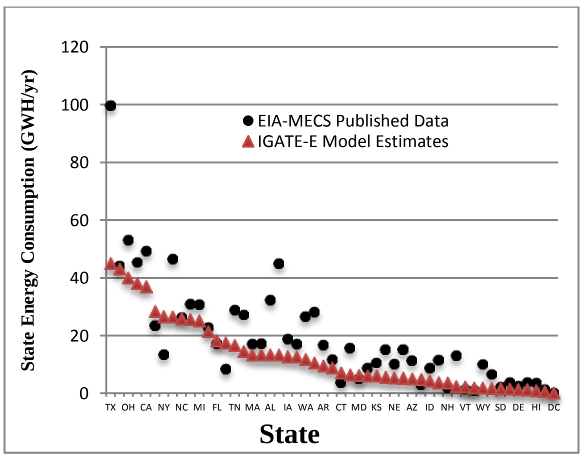

Figure 12. Comparison of Modeled Electrical Energy Versus EIA-MECS Published Data (Bottom up Approach).

This chart includes all 50 states, but there is limited space for labeling. As can be seen, the fitted data from the statistical module in most of the cases correlates well with the EIA-MECS published data for the 50 states. Likely, the deviations will tighten up as more information becomes available for the IGATE-E model. It should be mentioned that the IAC-DB, one of the main data sources for this study is updated on a frequent basis. This will definitely improve the quality of regressions and curve fit for some industrial sectors and the overall validation process.

b. **Geospatial Linkage**

The mailing addresses for the plants provide zip codes which are directly linked to the plant's geospatial coordinates. When linked to the manufacturing plant level energy information each plant was mapped and relevant information were displayed to US Map or Google earth as shown in Figures 13 and 14.

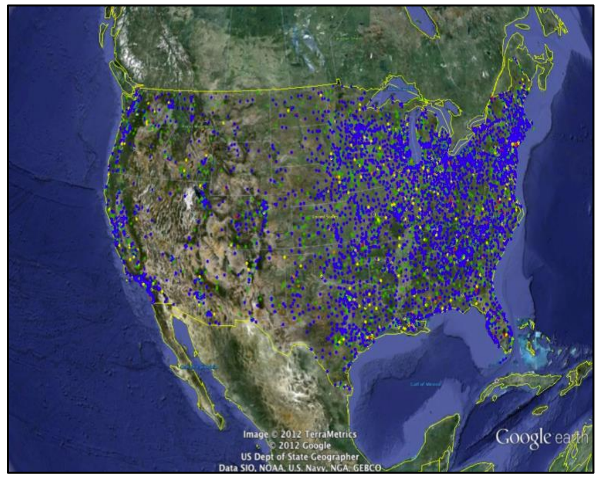

Figure 13. Geospatial Representation of Some Industries in Google Earth.

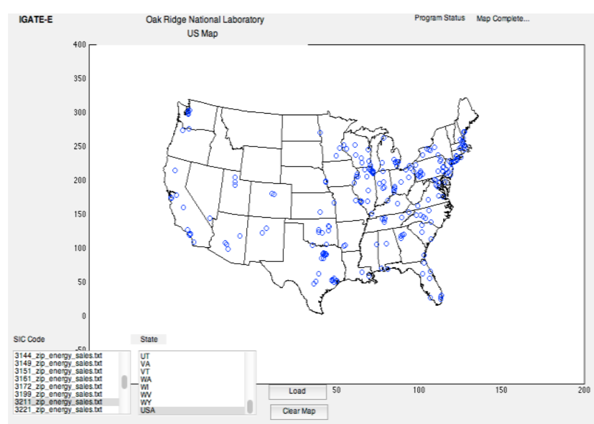

Figure 14. Geospatial Representation of Flat Glass Plants (SIC 3211) in US Map using MATLAB Mapping Function.

CONCLUSION

We developed a framework "IGATE-E" tool to utilize the available wealth of information in the publicly available datasets to provide a reasonable estimate of manufacturing electrical energy consumption at multiple levels of details and with minimal input information. The data input to the tool can be as little as a zip code or an SIC code of an industrial plant but the data output is numerous and can include information such as electric energy intensity (MWH/$) per industry type and per zip code at the state and nationwide levels. Future versions of the tool will augment several modules such as manufacturing processes steps, energy intensive processes, applicable energy efficiency technologies, combine heat and power, to provide detailed analysis on indices of interest such as CHP capabilities across manufacturing sector, available low grade waste heat per industry type and per Region. All this info is provided at the geo-spatial resolution.

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Plant Energy Benchmarking: A Ten Year Retrospective of the ENERGY STAR Energy Performance Indicators (ES-EPI) [1]

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ABSTRACT

Over the past several years, there has been growing interest among policy makers and others in the role that benchmarking industrial energy efficiency can play in climate, air, and other potential regulatory actives. For over ten years, the US EPA has supported the development of sector specific industrial energy efficiency benchmarks, known as ENERGY STAR Energy Performance Indicators (ES-EPI). To date there are ES-EPI that are either completed or under development for fourteen broad industries. Within these industries, ES-EPI account for over two dozen sub-sectors and many more detailed product types. Newer versions, or "updates" for three of the industries' ES-EPI have been developed in recent years. Through the process of updating this ES-EPI, the program has been able to observe changes in the energy performance of the sector as well as the range in performance found in the sector. This paper provides an overview of the approach that has been used in this research to develop this ES-EPI; summarizing the industry specific and general findings regarding the range of performance within and across industries. Observations about industrial plant benchmarking and lessons learned will be explored. In general, there are no sectors that are easily represented by a simple "energy per widget" benchmark; less energy intensive sectors tend to exhibit a wider range of performance than energy intensive ones; changes over time in the level and range of energy performance, i.e. "industry curve shift", for ES-EPI that have been updated do not reveal any single pattern.

Introduction

ENERGY STAR is a voluntary program launched by the EPA in 1992 to identify and promote energy efficient products[2]. Since its inception it has partnered with more than 23,000 organizations. In 2003, the EPA expanded the program to encompass energy performance beyond products to include the manufacturing plants that produce them. The goal of ENERGY STAR for Industry is to identify and promote energy efficient *plants* in order to encourage better corporate energy management. In order to identify energy efficient plants, ENERGY STAR has supported the development of a suite of sector specific, intra-industry benchmarking tools called the ENERGY STAR Energy Performance Indicator (ES-EPI). The ES-EPI computes an Energy

[1] This paper was developed at Duke University with funding from the U.S. Environmental Protection Agency's Office of Atmospheric Programs, ENERGY STAR for Industry. The paper and associated analysis would not have been possible without the input of all the industry participants in the ENERGY STAR Focuses on Energy Efficiency. Their willingness to provide data, guidance on important issues affecting manufacturing energy use, and time and energy in testing the models was invaluable. Some results in this paper were prepared while the author was a special sworn status research associate at the Triangle Census Research Data Center. Any opinions and conclusions expressed herein are those of the author and do not necessarily represent the views of the U.S. Census Bureau. All results have been reviewed to ensure that no confidential information is disclosed. Any errors are the sole responsibility of the author.

[2] See EPA (2011) for more information.

Performance Score (EPS) that ranks the specific plant on a percentile scale (1-100) based in individual product, material, and location characteristics that impact energy use.

Defining Energy Efficiency[3]

Efficiency is a measure of relative performance; but relative to what? Defining energy efficiency requires a choice of a reference point against which to compare energy use. The difference between the observed level and potential level of performance has been called the "efficiency gap." (Jaffe and Stavins 1994) discuss a range of concepts from which to define "potential," including economic, technical, social and hypothetical. They also explore the various market and non-market reasons why there is an efficiency gap, regardless of how potential is defined. The first market failure they identify that leads to an efficiency gap is lack of information. It is the lack of information regarding economic potential for lower energy use that is the focus here. In other words, we are interested in *measuring economic potential based on observed practice*, which is by definition economically feasible. By providing this information we hope to lower the barrier to more widespread adoption of economic potential for lower energy use.

The reference point for economic potential (observed practice) depends, in part, on the reason for measuring efficiency as well at the available information to create a reference. Generally, the *Ceteris Paribus* principle ("all other things being equal or held constant") is usually desired in creating the reference point, or benchmark. From a practical perspective there is a hierarchy of measures and methods by which one can "hold constant" things that influence *energy use* that are not part of *energy efficiency.* The first is some measure of production activity, either production itself or alternatively a ubiquitous input into the production process. This is most commonly done by computing the ratio of energy use to activity, a measure of energy intensity. Energy intensity is a common metric that controls for changes in production and is commonly confused with energy efficiency, as in the statement "*the industry or plant's energy efficiency has improved based on the fact that the corresponding energy intensity has declined over time.*" This type of statement brings us to the second way that one may approach the ceteris paribus principle for measuring efficiency, comparing energy intensity a particular plant, firm, or industry to itself over time. This approach is a plant (firm, etc.)[4] specific *baseline* comparison, or *intra-plant* efficiency benchmark. Baselines have the advantage of controlling for some plant specific conditions that do not change during the comparison period. The next level of this ceteris paribus principle is an *inter-plant* comparison that may include a variety of factors that influence energy use, but may not be viewed as efficiency. Factors may include difference in the types of product and materials used, as well as location specific conditions. Intra-plant comparisons within an industry also get us closer to the notion of an observed best-practice benchmark of economic energy efficiency, since by definition there is some group of plants that are the best performers. The next section focuses on the first and third of these notions, single factor intensity and multi factor benchmarks.

[3] This section draws from Boyd, G. (2012). A Statistical Approach to Plant-Level Energy Benchmarks and Baselines: The Energy Star Manufacturing-Plant Energy Performance Indicator. Carbon Management Technology Conference. Orlando, Florida USA.

[4] Throughout the paper we will refer to the plant level as the unit of observation, but the concept may also apply to more aggregate levels like firms and industries, an sometimes to less aggregate levels like process units.

Intensity To measure intensity you need a measure of energy and something for the denominator. (Murray G 1996) raise issues about both the numerator and dominator. For the numerator in our case we use total source purchased energy, defined as the net Btu total of the fuels (Btu) and electricity (Kwh) with electricity converted to Btu based on the level of efficiency of the U.S. grid for delivered energy, i.e. including generation and transmission losses. A net measure is needed for when energy is transferred off site, most commonly in the form of steam or electricity. This measure does not try to account for internally generated fuels directly, but treats the ability to use by-products as a form of relative efficiency.

The choice of the denominator is a major issue for measuring intensity. (Freeman, Niefer et al. 1997) show that industry level trends in energy intensity based on value, both total and value added, can differ dramatically from those based on physical quantities. At the simplest level value it simply price times physical quantity so price movements account for these differences. Freeman et al observe

> *"For an industry producing a single, well-defined, homogeneous good, it is relatively easy to construct an accurate price index. Most industries, however, produce many poorly-defined, heterogeneous goods. For a variety of reasons, the more diverse the slate of products produced by an industry, the more difficult it becomes to construct an accurate price index. …the accuracy of industrial price indexes is of extreme importance to industrial energy analysts and policy makers who use value-based indicators of energy intensity."*

Out of 450 Census 4-digit Standard Industrial Classifications (SIC) Freeman et al analyze physical output data for only 14. This choice may be driven by the available data, but is in part based on the diverse types of production that may be included within the Census classifications. For physical production to be meaningful it needs to be at a high level of industry specificity. For example, the "Dairy" industry produces many products that could not be aggregated, but "Fluid Milk" might.

Multi-Factor Benchmarks Comparing plants within an industry are one approach to assessing economic potential. By definition at least one plant in the industry represents the observed "best practice". This was the notion introduced by (Farrell 1957) and has been the basis for measuring production efficiency in economics. A modified approach has been adopted by Energy Star (Boyd 2005) and its evolution is discussed by (Boyd, Dutrow et al. 2008). The difficulty with applying an industry level inter-plant benchmark is controlling for inter-plant difference other than production volume. While the things that differ between plants are numerous, we have found that the primary difference that have the most impact on energy fall into the following categories.

- Product mix
- Process inputs
- Size - Physical or productive capacity and utilization rates
- Climate (and other location specific factors)

The most obvious economic influence "missing" from the above list is price. The relative price of energy and the cost of capital are critical to economic decisions regarding the implementation of energy using (saving) technologies. Labor costs may also influence decisions on whether personnel are dedicated to the management of energy. We only examine production related factors in developing the inter-plant benchmark, i.e. take a production rather than cost approach to efficiency. This does ignore differences between plants that arise from difference in the aforementioned prices. We mitigate this somewhat by only considering plants located in the US (controlling for the larger global variation in prices that are often due to energy taxation) and for short time periods when prices are relatively stable. We also avoid the more difficult question about what is the "correct" cost of capital. Plants may internally apply different costs of capital due to the financial conditions of the firm (i.e. those based on external capital markets) and the practices of internal capital budgeting, which may include capital rationing and setting hurdle rates. Jaffe and Stavins make several distinctions between different definitions of economic potential, one of which assumes that practices of capital budgeting do not bind the technology choices, i.e. those decisions are based solely on market returns. However, observed practice may include practices like capital rationing. From that perspective the benchmark we develop is *feasible* based on observed practice, including the possibility of rationing relative to industry specific practices, but does not accounting for regional variability in energy prices.

The EPI uses a multivariate approach to normalization where multiple effects are simultaneously considered (Boyd and Tunnessen 2007). The next sections discussed the four basic categories of effects that are commonly considered. There is further elaboration on the way this is implemented the section on industry specific comparisons.

Product Mix Energy is the derived demand for energy services used in support of various manufacturing processes. The results of these processes are various intermediate and final products produced by the plant. It is common to evaluate the efficiency of energy use in terms of the intensity of energy input relative to a desired energy services (e.g. per lb of compressed air), relative to a particular intermediate process (e.g. per lb of crushed limestone), or relative to the final product of the plants (e.g. per ton of finished cement shipped). Each of the energy services or intermediate processes contributes to the overall energy use, hence energy efficiency, of the entire manufacturing plant. However, not all plants produce exactly the same product. In fact, many plants themselves produce multiple products. The diversity between plants gives rise to a mix of derived demands for specific processes and energy services. To the extent that the final product is the results of a series of energy using steps the energy use of the plant will depend on the level and mix of products produced. Rather than specifying each process step individually, the approach used here is to identify those products that use significantly more (or less) energy and measure those energy requirements with a statistical comparison.

One approach to controlling for product mix is to segment the industry into chohorts based on product categories. This works best when there is no overlap between plants that produce the various basic products and there are sufficient numbers of plants to conduct the statistical comparison between those resulting groups. This means each sub-group is effectively treated as a separate industry for evaluation proposes. When such natural sub sectors do not exist and multiple products are produced within a plant, additional approaches are needed. The statistical approach used by ENERGY STAR is well suited to testing if a particular grouping of products is appropriate for benchmarking differences in energy. Other industries like pharmaceuticals or autos that also have a diverse range of products may be treated differently for benchmarking.

Physical Size Size and utilization rates may directly impact energy use. Size may impact specific engineering and managerial advantages to energy use. If there is a substantial "fixed" level of energy use in the short run, the utilization rates may have a non-linear impact on energy intensity. In order to include size (and utilization) as a normalizing factor in the EPI a meaningful measure of size or capacity is needed. It may be measured on an input basis, output basis, or physical size. In some cases there may be advantages to larger scale of production. If it is the case that a larger production capacity or larger physical plant size has less than proportionate requirements for energy consumption then there are economies of scale with respect to energy use.

Process Inputs There are three ways that process inputs are important for benchmarking. The first is that inputs like materials, labor, or production hours may be good proxy measures of overall production activity when measures of production output are not available or have specific shortcomings[5]. The second is in the identification for upstream (vertical) integration, i.e. whether a plant makes an intermediate product or purchases some pre-processed input. This is an important "boundary" issue for the energy footprint of a plant, even when two plants produce identical outputs. The third way is a variation of the second, relating to material "quality." If there are alternative input choices that differ qualitatively and also with respect to energy use then input quality measures can be introduced into the benchmark.

The first way process inputs can be helpful in developing a statistical benchmark of energy use is that inputs like materials, labor, or production hours may be good proxy measures of overall production activity when measures of production output are not available or have specific shortcomings. If a physical measure of output is not readily available and pricing makes the value of shipments a questionable measure of production then physical inputs can be a useful proxy. For some industries the basic material input is so ubiquitous that it makes sense to view energy use per unit of basic input rather than (diverse) outputs. Process inputs may also be useful in measuring utilization, either directly or indirectly.

Sometimes physical production data is lacking in some way but material flows can be used instead. For example, sand, lime, soda ash, and cullet (scrap glass) are the primary inputs to glass manufacturing. Since the Census only collects data on the value of glass shipped these basic materials provide a good control for the level of physical production at a glass plant.

When levels of materials or outputs are not measured in common units and value units may introduce other problems, production labor rates may also control for differences in production activity between plants and differences in utilization rates within plants. While the link between energy and labor is not as direct as energy and production, the fact that it takes both labor and energy to manufacture a product allows an indirect link to be estimated. One advantage is that labor hours can provide a common denominator in terms of measurement.

The second way that process inputs are important for inter-plant benchmarking is when vertical integration is common in a sector. Industries are categorized by the products they produce, but some sectors may face a "make or buy" decision in the way they organize production. A plant may purchase an intermediate product or produce it at the plant as part of a vertically integrated plant. For example, an auto assembly plant may stamp body panels or ship them in from a separate facility. The energy use of these two facilities is not directly comparable. The inter-plant benchmarking approach must account for those "make or buy" decisions in the specific plant configurations.

The third way that process inputs are important for inter-plant benchmarking is when differences in material quality may also be related to energy use. For example, if the materials mix to produce a product directly impacts energy uses, then the statistical model can apply different weights to the materials mix in the same manner that it does with product mix. In other words, product/process level differences in energy use can be inferred from the volume and types

[5] As discuss in Freeman, et al (1997)

of materials used in production. To be considered in the statistical normalization, they must be measured on a consistent plant-level basis across the industry. For cement plants the hardness and moisture content of the limestone is hypothesized to influence energy use, but no consistent data is available for this, leaving it the subject of future analysis if data can be collected.

Climate and other location specific factors There are many things under the control of a plant or energy manager, but one they cannot control is "the weather." In most manufacturing plants heating, ventilation and cooling (HVAC) contributes to energy demand and weather determines how much is required to maintain comfort. Since the benchmarking approach used here is annual, seasonal variation does not enter into the analysis, but differences due to the location of a plant and annual variation from the locations norm will play a role. The approach that has been taken for all sectors under study is to include heating and cooling degree days (HDD and CDD) into the analysis to determine how much these location driven differences in "weather" impact energy use.

In principle all plant have some part of energy use that is HVAC related, but when the HVAC component of energy use is small relative to total plant consumption the statistical approach may not be able to measure the effect accurately enough to meet tests for reliability. Other location dependent impacts can be included, or at least tested, using the statistical approach. As part of the focus review process the altitude was proposed as having an effect on cement kiln energy use, because of combustion oxygen differences. The altitude was included in the analysis of the cement energy data, but no statistically significant effect was found. This type of hypothesis testing that the statistical approach allows provide for a dialogue between the researchers and the industry participants to understand the drivers of energy use in the various sectors.

Detailed Overview of the ES-EPI tools

Drawing from the general approach above, Table 1 summarizes the factors that have been included in each EPI to explain difference in inter-plant energy use. It is clear that each industry is unique in the characteristics that "matter" for benchmarking. About half of the sectors have been finalized by EPA and the rest are under review. Twenty use some type of physical units for activity; of those, 18 have 2 to 5 different sub-product types or use some other information to further characterize product differences, i.e. price or size. Some measure of plant size and utilization is included in 5, but the small number is due more to data limitations, i.e. available plant level capacity information. Person or operation hours are included in 8 industries. In some cases the labor hours *may* be playing a similar role to utilization, i.e. capturing non-production activity that uses energy. About half of the sectors include process inputs, either as a ubiquitous measure of input, e.g. corn in corn refining or scrap in minimills, or in the form of raw vs. preprocessed inputs, e.g. fresh fruit vs concentrate in Juice production or virgin vs. recycled fiber in paper production. The selection of inputs is based in part on data availability, but then only included when the estimated effect is of reasonable size and statistically significant.

Table 2 further describes the statistical form of the models. Seven sectors exhibit a skewed distribution of energy intensity and are modeled as stochastic frontiers; the rest are best approximated as log normal, i.e. the percentage difference from average performance are "bell shaped." The earliest benchmark year is 2002. This is largely driven by the data available when the analysis was conducted. 2007 is the most recently available data from Census. Sectors that use industry or trade association provided data tend to have more recent benchmark years. For the less energy intensive industries using Census of Manufacturing (CM) data, the energy content of the fuels is imputed using cost data and state level energy prices. This is done since the sample sizes in the Manufacturing Energy Consumption Survey (MECS) are too small. For industries with larger MECS samples the more detailed energy information is used directly. Sample sized vary depending on the industry, although these sample sizes should be viewed as a complete count of all the plants. Some data is dropped due to incomplete reporting or other “data quality screens” such as for extreme outliers.

The last column labeled 75 to 50th represents the third quartile range, i.e. percent difference of the 75th percentile, i.e. the ENERGY STAR certified plant level, and the average or median performance, the 50th percentile. This ranges from as low as 6% to nearly 44%. Figure one compares this third quartile range to the industry average share of energy cost to value added. This cost share reflects how “important” energy is in the sector. We see a clear correlation between high cost shares and the range of performance. This makes sense since industries with higher relative energy costs would put more effort into management of those costs. There are outliers in this relationship, however. They include pulp mills and ethanol (dry mill) plants. The latter is a preliminary estimate. The result for pulp mills may suggest the need for additional scrutiny. However, the EPI uses net purchased energy and pulp mills provide a large amount of internally generated power from black liquor and CHP. There may actually be a wide range of practices in terms of net purchased energy in this sector than for other energy intensive ones.

Table 1: ES-EPI Benchmarks Inputs, by Industry and Sub-Sector

Focus industries	Product mix	Units	Inputs	Size or capacity	External	Other
Cement (V 2.0)	3 product types	Tons	-	Capacity & # of Kilns	Utilization	Person hours
Corn Refining (V 2.0)	5 product types	Bushels	Corn	Capacity	Utilization	Feed moisture
Dairy - Fluid Milk *	6 product types	Gallons	Whole milk	-	Weather TBD	Person hours
Dairy - Ice cream *	4 product types	Gallons	2 types	-	Weather TBD	Person hours
Ethyl Alcohol **	Single	Gallons	-	-	-	-
Food - Juice (Canned)	4 x 2 product types	Gallons	2 types	-	-	-
Food - Frozen Fried Potatoes	Single	lbs	-	-	-	Warehouse (frozen)
Food - Tomato products **	1 sub-product type		2 types	-	-	Person hours
Baking - Cookies & Crackers	3 product types	lbs	-	-	-	-
Baking - Bread & rolls *	5 Product types	$, other	Flour	-	Weather TBD	Person hours
Glass - Flat	-	lbs	Sand	-	-	-
Glass - Container	Price	lbs	Sand, Cullet	-	-	-
Iron and Steel - Integrated *	5 product/activities	tons	-	Furnace capacity	Utilization	-
Iron and Steel – Minimills *	Price	tons	Scrap	Furnace capacity	Utilization	-
Metal casting - Iron *	4 product types	Tons, other	-	-	Weather TBD	Person hours
Metal casting - Investment steel *	-	hours	-	-	Weather TBD	Person hours
Metal casting - "Other" steel *	3 product types	$	-	-	Weather TBD	-
Motor Vehicle V2.0	vehicle size	#	-	-	Weather, Utilization	Air Tempering
Pharmaceuticals	3 activity types *	%	-	Facility size (ft2)	Weather, Utilization	Operation hours
Printing - Lithograph *	6 product types	$	2x3 types	-	Weather TBD	-
Pulp Mills	3 product types *	tons	2 types	-	-	Water treatment
Paper & Board Integrated Mills	3 product types *	tons	3 types	-	-	Water treatment, bleaching chemicals
Ready Mix Concrete *	2 activities	Tons,miles	-	-	-	-

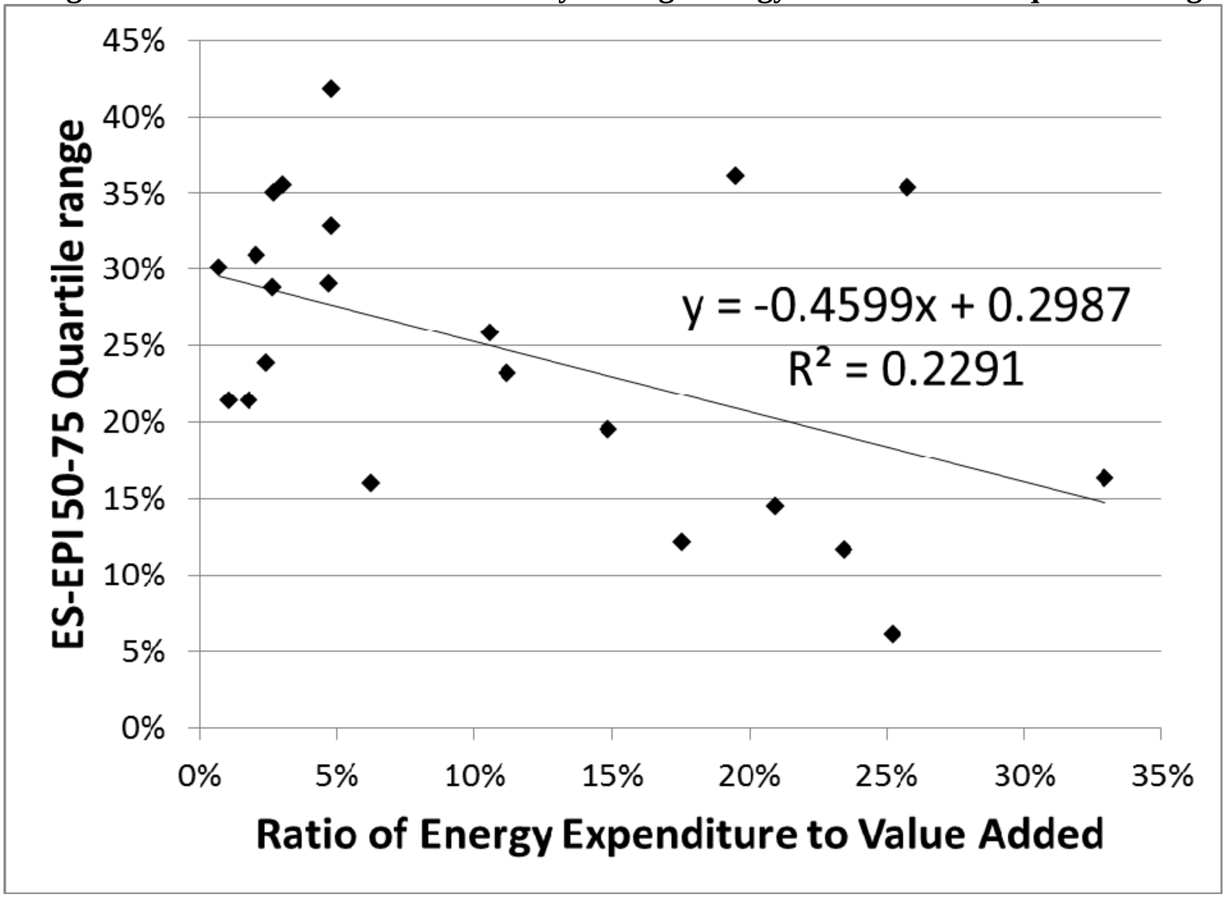
* Under Industry Review, ** Preliminary

Table 2: ES-EPI Benchmarks Model Details, by Industry and Sub-Sector

Focus industries	Model	Year	# of plants	Data source	75 to 50th
Cement (V 2.0)	log normal	2000-2008	96	PCA	-6.1%
Corn Refining (V 2.0)	half normal frontier	2004-2009	37	Industry	-14.5%
Dairy - Fluid Milk *	log normal	2002	258	CM	-29.0%
Dairy - Ice cream *	log normal	2002	89	CM	-23.9%
Ethyl Alcohol **	log normal	2007	111	CM	-35.4
Food - Juice (Canned)	log normal	2002	44	CM	-41.8%
Food - Frozen Fried Potatoes	log normal	2002	27	CM	-16.0%
Food - Tomato products **	log normal	2002	40	CM	-43.7%
Baking - Cookies & Crackers	log normal	2002	64	CM	-30.9%
Baking - Bread & rolls *	log normal	2007	207	CM	-28.8%
Glass – Flat	log half normal frontier	2002	38	CM, MECS	-16.3%
Glass - Container	log normal	2002	62	MECS	-11.6%
Iron and Steel - Integrated *	log half normal frontier	2005-2009	12	Industry	TBD
Iron and Steel – Minimills *	log normal	2002	39	CM, MECS	-12.1%
Metal casting - Iron *	log normal	2006	83	CM, MECS	-23.2%
Metal casting - Investment steel *	Exponential frontier	2007	51	CM	-32.8%
Metal casting - “Other” steel *	log normal	2007	59	CM	-25.8%
Motor Vehicle (V2.0)	Gamma frontier	2003-2005	33	Industry	-21.4%
Pharmaceuticals	log half normal frontier	2004-2006	61	Industry	-30.1%
Printing - Lithograph *	Log half normal	2007	775	CM	-35.0%
Pulp Mills	log normal	2002	28	CM, MECS	-36.1%
Paper & Board Integrated Mills	log normal	2002	99	CM, MECS	-19.5%
Ready Mix Concrete *	log normal	2008-2009	62	NRMCA	-35.5%

* Under Industry Review, ** Preliminary

Figure 1: Correlation between industry average energy share and 50-75 quartile range



Updates for benchmark year for three ES-EPI

In the 2010, EPA began a process of updating the benchmark year data for the first three ES-EPI that were officially released; Auto assembly, Cement, and Corn refining (see (Boyd 2005; Boyd 2006; Boyd 2008) for detailed descriptions of the earlier models). Comparing the old benchmark with the new benchmark reveals information about how these three, very different industries have changed over time. Since the ES-EPI analysis reveals both the general level and range of energy performance the comparison focuses on how much the change in the “best practice” and the change in the range of performance contribute to the overall reduction in energy use in the sector (see (Boyd and Zhang 2012), (Boyd and Delgado 2012), and (Boyd 2010) for the details of the updates).

For the cement industry, if one computes the ratio of total energy costs to total value of shipments (adjusted for inflation) in 1997 and 2007 from data collected in the Economic Census, one would conclude that this measure of energy intensity has fallen ~16%, from 0.184 to 0.158. Aggregate data may also give the impression that all plants have made the same steady improvements. The picture that emerges from our plant level statistical analysis is somewhat different and more subtle (figure 2); poorer-performing plants from the late 1990s have made efficiency gains, reducing the gap between themselves and the top performers, whom have changed only slightly. The results from this study focus on energy efficiency and controls for other structural changes in the industry, e.g., increases in average plant size, which also tend to lower energy use. Our estimate of the overall energy efficiency improvement in the 96 plants in our database represents a 13% percent change in total source energy and the source of these changes is clearly not uniform.

Results for the auto assembly industry are similar, but less dramatic (figure 3). There are two sources of improvement, the changes in the industry energy frontier, i.e. "Best Practices" and technology, and the changes in efficiency, i.e. whether plants are catching up or falling behind. The results suggest that slightly more than half of the improvement is changes in efficiency, which have slightly outpaced changes in the frontier. The combined effect when evaluated against the over 7 million vehicles produced in 2005 by the plants in our study implies in a reduction of 11.6%, or 1462 million lbs of CO_2, attributable to changes in observed industry energy efficiency practices.

The change in the distribution of energy efficiency for a representative corn refining plant is shown in figure 4. If we compute the shift in the benchmark for every plant in the database then we can estimate the change for the entire industry. If we multiply this plant-specific change in energy intensity by the level of corn input production for each plant operating in the industry in 2009, and total across all plants, we compute a reduction of 6.7 trillion Btu in annual energy use. Relative to an average annual total source energy consumption of 155 trillion Btu in 2009 for all the plants in our data set, this represents about a 4.3% reduction in overall energy use by this industry. When energy-related greenhouse gas emissions are considered, this represents an annual reduction of 470 million kg of energy-related CO_2 equivalent emissions from improved energy efficiency.

The change in performance from these three industry are all quite different. Cement reflects the case where best practice has changed very little, but "catching up" comprises the main source of improvements. Corn refining is at the opposite end of this spectrum, where there are substantial changes in the best plants, but laggards remain or in some sense are even falling behind by failing to keep pace. The auto assembly plants are a mixture of changes in best practice and some modest "catching up".

These benchmark updates also reflect different time periods. When we compute the average annual change from the total reduction in energy use for each sector we see that the auto industry has made the greatest strides (see table 3).

Table 3: ES-EPI Benchmarks Updates: Rate of change by Industry

Sector	New benchmark Year	Old Benchmark Year	Time period	Total reduction	Average annual change
Auto	**2005**	**2000**	**5**	**12.0%**	**2.3%**
Cement	**2008**	**1997**	**11**	**13.0%**	**1.2%**
Corn	**2009**	**1997**	**12**	**4.3%**	**0.4%**

Figure 2: Comparison of Two Benchmark Distributions of Energy Use in Cement Manufacturing (source: Boyd and Zhang 2012)

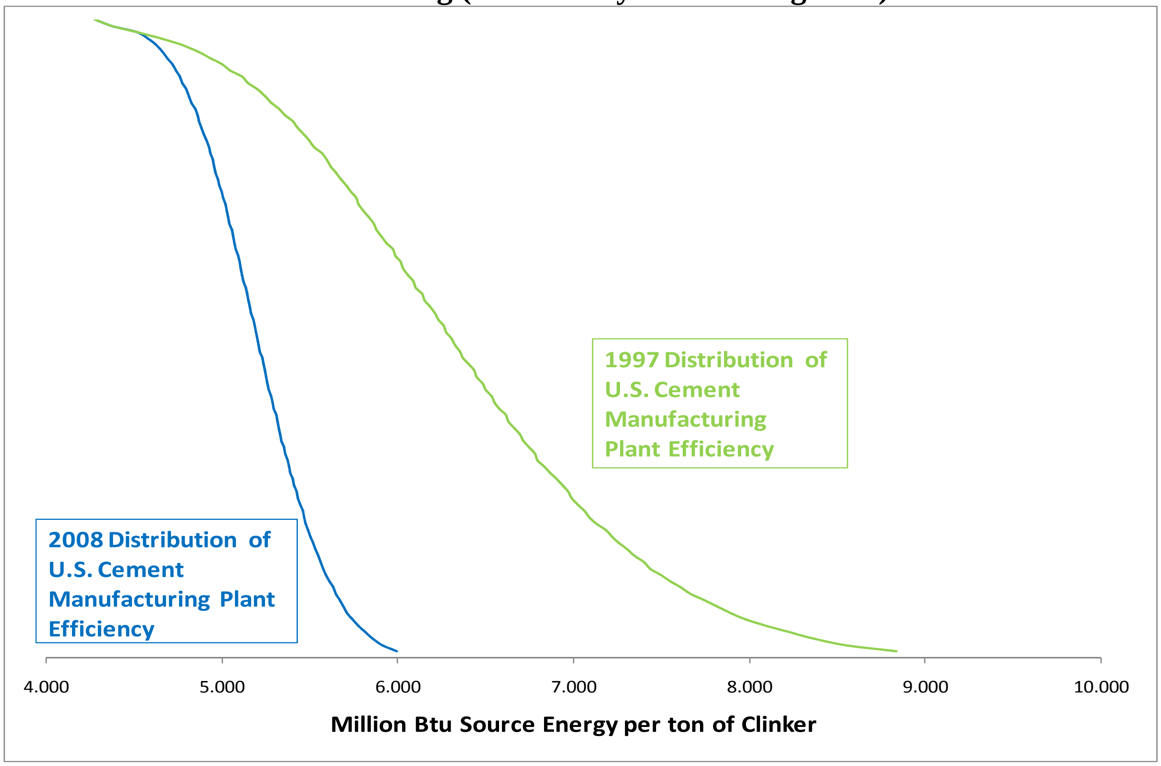


Figure 3: Comparison of Two Benchmark Distributions of Energy Use in Auto Assembly (Source: Boyd 2010)

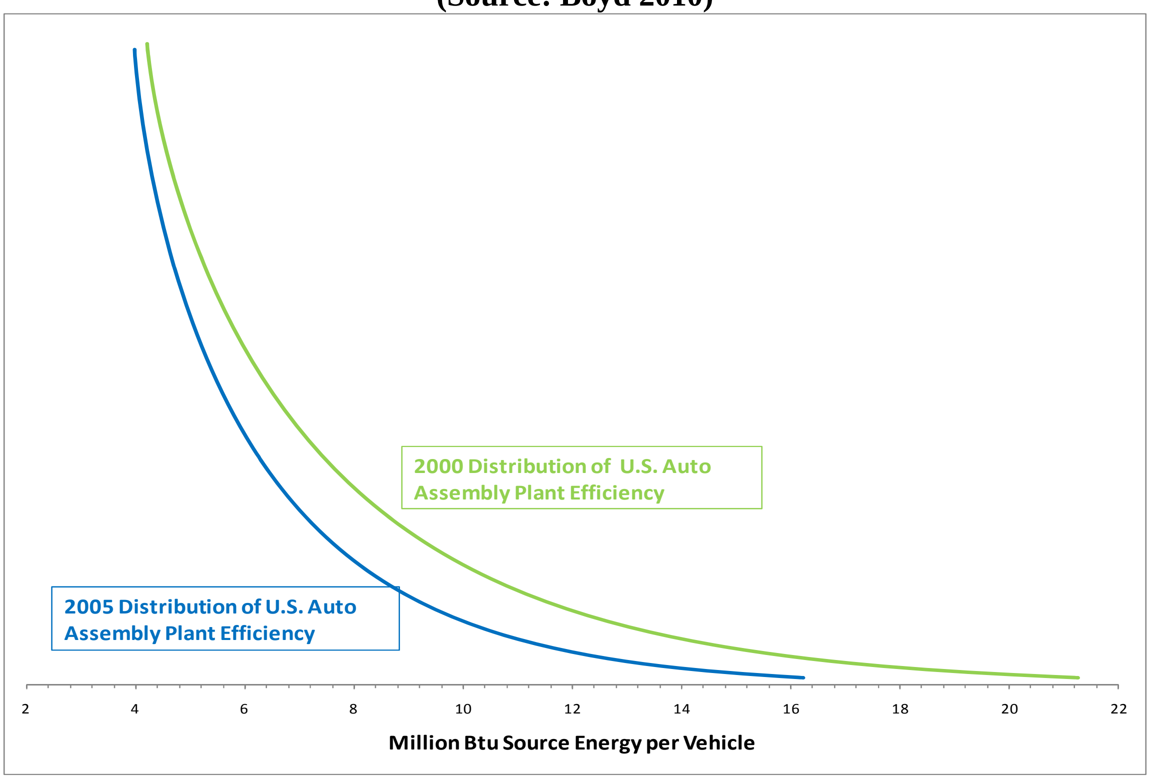
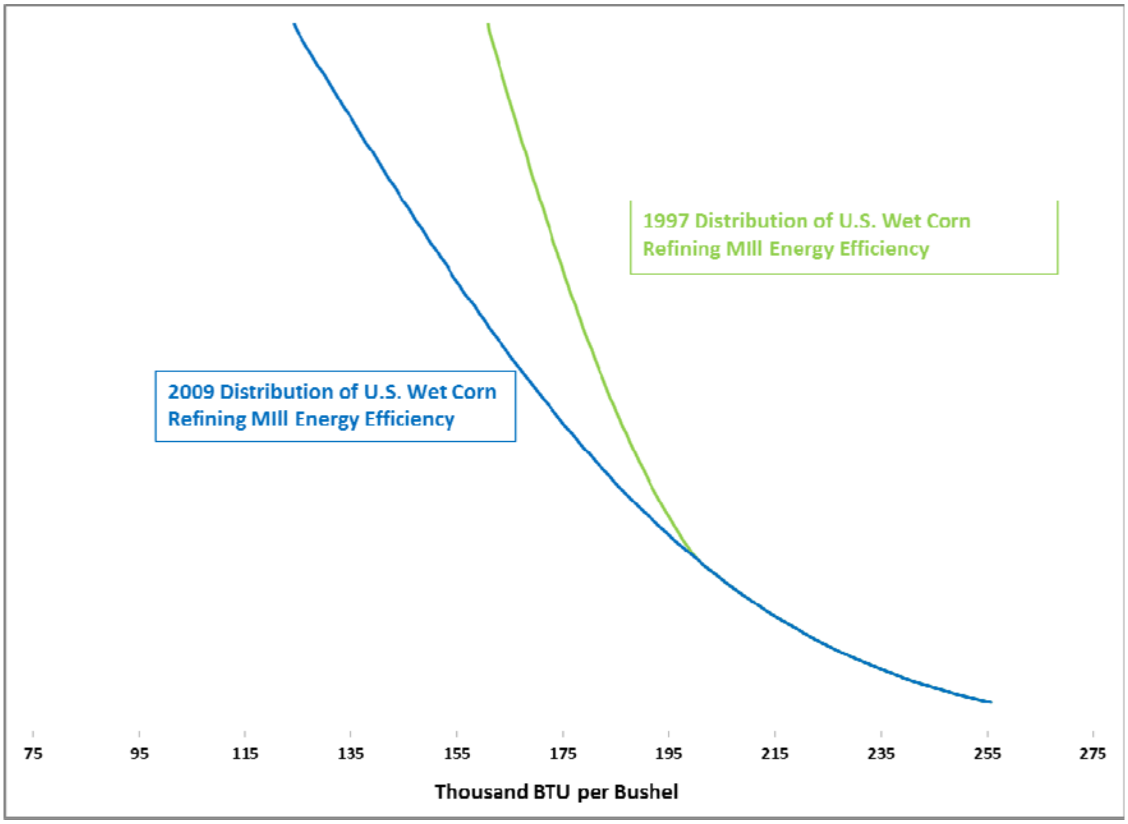


Figure 3: Comparison of Two Benchmark Distributions of Energy Use in Wet Corn Refining (source: Boyd and Delgado 2012)



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The Role of Visualization Systems in Managing the Energy of Production Systems

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ABSTRACT

The convergence of sustainability pressures, rising energy prices, and insatiable demand will have profound impact on our relationship with energy and its effect on the macro economy. There's no shortage of industrial users eager to turn crisis into future profits by taking the steps now to gain control over energy costs and consumption.

All this promise has led to the expansion of the presence of energy visualization products, or *energy management dashboards*, which all claim to offer unique features and attributes that enable the superior management of energy resources. Many of these systems are designed to optimize the energy of building systems and utilities: HVAC, water distribution, pneumatics, boilers, etc. In a typical industrial process facility, however, these systems account for only 16% of the energy demand.

This paper highlights the potential of energy optimization of production systems, and defines five proven techniques, called "process demand functions", that can be leveraged to mitigate process energy. For each process demand function, the role of the visualization system will be highlighted.

THE DRIVERS

Concern over energy use and sustainability policy in industrial manufacturing facilities has been expanding for some time, but never at the current rate. While industrial businesses strive to find fresh ways to build a competitive advantage, attract customers and skilled employees, and improve profit margins and share price, there has clearly been a shift away from ambiguous rhetoric to finding actionable ways of improving energy management.

The drivers of this trend are clear and can be categorized as follows:

Energy cost and price volatility

Beyond the obvious economic benefit of reducing energy quantity to increase operational margins, a more significant benefit is recognized through reduced financial performance risk associated with short term fluctuations in energy prices. As we've seen many times in modern history, a foreign political or economic crisis can quickly stimulate an energy price change (see Figure 1 for example)—forward-thinking manufacturers understand that less dependency on a variable business cost can result in a more competitive position.

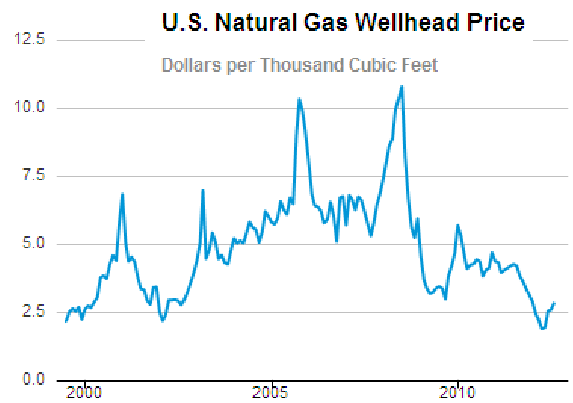

Figure 1: Volatility of US Natural Gas Wellhead Price, US Energy Information Administration

Corporate responsibility and shareholder value

Building a "green image" is more than just boardroom banter, it adds tremendous value to brand identity that can be turned into real revenue and a sustainable market advantage, which shareholders recognize as future earning potential. A.T. Kearney found "in 16 of the 18 industries examined, companies recognized as sustainability-focused...outperformed their industry peers [during the recession] and were well-protected from value erosion[1]". Furthermore, according to a study performed by Accenture on the topic of climate change, 64 percent of consumers are willing to pay a higher price for products and services that are produced in an environmentally sustainable way[2].

Regulatory pressures and supply chain mandates

Even for those locations without strict regulatory standards and carbon emissions penalties, it's becoming more common for large resellers and manufacturers to require specific sustainability measures of their suppliers. According to the Carbon Disclosure Supply Chain Report 2012, 4 percent of large corporations say they deselect suppliers who fail to implement formal environmental improvements and procedures, and 39 percent project that they will soon implement this policy in the future.

As the globe emerges from its recession, the re-generation of economic growth in emerging economies will serve as a wakeup call for those manufacturers who have not taken steps to adapt to this new norm of energy and environmental consciousness. The rising global demand for industrial energy resources, reflected in Figure 2, will predictably result in competitive pressures on all three of the drivers cited above.

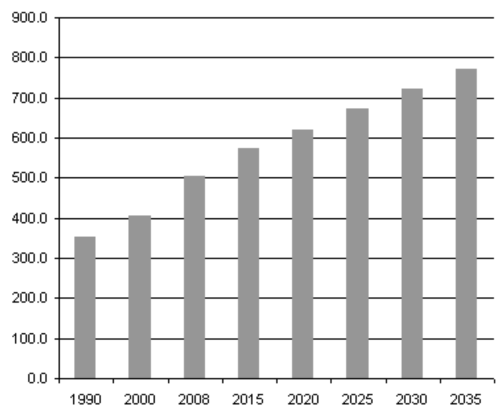

Figure 2: World Energy Consumption, Quadrillion BTU[3]

Today, there's no shortage of industrial users eager to turn crisis into future profits by taking the steps to gain control over energy costs and consumption. Such a strategy makes sound business sense, as the tools and processes associated with a credible energy management program can pay immediate dividends and in addition, also serve to establish a significant competitive advantage on a global stage.

STARTING WITH FACILITY SYSTEMS

An energy management initiative in an industrial facility typically starts with the nomination of an energy manager, usually a part-time role of someone within the facilities, mechanical, or environmental health and safety staff. Eager to make a quick-turn impact, the first action taken is typically in the form of an energy assessment, followed by a number of energy mitigation efforts targeted to the building systems. These projects include lighting upgrades, HVAC adjustments, occupancy sensors, and boiler tuning, which directly affect the very systems that the facilities department directly influences on a day-to-day basis. Such efforts may be enough for a commercial or government building, such as an office, hotel, or school, but in an industrial process facility, the majority of the energy used, 84 percent on average, is in the process, not the building systems (see Figure 3).

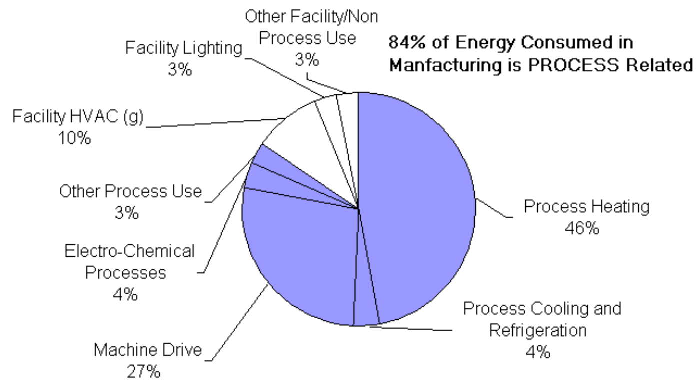

Figure 3: Proportions of Energy Used in Manufacturing[4]

To make a significant impact on energy consumption and sustainability, an industrial facility must look beyond the basics of its facility and consider process modifications.

THE BARRIERS TO PROCESS ENERGY CONSUMPTION AND HOW THEY ARE OVERCOME

Often, the opportunity to include process energy in the scope of energy mitigation efforts are impeded one or more of the following:

<u>Organizational structures:</u>

The energy manager, having come from a facilities background, often does not have the authority to influence the process, or has limited access to the skill sets needed to consider process efficiencies as a part of an energy plan. Even in larger organizations, the site energy manager may be the only person accountable for energy efficiency at a particular facility and reports to corporate through a different hierarchy than process managers.

Antithesis: Energy consciousness must be top-driven; if energy objectives are established at the enterprise level (as they are often), the organization may need help in conveying a sense of urgency to the plant level. The energy manager can help this cause through visibility and reporting. Establishing easily understood energy performance indicators (EnPIs), setting achievable objectives against these EnPIs, and making progress visible helps build an energy "culture" that changes behavior. Larger organizations can standardize EnPIs across the enterprise to enable comparison between facilities, creating a basis for cross-business challenges and best practice exchange.

ROI Expectations

Manufacturing organizations are accustomed to capital equipment payback periods of 18-24 months which can easily be demonstrated through increased production throughput or reduction in labor hours. Rate of return on energy projects, in contrast, require special considerations to be able to justify investments.

Antithesis: The financial controller should be leveraged as a cooperative member of the energy management stakeholders, rather than an obstacle to overcome. As a first step, it's often helpful to establish a "line item" for energy waste within the financial tracking reports by using the overall efficiency metric from the energy assessment and applying it to the energy budget. This budget should be separated into two lines: Budget for Energy Used and the Budget for Energy Wasted. By doing this, the Budget for Energy Wasted provides not only accounting and management visibility, but becomes a mutual target for reduction. The energy manager can then propose projects with a mix of ROIs based on standards that are different from other investments.

Production Priorities:

As manufacturers are continually pressured to increase profitability in light of global competition, energy projects are often misunderstood as "distractions" from these goals, and in some extreme cases, thought to actually serve as a barrier to advances in productivity.

Antithesis: Process-related energy efficiency initiatives can be strongly linked to overall gains in production efficiency. The simplest examples of this linkage exist in maintenance considerations; equipment that runs less often and at slower speeds, as production schedules allow, tend to break down less and cause fewer unplanned work stoppages. The best examples; however, come from energy analytics such as a properly applied operational dashboard leading to immediate improvements in both energy use and production efficiency that, together, boost ROI well into universally agreeable ranges. However, to succeed in this approach the chasm between facility energy management and process energy management must be crossed.

THE FIVE PROCESS DEMAND FUNCTIONS

The traditional facilities-based energy management program subjects are easy to understand and identify with: Lights can be seen, air leaks can be heard, steam temperature can be sensed. After all, the universal familiarity of these energy uses is what makes them such common targets for efficiency initiatives. Energy efficiency for production systems, however, seems much more elusive, requiring special competencies best left to the specialists. It turns out, however, that the energy management *techniques* that can be applied to production systems are definable and explainable, which means they can be appropriated to different process systems across almost any industry.

These techniques, called the five *process demand functions*, support the management of actions to control and reduce the usage/cost of energy within an industrial process on a continuous basis. As they are integral to the process, these functions also tend to generate *operational efficiencies* along with *energy efficiencies*, which have a compounding effect on associated investment return:

Peak Demand Management

The peak demand threshold is among the most critical elements of an industrial electrical supply contract: violating this threshold, even for a brief moment, can result in significant penalties or, at worst, can ratchet up the energy rate structure for the balance of the duration of the contract. The establishment of this threshold is often void of practical science: historical peaks for the facility are considered, a buffer is added, and the contract rate set on this threshold.

Peaks are commonly established during the startup of major equipment at line or shift changes, and especially during high HVAC loads. Often, these peaks are considered "normal" consequences of production and are not perceived as controllable.

With the right measurement and visualization system, however, these peaks can be managed; properly managed peak demand not only benefits the industrial user through the avoidance of penalties, but enables the energy contract to be negotiated to a LOWER rate schedule overall by determining how the peak threshold can be reduced.

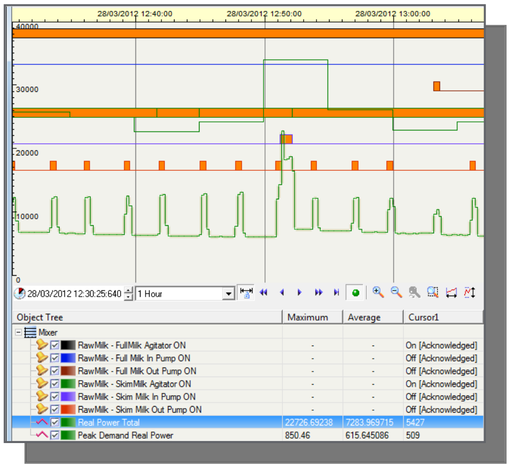

Figure 4: Example of Peak Demand Visualization System

Figure 4 depicts a simple demonstration of how a SCADA-based visualization system can be used to determine sources of peak demand. In this case, the cycling of two asynchronous pieces of equipment are shown to occasionally align to temporarily boost overall demand, which is represented by the bottom (green) curve. Simply by adjusting the logic associated with these machine cycles, this peak can be avoided. After making similar process adjustments over a period of a few weeks, a new "normal" peak was established, in this case, approximately 18% below the previous normal peak, which enabled the contract to be re-negotiated around a lower peak threshold, for a savings of $0.002 per every kWh consumed, or $67K per year , without any impact to production throughput. Total investment comprised a SCADA screen and the addition of 4 networkable power meters.

Additional peak demand management techniques include the establishment of near-peak alarms, automation of machine startup sequences, and augmenting of power sources during peak demand times with on-site generation (known as "peak shaving" systems).

Scheduled Demand Management

In areas of generation capacity limits, it can often be more cost-effective to run certain processes at lower energy cost "tariff" periods. The simplest case of this technique include the buildup of stored energy during evening off-peak hours: the filling of tanks, or the generation of ice to augment process cooling, are common examples. Sufficient incentives do exist in some locations, however, to schedule production runs based on varying tarrif rates during normal business hours.

When such multi-tier contracts are available, scheduling tools can be used to correlate production schedule with energy tarrif period to minimize energy cost while meeting production objectives. In the examples shown in Figure 5, the energy consumption of 5 different products, represented by the different colors, are compared with the tarrif rates at different work shifts throughout the day. A third factor, representing desired production output, is incorporated into the scheduling to determine the optimal production run rate per time period throughout the day.

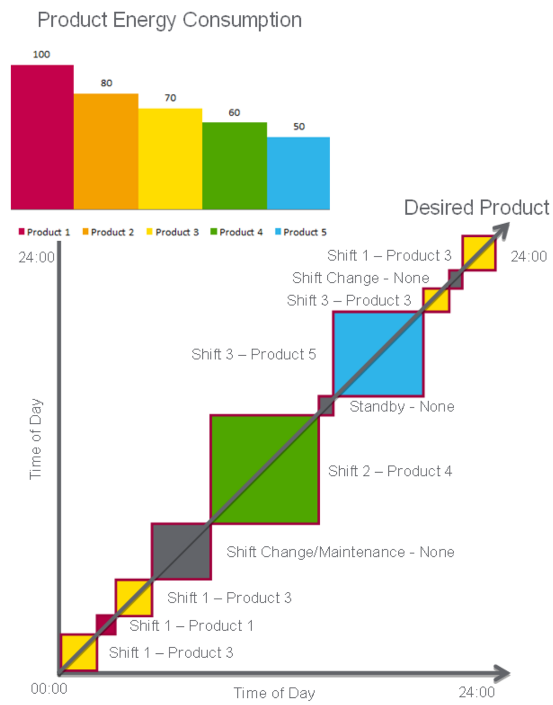

Figure 5: Example Scheduled Demand Management

Idle State Management

Most production facilities supporting discrete manufacturing or batch processes have a significant energy load from machinery running as it waits for raw materials or upstream work stations. Conveyor belts, blowers, pumps, tank heaters or mixers are often turned on at the beginning of the work day and are kept on at full operating speed, regardless of work in progress. As most process developers consider "idle state" to be equivalent of "off", leveraging idle state management often becomes impractical, as a priority is given to equipment being ready for material flow at any time during the work day, regardless of energy consumption.

It’s useful to recognize that there can be several *different levels* of idle states of production equipment, which would depend on any number of process variables, including:

- upstream process rate
- raw material availability
- work break scheduling
- unscheduled maintenance
- line changes
- downstream process conditions
- workflow blockage
- in-process inventory

Each of these conditions, typically identified in the automation system or SCADA system, can be used to trigger various idle levels of equipment, reducing energy load while still maintaining the readiness state required to resume operations as conditions dictate, without delay. Figure 6 depicts an example of the energy consumed for the same piece of production equipment, one at “Level 1” demand state and one at “Level 2:.

Figure 6: Multiple Levels of Demand to accommodate Idle State

During process idle time, placing a specific process or set of machinery in one of several predefined “wait” states enables the reduction of energy demand as well as unnecessary wear on equipment-this, in turn, reduces maintenance costs and unscheduled downtime.

An excellent example of this practise comes from a large manufacturer of tissue paper, where pulp is fed into the beginning of a production line and is fed through a series of dryers and rollers to produce the end product. In this case, the traditional workplace practise scheduled the dryers to be turned on at the beginning of the work day and off at the end. Throughout the day, however, the pulp material flow would be intentionally interrupted to account for colour changes, scrap removal, packaging changes, and work breaks. By automating a decrease in dryer temperature and associated blower speeds based on these conditions, this manufacturer was able to realize significant energy savings with no additional capital cost.

Energy Event Management

Another profitable practice to manage energy in a continuous improvement mode comes from combining process and energy data together to *model* the consumption habits of a process as over time. With data resources commonly in place in a manufacturing environment, production throughput can be correlated with associated energy demand to automatically build an energy forecast dependent on future production schedule.

Once the predictive model is established, an operational energy management system based in a Manufacturing Execution System (MES) would enable the detection and analysis of energy events. An *energy event* is a condition that causes the actual energy to exceed the forecasted energy, even for an instant. This energy management system captures not only the time and date of each event, but also all of the relevant process variables associated with it. Within a short time, enough energy events are captured to perform a meaningful analysis with tools such as a Pareto chart (Figure 7).

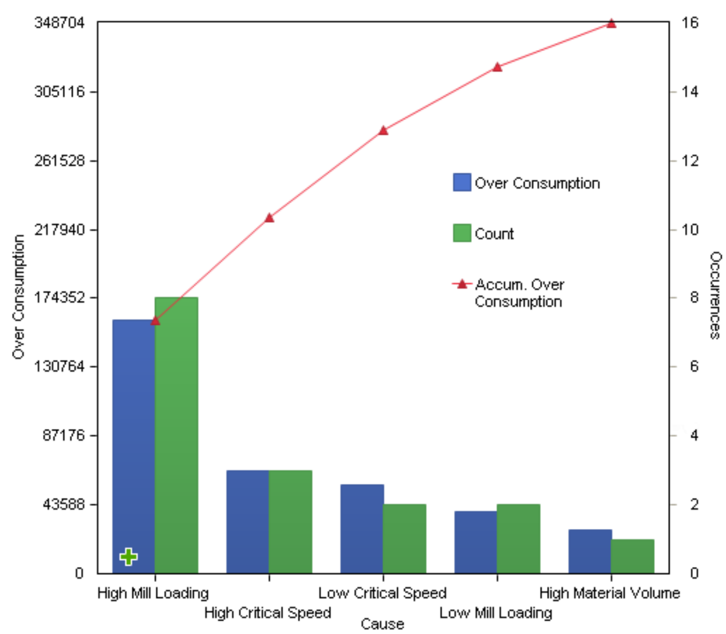

Figure 7: Pareto Analysis, Energy Events by Cause

In the example provided, it becomes clear that energy events in this manufacturing process are most often correlated with a process condition known as “High Mill Loading”. Further analysis may reveal that the mill is being loaded improperly by a specific work crew, which has adopted an unconventional work habit. Without analysis tools such as this, it would never be apparent that this practice is increasing real operating costs in the form of energy consumption.

Demand-Response Management

Demand-Response systems allow an electrical consumer to change instantaneous electric demand in response to incentives provided by their energy supplier. A common practice in building systems involves the adjustment of the air conditioning compressor—on days of high load of the electrical utility grid, the utility will remotely turn off the compressor for an agreed period of time: 15 or 30 minutes, for example, in exchange for an energy bill credit provided to the energy consumer. Using this system, the utility is able to serve the temporary increase in demand without building new capacity.

This type of demand-response system takes advantage of *thermal storage* in a building as energy storage, and provides an incentive to the consumer for accessing this storage during periods of high demand. There is much more energy stored, however, in an industrial process than there is in the building that houses a process. Some examples include:

- Vessel temperatures
- Tank levels
- Momentum of grinding wheels
- Oxygen level of water treatment basin
- Conveyor speed
- Pipe pressure

Many of these process variables are normally kept well within tolerances during normal process conditions. Given proper contracted incentives, however, a system can be developed to aggregate these variables, translate them to amount of energy stored, and allow the utility or intermediary to access this storage under conditions acceptable by the energy consumer. Properly designed, the stored energy can be accessed through this system without impact to the production rate or quality.

The value of the visualization system in demand-response is mainly in the identification of the loads which can/should participate. The ideal view shows the current state of process variables within their tolerance range, and translates that buffer into a unit of energy: BTU per degree or KW per ppm of oxygen.

CONCLUSION

Industrial energy management initiatives have enormous potential to trim costs and reduce carbon emissions. With over a third of the world's energy demand coming from industrial facilities, the benefit of industrial energy mitigation efforts extends beyond the books of the manufacturers themselves. While working on facility energy consumption is a good start, such initiatives only represent the tip of the iceberg of energy saving potential.

Advancing the scope of an energy management program beyond the facility systems into the process not only provides a much larger playing field, but also the opportunity to improve production efficiency with the same investment dollar. Fortunately, advancements in the integration of information technology with production systems promote the ability to link production data with energy data, which provides a basis of correlation, trending and continuous improvement. The way this data turns into useful information, of course, is in the plant's process visualization systems.

In leveraging these software resources for energy management, the five process demand functions, defined herein, serve as proven models which can be applied across a wide range of industries. Each one of these techniques fundamentally require energy measurements in the context of production output, and applies that perspective to make potentially substantial impacts on energy mitigation efforts.

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1 Carbon Disclosure Project-Supply Chain Report 2010

2 Two-Thirds Of People Will Pay Premium For Green Products, Environmental Leader News 10/2007

3 US EIA: World Energy Outlook 2011

4 US Manufacturing Energy Consumption Survey (MECS) table 5-4, End Uses of Fuel Consumption, All Manufacturing Industries (Electricity,Fuel Oil,Diesel,Natural Gas,NGL,Coke and Breeze)

Early Results of ISO 50001 Deployment by Utility Programs

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ABSTRACT

Few industrial energy efficiency innovations in the past decade have received as much attention as the ISO 50001 standard for Energy Management Systems. The standard unites organizational business practices in a management system to drive persistent results, and since its release in 2011 numerous companies around the world have deployed it. At the same time, program administrators from leading utilities and resource acquisition organizations have implemented energy efficiency programs that target business practices and management systems. These programs have had several names, with Strategic Energy Management (SEM) being a common name for the program category.

Recently, some program administrators have investigated ISO 50001 as it relates to their SEM strategy. These investigations have ranged along a continuum. At the light end, many program administrators have conducted cursory reviews of the standard to estimate its role with their customers. Other program administrators have conducted specialized studies of their market potential for ISO to guide them on potential offerings. One administrator benchmarked their program to the standard and at the same time solicited customer interest in ISO. A handful of administrators have participated in ISO-based pilots run by the US Department of Energy for their Superior Energy Performance program. At the involved end of the continuum, one program administrator has conducted two ISO implementations with customers to deliver energy savings to meet robust resource acquisition requirements, and to return findings to the program on how to refine future implementation as well as influence deployment of their core SEM offering. This paper will outline the above program administrator activities, what they mean to each organization, and what these collectively mean to the market.

INTRODUCTION

This paper sets the stage by describing ISO 50001's origin, summarizing it's requirements, and providing a current status of the global certification. Next, the paper describes how program administrators are taking action around ISO 50001, across a continuum of effort. The paper concludes with common findings and recommended next steps for program administrators.

Origin of the Standard

In June 2011, the International Organization for Standards (ISO) launched ISO 50001, after a multi-year development effort (that included one of the paper authors, Chad Gilless, on the US team). ISO 50001 aims to deliver continual improvement in energy efficiency through the use of management systems, in the same way that the well-known ISO 9001 standard aims at continual improvement in quality.

Requirements for Customers

The heart of ISO 50001 compliance is a comprehensive energy management system (EnMS). This is not a technology system; instead it is a management approach for energy, similar to a Quality Management System. An ISO-compliant EnMS includes an energy policy, energy teams, clear management involvement, energy-related purchasing procedures, energy goals, employee engagement, training, and numerous other structures and processes.

Current Status of the Standard

Organizations typically launch the standard at a facility level, so they can learn and expand. As of March 31, 2013, 1522 companies worldwide had completed certification at 2422 sites in 58 countries[1]. 23 firms in North America are fully certified in at least one location, including 3M, Bridgestone, Cooper Tire & Rubber, Nissan, Schneider, and Volvo. While manufacturers are the typical adopters, we have also seen certification by retailers, public facilities, and office facilities. The US Department of Energy (DOE) has provided early results from 7 facilities who have implemented ISO in the last year

[1] Worldwide ISO 50001 deployments are tracked on a monthly basis by Reinhard Peglau, Senior Scientific Officer on Environmental Management, at Germany's Federal Environment Agency (Umweltbundesamt).

and a half; one key finding was that 6 out of 7 facilities saw ROI in 2 years or less.

SEM Programs Administrators and ISO

Utilities and utility-based energy efficiency program administrators typically run programs that target commercial and industrial entities. Some of these program administrators also run strategic energy management (SEM) programs, continuous improvement-based programs that apply a management system approach to integrate energy management across the organization; these SEM programs have seen increased adoption across North America, with solid results:

- One program administrator's energy management program showed average savings of 4% across 15 sites.
- Another program administrator's SEM offering recently surpassed their lighting offering in terms of portfolio savings
- In terms of outright savings, one administrator's program produced over 69 million kWh of savings across 14 facilities

For all of these organizations, ISO has become a program of interest. ISO can be seen as an internationally recognized SEM standard, and with that comes several intriguing possibilities for efficiency program administrators:

- By incorporating ISO elements or making their current SEM offerings align to the standard, their customers may have easier transitions to the standard or, if they are already ISO certified, they may ease their integration.
- By basing their programs entirely on the standard, greater energy savings may potentially result from the higher management system expectations as well as from increased accountability due to third party ISO certification.
- ISO certified customers may participate in a greater number of efficiency programs. This may be a result of the program administrator's ISO program, or it may come from customer's whose facility is certified as a result of corporate parent activity elsewhere.
- Customers interested in ISO or already certified to ISO may appreciate specific and unique efficiency program offerings that drive savings.

Given this range of possibilities, leading efficiency program administrators are acting in a number of ways, as outlined in the following sections.

- Reviewing the standard to understand its requirements, its specific wording, etc.
- Reading reports by others on successes and challenges, whether in the US or in other countries
- Observing ISO-related activity in their territory, such as the level of customer interest, what types of companies are leaning toward the standard
- Integrating ISO components into their existing SEM offerings (SEM)
- Conducting ISO-based studies of their current market or of its future potential
- Conducting a gap analysis of their program offering(s) to ISO
- Conducting or participating in ISO pilots

It is important to share one program administrator's finding, which was that though experiences and case studies from other organizations are interesting, these are often not directly transferrable due to major differences in culture, values, energy costs and labor costs. With that, different program administrators have conducted different efforts to meet their own ISO-related needs. The following sections break out some of the more involved ISO-related activities.

ISO 50001 Studies

One program administrator conducted a pilot to understand their market, both where their customers were with respect to ISO and to understand what the market transformation potential was. They wanted to open a dialogue with their customers regarding SEM and ISO.

As to the type of analysis that the program administrator conducted, they looked at energy management standards such as the original ANSI-based US standard as well as DOE's SEP standard. Interestingly, they also looked at Lean Manufacturing as a potential approach with which to align possible ISO-based efforts, as Lean had some current market uptake, and it appeared to be successful without being too heavily focused on documentation.

The program administrator was focused on flexible and interesting customer solutions, and planned for savings protocols that would measure facility-wide savings as well as reliably report long-term persistence. Prior to this time, they were not sold on the value of savings or on the value of other non-energy benefits. In addition, they were focused on using ISO, or any SEM program, as a place to market and create demand for their core programs.

As to the program administrator's findings, they characterized their market as being in a state of early adoption, where there were currently a very limited set of customers implementing SEM, and fewer still interested in ISO. They definitely felt that the ISO management system standard will make it easier for them, and that without it, SEM to that level of robustness would be too difficult and not worth it for their customers.

The program administrator has a few potential next steps. These begin with promoting ISO to their customers as a viable and valuable standard. Next, the program administrator will look for opportunities to integrate ISO into their existing energy management programs. For example, one of their programs requires that energy management process be in place for the customer to be eligible for an incentive. In that case, if the customer has an up to date ISO certification in place, then that requirement would be met and the customer would receive the incentive. For the program administrator, they will focus on some manufacturing such as food processing, as well as mining, universities and steel production. Lastly, the program administrator will look at vehicles to reliably estimate operational savings that result from ISO.

<u>Benchmarking Utility Program and Customer Interest</u>

One program administrator mapped their SEM program to ISO, with the intent of determining the customer effort required to move beyond the existing SEM program to actually become ISO compliant. This analysis helped identify the program gaps and customer hurdles for future program enhancement.

In addition to benchmarking against ISO, the program administrator also compared their program to the programs of Efficiency Vermont, Wisconsin Focus on Energy, the Northwest Energy Efficiency Alliance (NEEA), the Ontario Power Authority, and the DOE SEP program. This analysis helped to conclude that, though the program administrator's program was significantly off of the ISO standard, they were ahead of most of the other programs.

The gaps identified by that program administrator would likely be consistent with other programs, in areas such as internal audits, training, and documentation. In addition, some customers have stated the need for industry specific tools to help them address some SEM areas required by ISO, such as for monitoring and measurement. As they interviewed customers, they found that some were quite wary of the standard language, including requirements, audits, and certification; this was particularly true for customers who were less familiar with management systems.

<u>Conducting Customer-based ISO Pilots</u>

Program administrators that wanted to conduct ISO pilots with their customers were typically in two categories: those that participated in ISO-based US DOE SEP pilots, or those that conducted their own ISO test offering.

- By participating in the SEP pilots, program administrators were able to leverage existing funding sources, such as for consulting resources and tools. In addition, they were able to utilize customer recruiting from DOE. These administrators could also evaluate the specialized SEP certification process and its potential value to help customers reduce their energy costs and manage their energy usage more effectively.

- By conducting their own test ISO offering, one was able to determine the real cost and time to implement and certify to ISO in a very hands-on fashion. This would enable a more direct evaluation of ISO as a potential threat or opportunity for their existing programs. For example, they could better understand whether ISO would unnecessarily duplicate too many SEM program elements, either competing with their program or going in a different direction than their program.

As for additional rationale, most administrators wanted to investigate how ISO could impact their customers who had existing energy management experience. In addition, they sought to investigate the potential for deeper saving from areas such as operations and behavior. Some administrators wanted to push their markets to develop additional SEM practices, and saw the ISO standard as a positive driver across multiple vertical markets and sectors.

To recruit customers, administrators working with an SEP pilot leveraged customers recruited by DOE, and others customers who were aware of the pilot through the DOE proactively proposed to their utility to participate in the pilot. To recruit customers for their own ISO-related efforts, program administrators typically used their existing customer pool, focusing on those with previous SEM experience.

To qualify customers to participate, the common criteria was the clear expression of top management commitment to support energy management in general as well as the specific ISO effort.

As to the current status of these efforts, in the case of three program administrators, customers are still heading towards ISO 50001 certification. For those working with SEP pilots, anecdotal results show that around half of the participant customers remain in the pilot through the end and then plan to move forward with certification. Some customers still intend to be certified, but other priorities are delaying the process.

Common Findings

Program administrators had a range of involvement with the ISO implementations. All used third parties for implementation support, either using their own contractors or using DOE's SEP contractor, Georgia Tech. Some administrators participated in implementation sessions alongside their customers to witness the experiences first-hand.

Common customer needs included tools and coaching on certain topics specific to the individual needs; there was a consensus that, although ISO 50001 is a standard, how it is implemented is customized in every client situation.

Consultants are seen as key players in an ISO-based solution, as this area of expertise is still niche and has not percolated into program administrator staff. They bring experience in training, coaching, and in viewing customers through the lens of a Certification Body. Program administrators emphasized a need for qualified practitioners, qualified by more than just a personal certification buy by having hands-on ISO experience.

For those considering future ISO-based programs, program administrators agree that they would require customers to have SEM experience, as the volume of their ISO effort would decrease based on how much SEM experience they had. In addition, they would also require a clear commitment by top management.

At least two program administrators commented that an ISO based program is becoming increasing viable as a resource acquisition program, as behavior based energy savings approaches are becoming more accepted in their territories. Still, these groups are not clear on what model they would use to estimate the savings at a level of rigor necessary for their regulatory commissions.

Program administrators were not clear on how many customers would see ISO as appropriate. This is due to the newness of the standard and its developing role in the market. As facility needs are clarified from their supply chain, from sustainability goals, or from other areas, they will be able to more clearly articulate needs that an administrator's program could address.

There is a range of possibilities amongst program administrators as to their interest in doing an ISO or SEP implementation in the future. Three administrators felt that they would do so, but that they would do things differently. Examples of differences include requiring customers to commit in a more tangible manner so that they would more seriously evaluate withdrawing for the offering. Another program administrator felt that if they would do the program again if they were able to acquire program energy efficiency savings as a result of the implementation. There was no consensus amongst these administrators on how to financially support such future ISO implementations, whether paying for ISO consultants or providing incentives for resulting energy savings.

Some administrators plan to support their customers to become ready for ISO, but not to help them towards the entire effort of certification. Others continue to align more of their SEM program elements to ISO, to align their offerings to the market and to ease their customers' potential transitions to ISO.

Conclusion

Program administrators are still early in clearly understanding the benefits of ISO, how it will truly benefit them and their customers. At the same time, they do not clearly understand risks to their current

SEM programs, about what challenges ISO may pose from outside their programs or from within. Given that these and other program administration leaders are continuing to experiment in ISO studies and pilot programs, many more of these answers should continue to be answered so that more consistently successful customer programs may be launched.

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Implementing an Energy Management System at TOTAL Port Arthur refinery

INTRODUCTION

Increased supplies of shale gas in the USA have driven down Natural Gas prices, subsequently reducing economic incentive for refineries and petrochemical plants to improve energy efficiency. However, many operating companies also have corporate commitments to improve energy performance. These seemingly opposite drivers result in a quandary; how to increase energy efficiency when it is not economic to invest in large scale energy conservation projects, such as installing air preheaters on furnaces and revamping preheat trains.

An ongoing energy efficiency improvement program at TOTAL Port Arthur refinery proves with even relatively low Natural Gas prices, a program of this type pays dividends and ensures the refinery has a competitive advantage when Natural Gas prices start to increase. The program identified savings of approximately 8% of total site energy costs with about half of the savings coming from non investment opportunities. Within the first five months of the project, the refinery had reduced energy costs by more than 1%. In addition to increasing energy performance, a number of yield constraints were removed, thereby improving refinery operation and profitability.

This paper describes the process used to execute the program. The paper will cover some background on the project team and illustrate the approach taken by KBC, Alexander Proudfoot and TOTAL to successfully improve and sustain overall system performance at the Port Arthur facility, which is comparable to the approach outlined in the international energy management standard ISO50001.

BACKGROUND

TOTAL, one of the major oil and gas companies in the world, operates a number of refineries and petrochemical facilities around the globe. In 2010, the company embarked on a program to improve energy efficiency at each of its refineries. TOTAL engaged Alexander Proudfoot and KBC to work together across their global refining system to realize their goals.

For more than thirty years, KBC has assisted refiners and petrochemical plants reduce their energy costs and improve profitability, combining strong process engineering and industry leading software tools with practical plant experience.

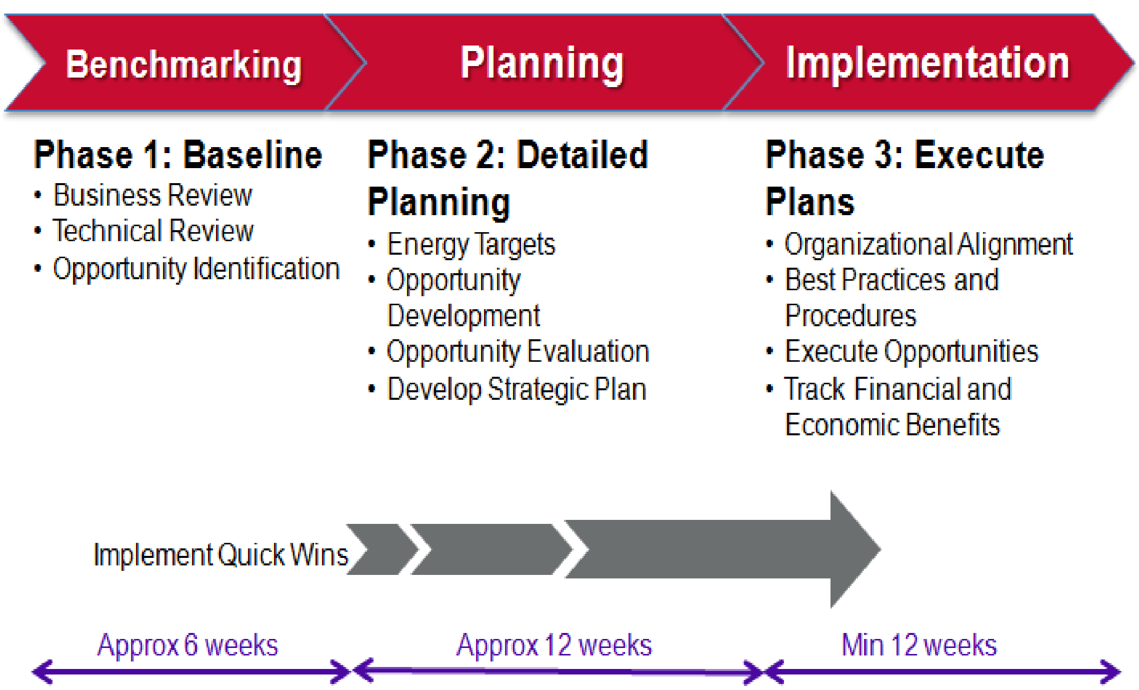
Since 1946, Alexander Proudfoot has helped clients achieve increases in top-line and bottom-line performance by working on process improvement and peoples' behaviors and attitudes through Management Operating Systems.

The energy management project was named "Project AMPERE" (**A**ct to **M**anage our **P**erformance in **E**nergy for **Re**fining) by TOTAL and was kicked off in 2010. Successfully executing three programs in Europe, the AMPERE team initiated the approach at the Port Arthur refinery in February 2012.

THE APPROACH
The systematic approach, which was applied for project AMPERE, was divided into three distinct phases:

- **Phase 1 – Benchmarking**
  Following a technical and business review the team benchmarked the site energy performance and compared to proven good practices. In addition, a number of energy saving opportunities were identified and prioritized.
- **Phase 2 – Planning**
  Following opportunity evaluation, the team developed a strategic improvement plan which included a set of strategic goals and an implementation plan to align the various initiatives
- **Phase 3 – Implementation**
  The team developed and implemented the actions defined in the strategic improvement plan. The financial benefits are tracked to reinforce continuous improvement and provide continuous feedback, closing the loop.

Phased Approach to Energy Management



Although implementation is in phase 3, "quick wins" (energy efficiency improvements) are implemented throughout phase 2, in order to increase refinery profitability and increase the buy-in of employees at the site. Coupled together, these gains provide positive momentum for the project team to successfully execute the project.

Multidiscipline team
The success of the energy efficiency program largely depends upon the make-up and dynamics of the project team. The team must combine the right blend of skills and experience and include technical specialists, organizational specialists and site expertise. Some of the team roles and contributions are listed below:

Team Roles and Contributions

<table>
<tr><td>Organizational Specialist</td><td>Gain an understanding of the business processes, systems and technology with respect to energy efficiency
Gain an understanding of the Energy management systems and routines in different areas
Facilitate change within the organization:
Communication & awareness
Supervisors Management Training
Project management</td></tr>
<tr><td>Energy/Utility Specialist</td><td>Gain an understanding of the interactions between utilities and the process plants in order to take a balanced approach to opportunity identification
Gain an understanding of the clients perspective with respect to energy
Knowledge of energy efficient equipment and systems
Understanding of site energy prices and marginal mechanisms</td></tr>
<tr><td>Process Specialists (e.g. CDU/VDU, FCC, Hydroprocessing, Sulphur)</td><td>Underlying knowledge of process technology
Knowledge of the understanding of key influencing parameters and the tradeoffs between yield and energy</td></tr>
<tr><td>Mechanical Specialist</td><td>Equipment care and conditioning experience
Knowledge of equipment performance and reliability KPI’s
Experience in asset policies and maintenance practices</td></tr>
<tr><td>Site Expertise</td><td>Understanding of existing operating procedures, practices and constraints
Ultimately responsible for implementing change
Input is required in all areas of the plant, from process engineering to operations and maintenance</td></tr>
</table>

The combined strength of KBC, Alexander Proudfoot and TOTAL, provided a solution addressing both the technical and human sides of energy management, from opportunity identification and evaluation through to the implementation of energy initiatives. The first step in this process is benchmarking.

PHASE 1: BENCHMARKING

Before attempting to improve the energy efficiency of a facility, it is important to assess the existing energy performance from both a technical and organizational standpoint. Essentially, two questions need to be answered:

1. How efficient is the facility?
2. What are the inefficiency gaps?

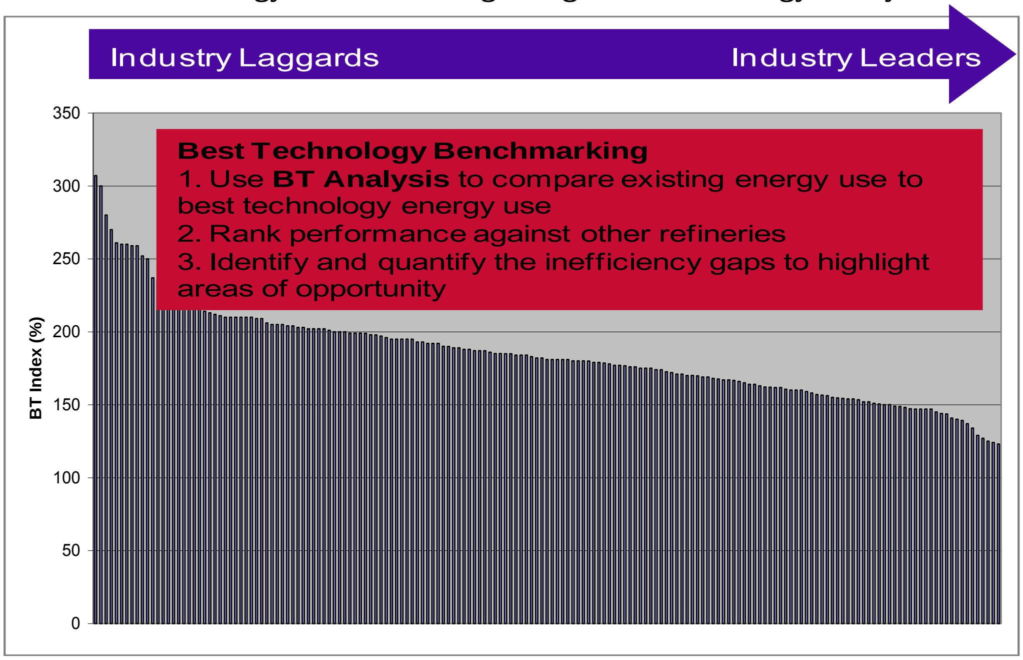
KBC benchmarked the refinery energy performance using their "Best Technology" (BT) methodology, which is a ratio of existing energy consumption to KBC's benchmark energy consumption. The Best Technology benchmark for a refinery can be described as the energy consumption in the same refinery (i.e. with the same feed, process units and product mix), but now built with the most efficient technology. For example, this includes heaters and boilers with efficiencies of more that 92%, heat exchanger networks designed in accordance with pinch principles, optimum process steam consumption, zero flaring and power generation efficiency of at least 80%.

KBC ranked the BT energy performance of the Port Arthur facility against other refineries in the world and the inefficiency gaps were quantified. Gaps were found in four areas:

- Power Generation Efficiency
- Heater Efficiency
- Process Unit Design and Operation
- Heat Integration effectiveness.

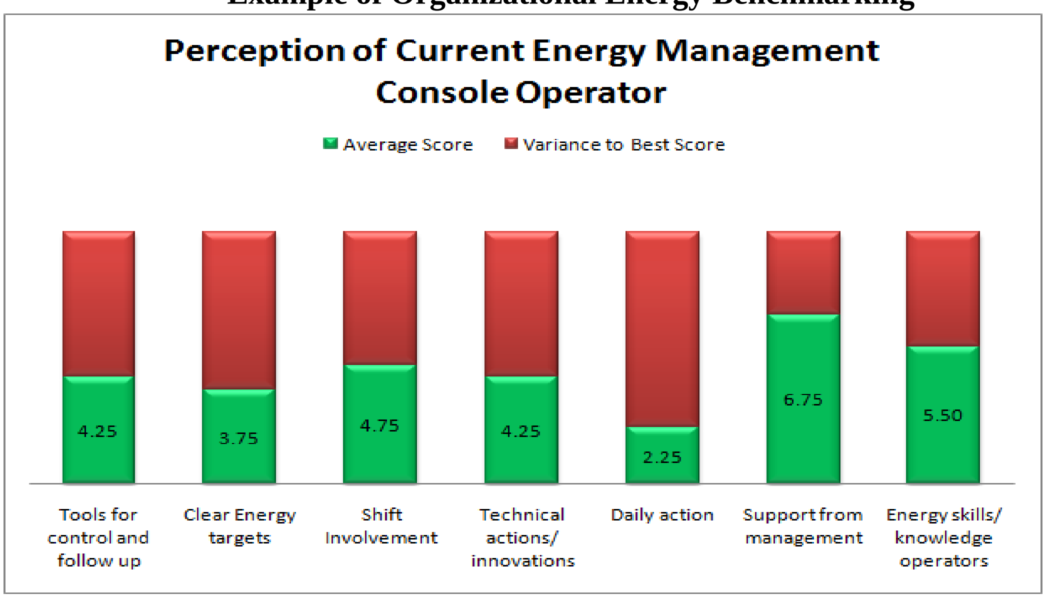
Although the gaps highlight areas of inefficiency, these gaps do not necessarily mean it is economic to close the gaps. For example, one of the largest inefficiency gaps at Port Arthur was power generation efficiency, since the refinery imports a significant amount of power from the grid. However, the only way to close the gap was to install additional cogeneration at the refinery. This option proved uneconomic at existing fuel and power prices. The challenge is to identify economic gap closing projects.

Energy Benchmarking using Best Technology Analysis



In parallel to the technical benchmarking, Alexander Proudfoot employed a variety of tools to benchmark the organizational performance at the refinery with respect to energy efficiency. Although the energy awareness at the refinery was generally positive, a number of areas for improvement were identified. In particular, the team identified an opportunity to improve the monitoring and targeting of energy use at the refinery, improving energy practices throughout the site.

Example of Organizational Energy Benchmarking



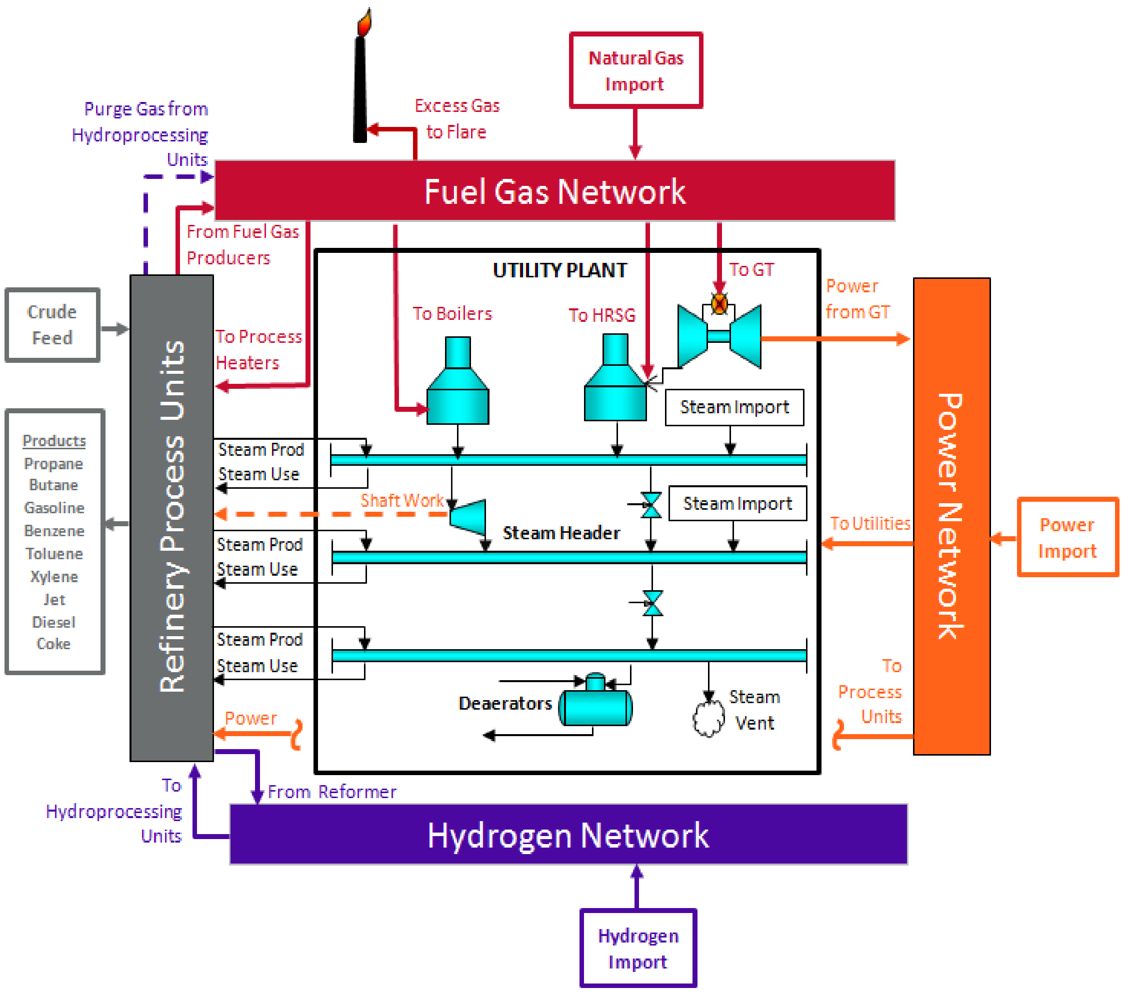
A Balanced Approach to Opportunity Identification

In addition to energy performance benchmarking, phase 1 required identifying energy saving opportunities for the plant. For successful opportunity identification, the project team must quickly learn how the plant operates and what the constraints are.

A refinery can be considered an interlaced network of energy users and producers whose interactions can have a profound impact on the overall system performance. Before implementing any energy saving opportunity, understanding the many interactions which take place in a utility system as well as the impact of energy on yield is essential. A ProSteam utility model was built to help understand the many interactions between utilities and Petro-SIM software was used to analyze tradeoffs between energy and yield.

One important feature of the utility balance at TOTAL Port Arthur was the regular fuel gas containment limit (not uncommon for a high conversion refinery) which meant for the existing balance, opportunities which saved fuel (e.g. reduce heater excess O2's and increases heater coil inlet temperature) would have **zero** value from an energy efficiency standpoint. On the surface, this limit eliminates about one third of the potential opportunities at the site. However, to get around this constraint, the project team focused on identifying steam saving opportunities, even if it meant burning some additional fuel gas. Because marginal steam was imported from 'over-the-fence', saving steam had no adverse affect on the refinery fuel balance. The following diagram illustrates the system relationships.

TOTAL Port Arthur as an Interlaced Network of Energy Users and Producers



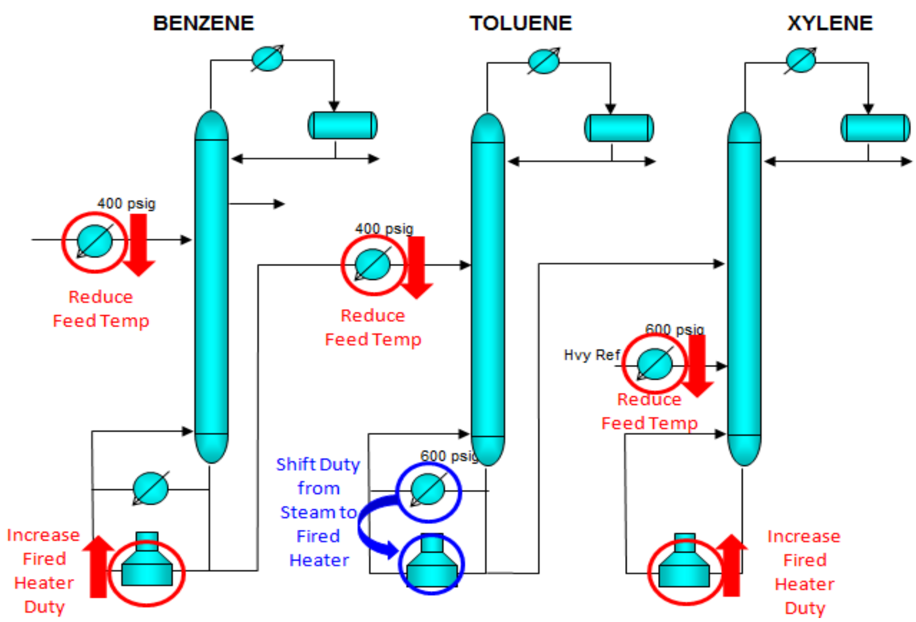
At the start of phase 1, approximately 120 potential energy saving opportunities were identified. At the end of phase 1, these opportunities were prioritized according to business impact, risk, and ease of implementation. About half of these opportunities were given priority status and carried forward into phase 2 for further evaluation. Of these, approximately 30 opportunities finally ended up in the strategic plan. The majority of which were non-investment and minor investment items.

PHASE 2: PLANNING

Opportunity Evaluations

The prioritized opportunities carried into phase 2 required further development to determine the feasibility, economic saving, estimated installed cost and impact on the utility network. An example of a non-investment opportunity identified as part of the program is shown below for the Benzene, Toluene and Xylene (BTX) towers. The feed temperature to the BTX towers was typically fixed. However, a Petro-SIM simulation of the towers confirmed an opportunity to reduce the feed temperature, to save high pressure steam, and increase the fired reboiler duties. In addition, an opportunity existed to shift load from the Toluene tower steam reboiler to the fired reboiler. Not only did this opportunity save a significant amount of energy, but it moved the refinery away from the fuel gas containment limit. The changes are illustrated in the diagram below.

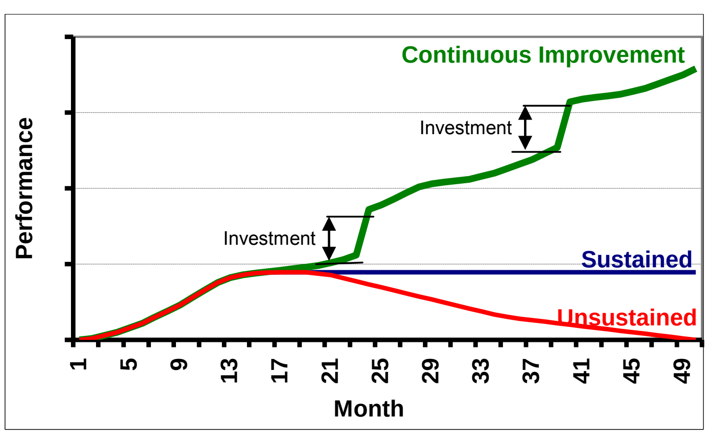
Example Opportunities for BTX



Develop and Sustain an Energy Culture

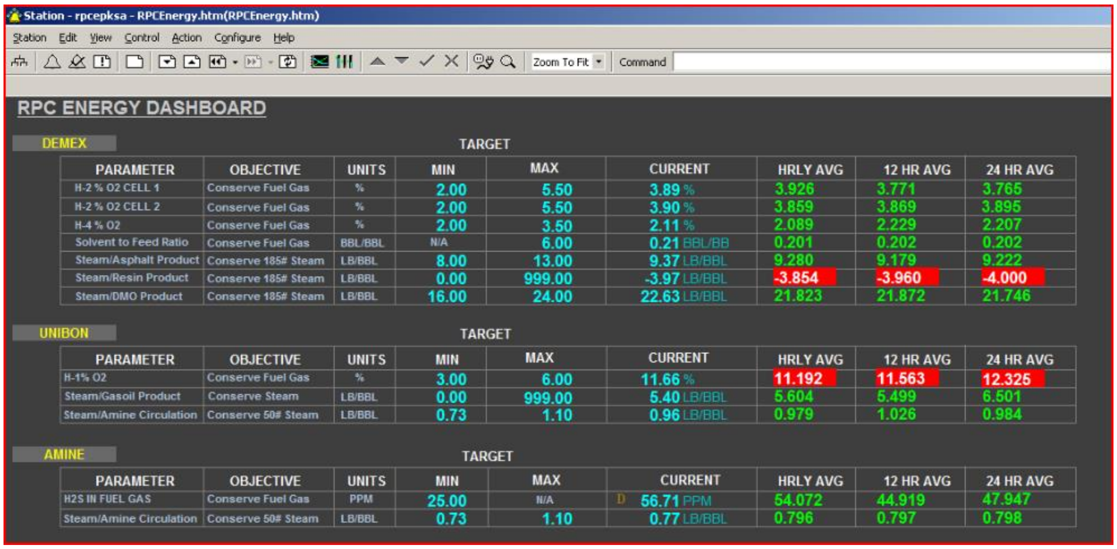
Refineries and petrochemical plants commonly develop long lists of energy saving opportunities as part of an energy efficiency program. After the first twelve months of the program, the plant is able to reduce energy use, but a few months later focus is shifted elsewhere and energy use stagnates or starts to increase. The following chart shows the typical project cycle depending on the level of commitment to the program.

Continuous improvement



To enable the successful implementation of opportunities and to support continuous performance improvement, TOTAL Port Arthur Refinery was aligned with its energy management strategy. This alignment was achieved by embedding energy into all aspects of refinery operation, from planning to production and maintenance. The energy culture was enhanced through better communication, awareness, training and tools. One of the key elements was ‘Energy Management at the Point of Execution’ which involved the development of energy dashboards for the site, enabling operators to target energy influencing variables and allowing management to monitor energy consumption on a daily basis.

Example of Energy Dashboard



New work processes were established for items such as fixing steam leaks, replacing steam traps, repairing insulation and operating and maintaining process equipment (e.g. pumps, compressors and turbines). This aspect created the necessary organizational infrastructure to execute the plan.

Strategic Plan

The strategic plan, delivered at the end of phase 2 provided the site with a framework to improve and sustain energy performance. Although the majority of the opportunities in the plan were non-investment items, a number of capital projects also made it onto the list. This step brought together technical and organizational opportunities into a plan ready for implementation.

PHASE 3: IMPLEMENTATION

Early implementation

The program puts a strong emphasis on “quick win” opportunities and the plant did not wait for phase 3 to implement non-investment items. By the end of phase 2, total site utility costs had been reduced by more than 1%. . Not only did this increase refinery profitability but it promoted project AMPERE throughout the refinery and ultimately increased the buy-in of the employees.

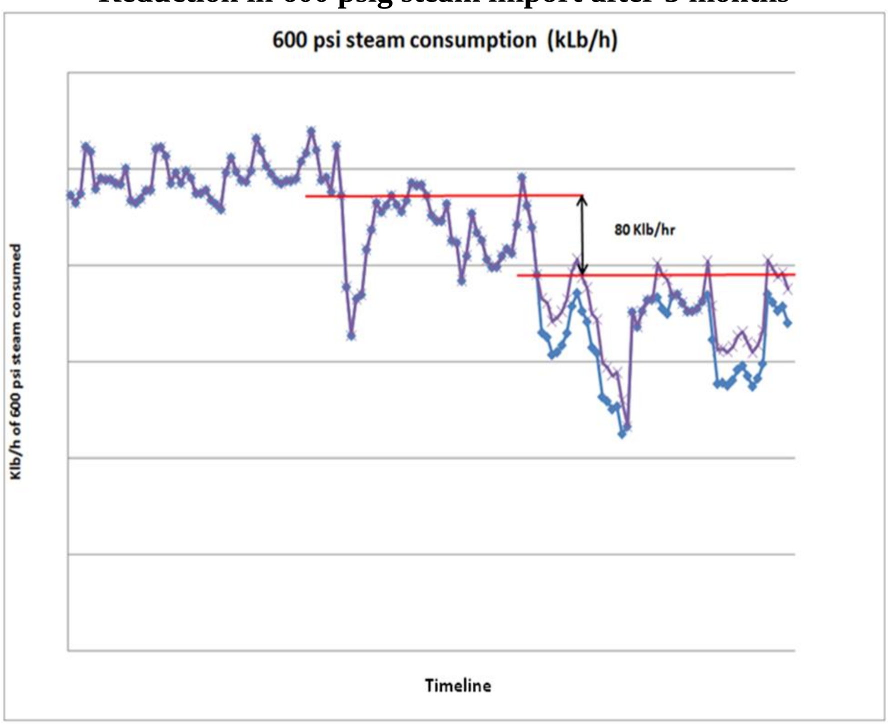
Target Savings
A savings realization chart will be used by the refinery to track achieved savings versus plan over time. The chart, which is presented to senior management on a regular basis, includes all opportunities outlined in the strategic plan. The purpose is to reinforce continuous improvement and provide continuous feedback, closing the loop.

RESULTS

Identified Savings

The total identified savings, carried into phase 3 of the program equated to an 8% reduction in existing utility use, of which approximately half the benefits can be achieved at zero investment. In phase 3, design feasibility studies will be carried out for the capital projects. Some of the projects may eventually be dropped because of process or economic constraints. After completion of all the design feasibility studies and implementation of all the feasible opportunities, the refinery expects the achieved cost savings to be closer to 4%.

Reduction in 600 psig steam import after 5 months



Constraint Reduction
In addition to reducing utility costs and carbon footprint, a number of refinery operating constraints were also removed as a result of the program. For example;

- By swapping steam use for fuel use, the refinery moved away from its existing fuel gas containment limit and enable implementing other relatively straight forward fuel gas reduction opportunities (e.g. reduce heater excess O2's)
- During certain periods the refinery used to be short of steam. However, after implementation of the steam saving opportunities, the steam cushion increased, which increased the availability of the Sulpholane unit.

CONCLUSIONS
Project AMPERE utilized a multidisciplinary team of technical and organizational specialists to successfully improve energy efficiency at the TOTAL Port Arthur refinery. The program identified potential energy cost savings of 8%, with approximately half of the identified savings requiring no investment. After completion of design feasibility studies, and implementation of all opportunities, the refinery expects the achieved savings to be closer to 4%. Within the first five months of the program, the refinery had reduced energy costs by more than 1%, removed constraints and reduced water use. The refineries strategic plan, combined with the enhanced energy culture and tools will ensure continuous energy improvement.

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ENERGY DESIGN REVIEWS: THE END OF THE ENERGY AUDIT?

Integrating Energy Management in Engineering Design

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Abstract

It is much more cost effective to design an industrial plant upfront for optimum energy efficiency rather than retrofit an existing plant, yet typically design engineers and project managers continue to focus on capital costs, not lifecycle costs, often ignoring substantial energy savings potential over the 20-50 year plant life. An average of over 30% in annual energy spending relative to the "business as usual design" baseline was identified in four recent energy design reviews (EDR) for large industrial companies. Typically, energy audits identify energy cost savings of 5-10% of energy spending, thus demonstrating the much larger savings potential of energy design reviews.

This paper will define an EDR, list the benefits, compare an EDR with Leadership in Energy and Environmental Design, describe the methodology, present case study results and lessons learned from four EDRs, and conclude with suggestions on how to incorporate energy design reviews in your organization.

Introduction

It is much more cost effective to design an industrial plant upfront for optimum energy efficiency rather than retrofit an existing plant, yet typically design engineers and project managers continue to focus on capital costs, not lifecycle costs, often ignoring substantial energy savings potential over the 20-50 year plant life. Hatch believes the key to long-term energy reduction is to systematically integrate energy management in industrial plant engineering design.

An average of over 30% in annual energy spending relative to the "business as usual design" baseline was identified in 4 recent energy efficiency design reviews for large industrial companies. Typically, energy assessments (i.e. audits) identify energy cost savings of 5-10% of energy spending, thus demonstrating the much larger savings potential of energy design reviews.

In a carbon-constrained world where fossil fuels are in limited supply, greenhouse gas emissions are being regulated and energy prices are on the rise, it is even more critical to ensure that energy be used as efficiently as possible.

This paper defines an energy design review, describes the benefits, compares it to the Leadership in Energy and Environmental Design for New Construction rating, describes the methodology, presents results and lessons learned from four case studies, and concludes with suggestions on how to incorporate energy design reviews in your organization.

What is an Energy Design Review?

An Energy Design Review is a structured, interdisciplinary and recorded analysis of the design of an industrial Greenfield or large expansion project to determine the most efficient energy solutions that would allow the project to operate safely and reliably. Companies that want to minimize lifetime operating costs carry out these reviews to help maximize the energy efficiency and competitive advantage of facilities thus improving the return on their investment[1].

Benefits of an EDR

The main benefit of conducting an EDR is clearly the reduced long term energy expenses that are typically over 30% in savings each and every year. This leads to decreased long term energy intensity (a common key performance indicator) as well as potential improved long term operational efficiency and improved long term operations and maintenance. Improvements in other key business drivers such as quality, safety, productivity, etc. may also be achieved depending on the opportunities identified.

In addition to energy, greenhouse gas emissions will be reduced on a long term basis, which will save money in jurisdictions with carbon taxes/fees, and also provide improved employee morale, corporate social responsibility and customer relations.

Energy efficiency solutions do not always have a higher capital cost; some solutions actually have a reduced capital *and* operating cost. Specially trained Certified Energy Managers combined with process experts will bring the largest benefit to your organization.

Comparison of an EDR with Leadership in Energy and Environmental Design (LEED) for New Construction

LEED consists of a suite of rating systems for the design, construction and operation of high performance green buildings, homes and neighborhoods. LEED for New Construction focuses on the design and construction of new residential, commercial and institutional buildings. Hatch's EDR approach for industrial facilities uses some of the same principles as LEED; however, the EDR approach leverages Hatch's process expertise to obtain substantial savings related to optimizing energy consumption of the industrial process.

Hatch's EDR process also leverages ISO 50001 principles for design and operation. The table below highlights the differences between LEED for New Construction and EDR.

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[11]Dover, Megan, Griesbach, Robert, Storey, Robert, and Thorn Corthay, Emily. Carbon Management Technology Conference Paper, "Energy Design Review" 151343-PP Rev. 1, February 2013

Table 1. Comparison between LEED for New Construction and EDR

Criteria	LEED for New Construction	EDR
Type of Facility	Residential, Commercial, Institutional	Industrial
Scope	Energy & Atmosphere, Water Efficiency, Indoor Air Quality, Sustainable Sites, Materials & Resources	Energy
Approach	Benchmarking, Rating	Best Practices Database, ISO 50001
ROI	2% investment →20% lifecycle savings[1] [2]	20-40% energy savings
Practitioners	LEED AP	Certified Energy Manager (CEM)

[2] The Business Case for Green Building" US Green Building Council, July 27, 2012

Methodology

An energy design review is led by Hatch's energy management team and can be conducted on a design that is done by Hatch, the end user or another consultant. Hatch process experts are also involved in helping identify opportunities for energy savings improvements.

A typical project is broken down into different phases: business planning, conceptual study, pre-feasibility study, feasibility study, execution and commissioning as shown below. Contrary to what might be expected, all design phases have the potential to identify options for reduced energy consumption through an EDR – during conceptual, pre-feasibility, feasibility and execution.

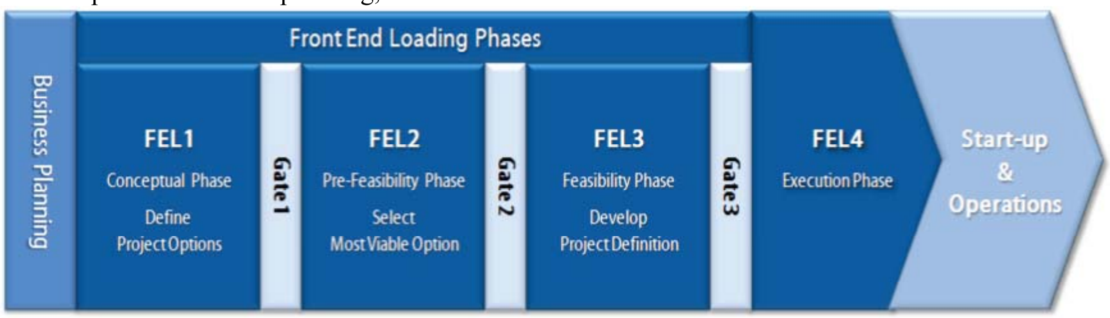

Figure 1. Phased Project Approach

Ideally, an energy design review is not a static, one-time event focused around the EDR opportunity workshop but rather an entire process over the whole project phase where all design engineers incorporate the energy optimization framework identified at the beginning.

Hatch's Energy Design Review approach includes the following:

- Baseline energy use analysis
- Benchmarking against energy management best practices
- Establishing a framework for energy consumption analysis and communicating it to discipline leads
- Interactive workshop style design review focusing on reducing energy waste, improving energy efficiency and optimizing energy supply
- Identifying and quantifying energy-saving and greenhouse gas reduction opportunities using established tools including Hatch's Sustainable Plant Design Guidelines and Hatch's internal Energy Conservation Measure Database
- Integrated design review process using LEED principles and providing awareness of how the international energy management standard ISO 50001 relates to design, procurement, and business planning processes for optimization of energy performance
- Cost-benefit analysis of key opportunities and review with project team
- Operational best practices in line with ISO 50001 to be used once the site has been commissioned

The specific steps in Hatch's methodology are shown in the figure below and described in the following paragraphs.

Figure 2. EDR Methodology

EDR can fit seamlessly into an existing design project or be conducted after a phase has been completed. In either case, it is recommended to have a kick-off meeting for the EDR portion of the project to ensure all stakeholders are properly informed and aligned with the objectives. After collecting the necessary data such as process flow diagrams, piping & instrumentation diagrams, baseline energy consumption estimates etc., preparation for the opportunity workshop begins. This preparation is critical to ensure that all potential opportunities are uncovered. Preparation typically includes reviewing Hatch's proprietary Sustainable Plant Design Guidelines and internal Energy Conservation Measure Database as well as industry guides for industry-specific opportunities such as those prepared by the Canadian Industry Program for Energy Conservation (CIPEC). Identifying best practices used in one industry that could be potentially innovatively transferred to another industry is also employed.

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Key Components of the Methodology

Some of the key components of the EDR methodology are highlighted below:

- Assign an Energy Manager to the project

Assign a member of the design team as "Energy Manager" with responsibility for assisting project personnel in adequately including energy consumption factors in their design work. This role maintains a focus on the project's energy consumption and seeks to meet or exceed the target. This position is important as other factors such as schedule, capital cost, and throughput objectives can be strong project drivers and energy needs to have a champion within the project management structure. The energy manager also has knowledge of leading energy efficiency technologies that other project members may not possess, will challenge the status quo, and will take the time to conduct a high level economic analysis to determine if an energy conservation opportunity is economically feasible.

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At the start of the design work, establish an overall framework for considering energy consumption as one of the criteria in the design of each component of the project. Establish a consistent set of parameters that all project personnel should use in making tradeoffs between size, capital cost, source of energy and energy consumption of components. Set an aggressive target for the overall energy consumption level of the project by benchmarking against the energy consumption of facilities processing similar materials under similar circumstances.

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The table below provides a sample of design criteria used in carrying out an EDR that are included in Hatch's Sustainable Plant Design Guidelines. These particular criteria are a portion of those in the heat transfer and heat recovery section; they have been grouped according to the stage where they are best applied in the engineering design – either concept, preliminary or detailed phases.

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Cleaning of hot gases should be carried out using ceramic bag-houses or other high temperature dust removal devices (e.g. electrostatic precipitators)	Preliminary

where economic to allow heat recovery downstream.	
Prepare a table of recommended insulation thicknesses based on life-cycle costing	Preliminary/detailed
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Table 2: Sample Energy Design Criteria

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Take steps to operate the project under an energy management system in compliance with the international energy management standard ISO 50001.

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This section provides a highlight of the results from four separate case studies. Two of these case studies, the Atmospheric Emissions Reduction project for Vale's Copper Cliff Smelter and Refinery in Sudbury, Ontario, Canada and the New Galvanizing Line for ArcelorMittal Dofasco's Hamilton, Ontario, Canada plant, were part of an EDR pilot project mainly funded by the Ontario Power Authority (OPA). Hatch wishes to express thanks to the OPA as well as to Union Gas and Enbridge for funding the EDR pilot project. The goal of that pilot project was to demonstrate the economic viability of implementing a separate cross functional third party energy efficiency and renewable energy design review in the industrial sector through creation of business cases for multiple Ontario projects.

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During the prioritization process, each opportunity is typically prioritized based on ease of implementation, capital cost and energy savings. Ease of implementation includes not only simplicity or complexity of the project, but also risk and time for implementation. An example of prioritization of opportunities from the EDR of the Vale Atmospheric Emissions Reduction project is shown in the table below. Ideal projects would be located in the cell A1, with the least desirable in the cell D4. In this case, the two preferred projects to begin with are located in C1 as they are easy to implement, have relatively low cost of implementation and medium annual savings.

VALUE OF BENEFIT	**COST OF IMPLEMENTATION** 4 > $ 1M	 3 $ 500k- $ 1M	 2 $ 100k - $ 500k	 1 < $100k
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For the key opportunities, opportunity sheets are prepared that typically include the following information:

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The major results from the EDR of a pre-feasibility study of a confidential greenfield mine & mill follow. Nine key opportunities were identified and quantified and more than 35 other opportunities were identified but not quantified. Forty-two percent energy savings were found compared with the baseline. The three largest opportunities have already been incorporated into the pre-feasibility study design, and the remaining six key opportunities are still under consideration. The key opportunities, ranked by decreasing net present value, are shown below:

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Lessons learned

In conducting the above case studies, the following lessons were learned:

1. Both engineering design consultants and end-users should be targeted for training/incentive programs/tax reductions to conduct energy design reviews since end-users often contract out the designs to engineering consulting firms.
2. A cultural change is often needed for an energy design review to succeed. Bigger is not necessarily better. Also, the project manager needs to buy into the value of an EDR.
3. The earlier an EDR is conducted, the larger the potential for savings (i.e. an EDR at the conceptual stage can have a larger impact than at the detailed engineering stage); however, there are benefits to conducting an EDR at every phase of a project.
4. An EDR should be conducted at the beginning of each phase so that the results can be incorporated into the design of that phase (e.g. at the beginning of the pre-feasibility stage, or at the beginning of the detailed engineering stage).
5. EDR is a whole process over an entire project phase, and ideally over each project phase. It is not just one energy savings workshop identification and prioritization, but rather a change in the mindset of all design engineers to design for optimum energy efficiency as well as for optimum cost, size, timing, complexity, risk, etc.

Keys to incorporating EDR into your company

The following points are some suggestions on how to incorporate conducting EDRs on design projects at your organization.

1. Identify & address internal and external barriers to conducting EDRs.
2. Investigate if funding is available (e.g. British Columbia Hydro's New Plant Design program offers 100% funding for an EDR study and 75-100% of the incremental costs to implement energy efficient solutions identified in design).
3. Create energy design specifications and use them as an integral part of the capital projects process.
4. Use management systems (e.g. ISO 14001, ISO 50001) to formally require energy be

considered in design and in procurement documents.

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The business case for conducting an energy design review is proven. If you are involved in a design project or have colleagues that are, start the discussion today on incorporating an energy design review into your new Greenfield project or large expansion.

ENERGY DESIGN REVIEWS: THE END OF THE ENERGY AUDIT?

Integrating Energy Management in Engineering Design

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Director, Energy Consulting
Hatch Ltd.
Toronto, Ontario, Canada

Abstract

It is much more cost effective to design an industrial plant upfront for optimum energy efficiency rather than retrofit an existing plant, yet typically design engineers and project managers continue to focus on capital costs, not lifecycle costs, often ignoring substantial energy savings potential over the 20-50 year plant life. An average of over 30% in annual energy spending relative to the "business as usual design" baseline was identified in four recent energy design reviews (EDR) for large industrial companies. Typically, energy audits identify energy cost savings of 5-10% of energy spending, thus demonstrating the much larger savings potential of energy design reviews.

This paper will define an EDR, list the benefits, compare an EDR with Leadership in Energy and Environmental Design, describe the methodology, present case study results and lessons learned from four EDRs, and conclude with suggestions on how to incorporate energy design reviews in your organization.

Introduction

It is much more cost effective to design an industrial plant upfront for optimum energy efficiency rather than retrofit an existing plant, yet typically design engineers and project managers continue to focus on capital costs, not lifecycle costs, often ignoring substantial energy savings potential over the 20-50 year plant life. Hatch believes the key to long-term energy reduction is to systematically integrate energy management in industrial plant engineering design.

An average of over 30% in annual energy spending relative to the "business as usual design" baseline was identified in 4 recent energy efficiency design reviews for large industrial companies. Typically, energy assessments (i.e. audits) identify energy cost savings of 5-10% of energy spending, thus demonstrating the much larger savings potential of energy design reviews.

In a carbon-constrained world where fossil fuels are in limited supply, greenhouse gas emissions are being regulated and energy prices are on the rise, it is even more critical to ensure that energy be used as efficiently as possible.

This paper defines an energy design review, describes the benefits, compares it to the Leadership in Energy and Environmental Design for New Construction rating, describes the methodology, presents results and lessons learned from four case studies, and concludes with suggestions on how to incorporate energy design reviews in your organization.

What is an Energy Design Review?

An Energy Design Review is a structured, interdisciplinary and recorded analysis of the design of an industrial Greenfield or large expansion project to determine the most efficient energy solutions that would allow the project to operate safely and reliably. Companies that want to minimize lifetime operating costs carry out these reviews to help maximize the energy efficiency and competitive advantage of facilities thus improving the return on their investment[1].

Benefits of an EDR

The main benefit of conducting an EDR is clearly the reduced long term energy expenses that are typically over 30% in savings each and every year. This leads to decreased long term energy intensity (a common key performance indicator) as well as potential improved long term operational efficiency and improved long term operations and maintenance. Improvements in other key business drivers such as quality, safety, productivity, etc. may also be achieved depending on the opportunities identified.

In addition to energy, greenhouse gas emissions will be reduced on a long term basis, which will save money in jurisdictions with carbon taxes/fees, and also provide improved employee morale, corporate social responsibility and customer relations.

Energy efficiency solutions do not always have a higher capital cost; some solutions actually have a reduced capital *and* operating cost. Specially trained Certified Energy Managers combined with process experts will bring the largest benefit to your organization.

Comparison of an EDR with Leadership in Energy and Environmental Design (LEED) for New Construction

LEED consists of a suite of rating systems for the design, construction and operation of high performance green buildings, homes and neighborhoods. LEED for New Construction focuses on the design and construction of new residential, commercial and institutional buildings. Hatch's EDR approach for industrial facilities uses some of the same principles as LEED; however, the EDR approach leverages Hatch's process expertise to obtain substantial savings related to optimizing energy consumption of the industrial process.

Hatch's EDR process also leverages ISO 50001 principles for design and operation. The table below highlights the differences between LEED for New Construction and EDR.

[11]Dover, Megan, Griesbach, Robert, Storey, Robert, and Thorn Corthay, Emily. Carbon Management Technology Conference Paper, "Energy Design Review" 151343-PP Rev. 1, February 2013

Table 1. Comparison between LEED for New Construction and EDR

Criteria	LEED for New Construction	EDR
Type of Facility	Residential, Commercial, Institutional	Industrial
Scope	Energy & Atmosphere, Water Efficiency, Indoor Air Quality, Sustainable Sites, Materials & Resources	Energy
Approach	Benchmarking, Rating	Best Practices Database, ISO 50001
ROI	2% investment →20% lifecycle savings[1 2]	20-40% energy savings
Practitioners	LEED AP	Certified Energy Manager (CEM)

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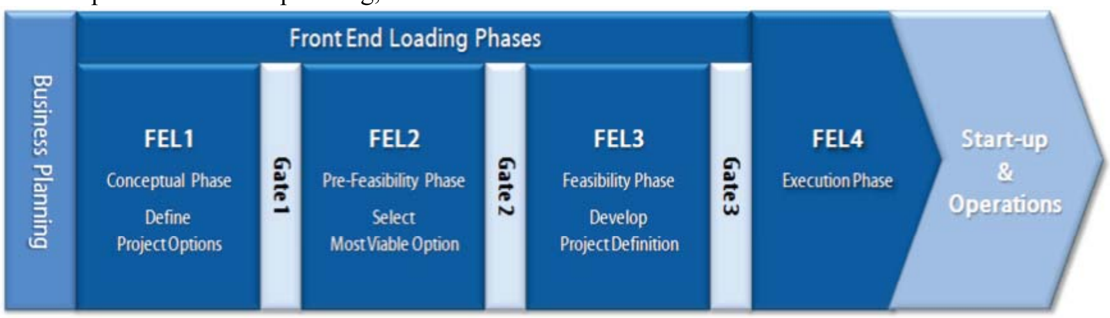

Figure 1. Phased Project Approach

Ideally, an energy design review is not a static, one-time event focused around the EDR opportunity workshop but rather an entire process over the whole project phase where all design engineers incorporate the energy optimization framework identified at the beginning.

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CEPSA: Site-wide Energy Model Empowers Operators to Drive Sustainable Savings

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ABSTRACT
CEPSA operates a complex steam, fuel gas and hot oil network at its chemical complex that produces Purified Terephthalic Acid (PTA) at San Roque (Spain). The site also contracts with neighboring industrial facilities for the exchange of steam, water and fuel gas. The operation of such a complex energy network presents a significant challenge for operators to minimize cost.

"Handles" with which the challenge was addressed included manipulation of boiler steam production, the export/import of steam, fuel gas import and the management of hot oil/steam trade-off for process heating. Real-time management in consideration of these factors presents an overwhelming challenge for the operator.

An online model which considers plant control strategies and system reaction to changes in the utilities was developed and deployed in order to give the operators direct advice about minimum cost utility operation. The following will describe key aspects important to the implementation of a viable solution.

INTRODUCTION

CEPSA was struggling to manage the operation of such a their utility network, which includes management of boilers, the import and export of steam, the import of fuel gas from neighboring sites, and the use of both hot oil and steam for process heating due to the complicated nature of interconnected utility systems. So, CEPSA chose to implement Soteica's Visual MESA solution to optimize their utility optimization. Visual MESA is an online energy management system that enables operators to reduce costs (see references 1 to 6 below), which has been used to drive sustained operational energy savings at industrial sites worldwide through corporate partnerships for energy management with global leaders such as Chevron, Repsol, Phillips 66, and Air Liquide.

In keeping with Soteica's Project Management Organization practice, a complete Visual MESA model of the site was developed, containing the main optimization variables and constraints identified during the project execution. Both a large refining company and Air Liquide have implemented Visual MESA in "Closed-Loop," where setpoints for certain operating variables are sent directly to the control system for implementation. In CEPSA's case, however, the Visual MESA model was built for "Open-Loop" operation, meaning that the operators are required to implement the changes recommended by the model.

So, the key for the successful implementation and effective energy cost reduction is the use of the Open-Loop model by the control room operators on a day-to-day basis. Plant operators are trained to implement the recommendations generated by Visual MESA. These recommendations are continuously updated as the model is automatically executed at a given frequency. In order to capture savings, operators must respond by changing the corresponding controller set points according to the Visual MESA recommendations on a consistent, shift-to-shift basis.

The following describes the main steps required for Visual MESA project implementation steps, including important aspects related to the online model use and interaction with the control system.

CHEMICAL PLANT ENERGY SYSTEM DESCRIPTION

CEPSA is the only producer of purified terephthalic acid (PTA) and purified isophthalic acid (PIPA), in Spain. Both products are raw materials used in the manufacture of polyesters. CEPSA is one of only two producers of PTA and PIPA and manufactures 650,000 tons of PTA and 80,000 of PIPA annually.

At the San Roque refinery, CEPSA operates a complex energy system with the following main features:

- Five steam pressure levels
- Three fired boilers
- Three hot oil furnaces
- Process heat exchanger trains that use both steam and hot oil
- A fuel gas system that includes the contribution of refinery gas purchased from a neighboring site, process off gas and Natural Gas purchased for make up.
- A cogeneration unit, including a gas turbine with its heat recovery steam generation system

Figure 1 shows the high level view of the system in the Visual MESA Graphical User Interface (GUI). By double-clicking on icons of each plant area in the GUI the operators can navigate through the model and inspect the details of each piece of equipment, sensor, or header.

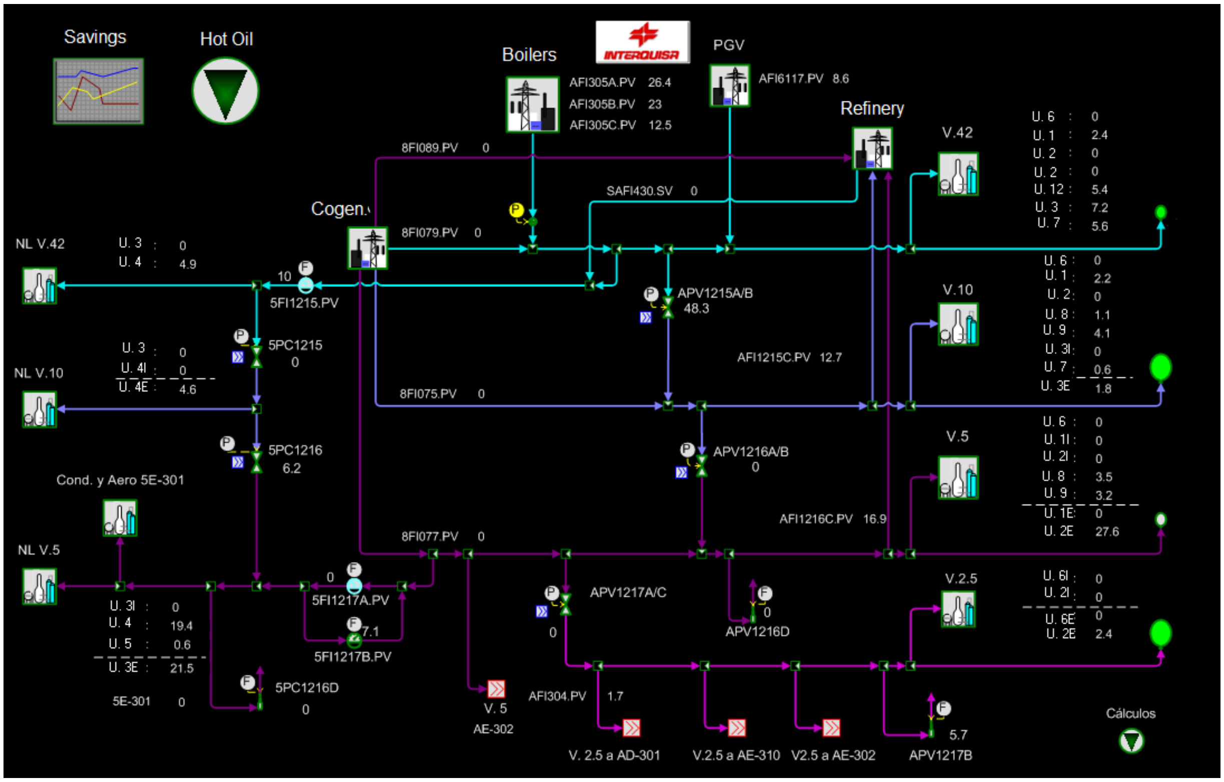

Figure 1. CEPSA Energy System. Top view from Visual MESA model GUI

Figure 2 shows the detail of the Boilers Plant and Figure 3, the Hot Oil distribution network.

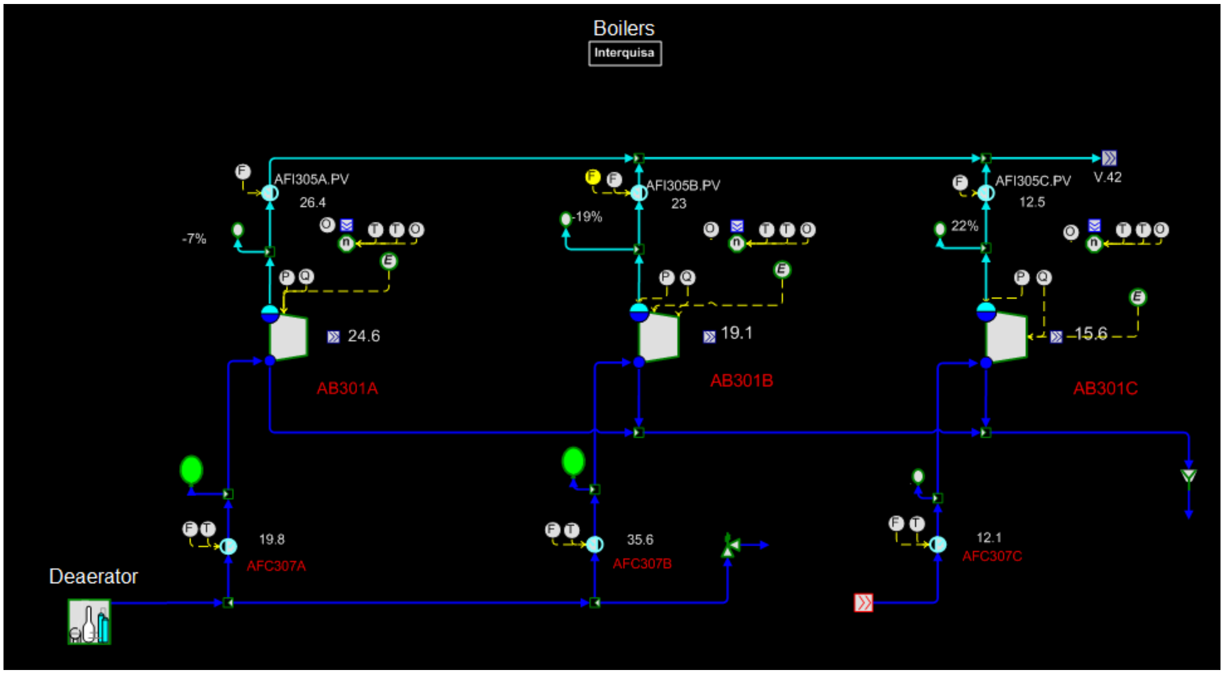

Figure 2. Boilers Plant Model Area View

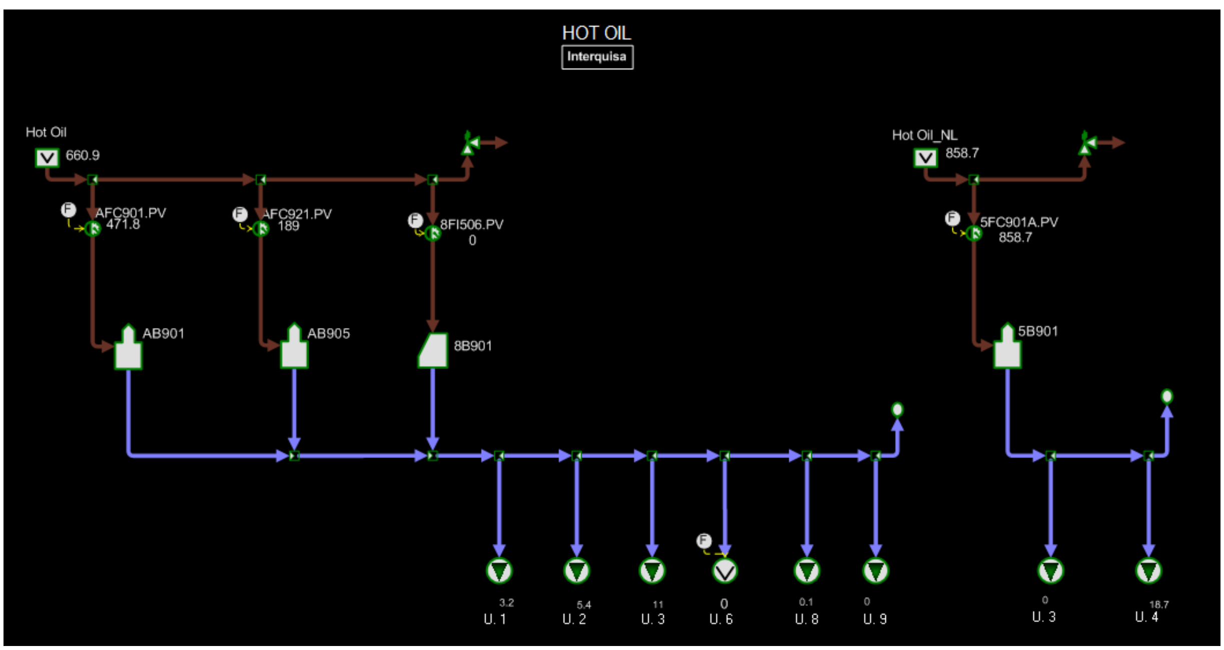

Figure 3. Hot Oil Network Area View

PROJECT METHODOLOGY AT CEPSA

Deployment of the Visual MESA solution at CEPSA began with an initial data collection stage that includes the gathering of needed Piping and Instruments Diagrams (P&IDs), a tag list from the Real Time Database (Plant Information System or Historian), Process Flow Diagrams (PFDs), and equipment data sheets.

Software installation and connection to the Plant Information system was also done at the beginning of the project. It is important to note that because online connectivity to the Plant Information system occurs at the inception of a Visual MESA deployment, a transition step from “offline” to “online” mode, as is often needed in the project development for other software, is not required for Visual MESA deployment.

Control system review was completed next and is an important step which will be described in more detail to follow.

Once the control strategy was well understood and online connectivity is established, Soteica built a complete model of the overall Energy System at CEPSA. The model included the complete sitewide fuel, steam, boiler feed water, condensate and electrical systems, specific to the San Roque site.

All the steam pressure levels were modeled as well as each of the production units’ utilities network, including a high level of detail including all the consumers and suppliers to the respective steam, boiler feedwater, hot oil and condensate headers. In particular, the hot oil system at San Roque was a unique aspect of their particular site model not seen at other sites.

Accuracy of electric power purchase and sale and fuel supply contract details was critical to the accuracy of the CEPSA model. Soteica has developed highly detailed and accurate contract modeling capability in Visual MESA. Electricity market cost data and natural gas pricing are provided in real-time from Plant Information system tags that are updated from online sources, such as www.theice.com. This was done at CEPSA, as it is in all Visual MESA implementations, to minimize the manual input required by the operator to ensure accuracy of the model’s optimization solution.

Modeling of fuel gas network at CEPSA included the fuel supply to steam and power generation equipment includes all constraints and degrees of freedom from the fuel perspective.

Visual MESA’s objective function is defined as the total operating cost of the system, calculated as follows:

Total Operating Cost = Total Fuel Cost + Total Electric Cost + Σ Miscellaneous Costs

The optimizer’s job is to minimize this objective function subject to operating constraints in the system. The optimization problem solved has a mixed-integer and non-linear structure and the decision variables include both continuous (i.e., boiler steam flows, fuel usage and let-down flows) and discrete ones (i.e., turbine or motors, boiler and fin-fan condenser statuses).

Total Fuel Cost is determined from the fuel use of each boiler, heater and combustion turbine multiplied by their respective fuel prices. The fuel price applied can be specific to the fuel use,

Total Electric Cost is determined from the net electric use of each motor, load, and generator multiplied by their respective electric prices. The electric generation is simply modeled as negative electric use. The model can take into account the electricity price corresponding to the actual hour of the day as well as the penalties associated to buying or selling more or less power than scheduled. Visual MESA has been deployed in both regulated and deregulated power market environments. Similar to fuel, the price applied to electricity use and generation can vary based upon the market rules and “net” power calculation, as needed.

Miscellaneous Costs are used to group other Energy System related costs, such as demineralized water makeup, cost of oxygen scavenger for water treatment and CO2 emissions cost.

After the initial model and optimization configuration was reviewed with users at CEPSA, training for both engineering and operator user levels was performed.

Model fine-tuning and analysis of the optimization result were then performed on a daily basis during the model review phase. Minor model modifications and addition or adjustment of constraints were also completed during this phase in order to ensure that the model accurate represents the operators’ “reality.” At the end of this stage, operators were consistently implementing Visual MESA’s recommendations on a shift-to-shift basis.

At the Commissioning stage, the model was being used by Operations for ongoing site-wide utility costs minimization and functioning as an “Energy Watchdog,” automatically seeking savings opportunities in the utility system 24/7/365.

Economic benefits that had already been obtained were reviewed and final improvements and plans were made for keeping the model "evergreen" post-implementation through Soteica's site-specific model Sustainability Program to which CEPSA subscribed.

The following describes important aspects of an Energy Management system implementation.

Control System Review

A key stage of an energy optimization online system deployment is the comprehensive review of the steam, power, and fuel control systems of the site.

The main goals of the Control System Review are as follows:

- Develop a good understanding of how the Visual MESA optimization handles and process constraints are related through the site control system.
- Identify any new control strategies or changes to existing strategies that are needed to implement the optimization recommendations.

The desired outcome is for operators to be able to implement the optimization recommendations using the site's operating procedures with existing control strategies and control structure.

The optimizer's main decision variables at CEPSA were the following:

- Steam production rates from boilers. Boilers can be either on pressure or flow control. If by pressure control, the boiler steam generation is controlled by the steam pressure header controller. If by flow control, operators change the boiler load manually, in accordance with the optimizer recommendations.
- Natural Gas import to the fuel gas system, usually manipulated by a Fuel Gas mix drum pressure controller.
- Letdowns, vents, and steam condensing, located in two plant areas, are controlled by the steam header pressure controllers, in the case of letdowns and vents, and by the manually start or stop of motors of fin-fan steam condensers.
- Steam and Fuel Gas sold and purchased to/from neighboring sites or consumed or supplied to internal plants, manually adjusted by the operators.

During the Control System Review, Operators give their input regarding the appearance of the model representation in the GUI. Oftentimes, effort is made to create graphical representations in the model that are similar to the appearance of their DCS screens. The model's success in an Open-Loop implementation is fully dependent on the operators taking action on the optimization recommendations on a regular basis, so great care is taken in the development of the model screens.

Real time data and sensor validation

A standard OPC-based (OLE for Process Control) interface is the standard interface in Visual MESA for communication with the client data sources for the model, which can include the Distributed Control System (DCS) in addition to the Plant Information system. OPC connectivity is a standard communication protocol, so connectivity to other systems is robust.

OPC supports protocols for both Data Access (DA) for instantaneous data acquisition and Historical Data Access (HDA) for historical data acquisition. So, Visual MESA can be used to evaluate cases with either real-time or historical data.

The CEPSA model in particular contains approximately 600 sensors. Most of these sensors are linked to tags from the Plant Information system providing real time data. Others sensors in the model are linked to Plant Information system tags to which they write back calculated data and Key Performance Indicators (KPIs) to be saved in history with every model run.

During the building of the model, sensors, with their associated properties, are linked to the model simulation and optimization blocks by simply dragging and dropping the corresponding icons from the builder's palette in the GUI. Each sensor object in the model is then configured to protect the model from measurement errors and bad values using the extensive set of validation features provided.

Figure 4 shows Visual MESA's standard configuration options in case of a sensor data validation failure. As the model is designed to be executed automatically, fed with online data, the raw values coming from the Plant Information System should be carefully validated each time they are acquired. If a sensor fails, the software allows the user to configure predefined actions for the model to take regarding default values to use, configuration of optimizers or constraints related to the given sensor, and other important aspects related to real-time optimization run.

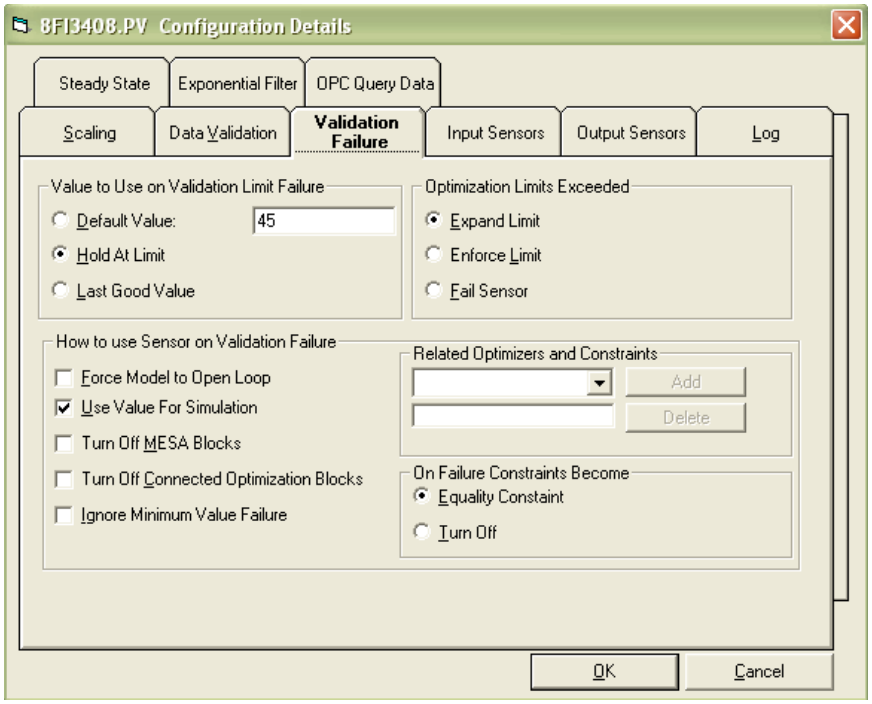

Figure 4. Configuration Details of a Sensor Added to the Model

Installation Architecture

Visual MESA was created for two types of uses:

- Stand-Alone use (Engineering station)
- Client-Server use (Engineering, Shift Supervisors, Operators and Managers stations)

The purpose of the Stand-alone use (Engineering station) is for individual users to be able to run case studies on their own PCs, using the current site model or any other model the user may have built to perform "What-if?" analyses. The models can be populated with current data, or historical data from the Plant Information System via standard OPC Historical Data Access. Multiple runs with varying parameters can be configured and launched from within MS Excel, writing back the desired model output values.

The purpose of the Client-Server use is to calculated and share the current online optimization results, primarily for the operators in order for them to implement the recommendations in operations to capture available savings. The secondary purpose of the Client-Server use is to broadcast the results of the model, not only the savings, but also other KPIs, such as equipment efficiencies and incremental cost, across the organization. The Visual MESA server runs as a service on the Visual MESA server, meaning it launches the optimization automatically every 15 minutes, in the case of CEPSA, and publishes results through the Excel report and to the Plant Information System. Any user's machine connected to the plant network can be configured to access the model and the reports. Users can view model results in multiple ways (html and Excel reports, Graphical User Interface).

Figure 5 shows the information and control network at CEPSA site, including the location of Visual MESA server and PC clients.

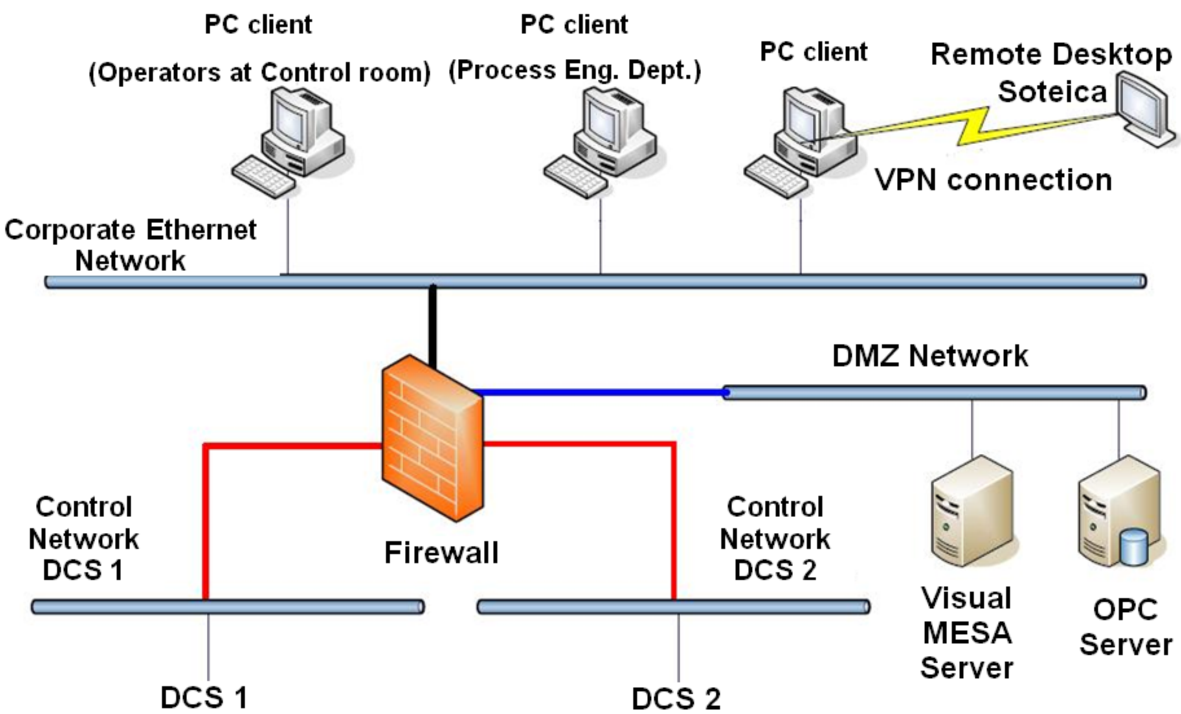

Figure 5. Installation Architecture

Writing Results to History

Visual MESA writes selected calculated results from the model, including KPIs, utility system economics and calculated efficiencies to the Plant Information System. The predicted savings are calculated with every automatic execution of the optimizer. The predicted savings are the most important KPI that the model calculates. This value is the savings that could be captured if the operator follows all of the recommendations of the model.

As the operators implement the optimum solution on a regular basis, the projected available savings will decrease as the operators manage the utilities closer and closer to optimum. Eventually, a regular pattern develops with the system detecting a new saving opportunities due to an operational or pricing change followed by the operators taking action on the optimization recommendations. A persistently high projected savings trend will trigger questioning from Supervision or Engineering staff or other member of the operations team.

Equipment efficiencies commonly saved to history are:

- Boiler and heater efficiency
- Gas Turbine and Heat Recovery Steam Generation (HRSG) system efficiencies
- Gas Turbine heat rate
- Header imbalances (The software automatically calculates the imbalances for each header where a special ad-hoc calculation block, called a “balloon” is located)

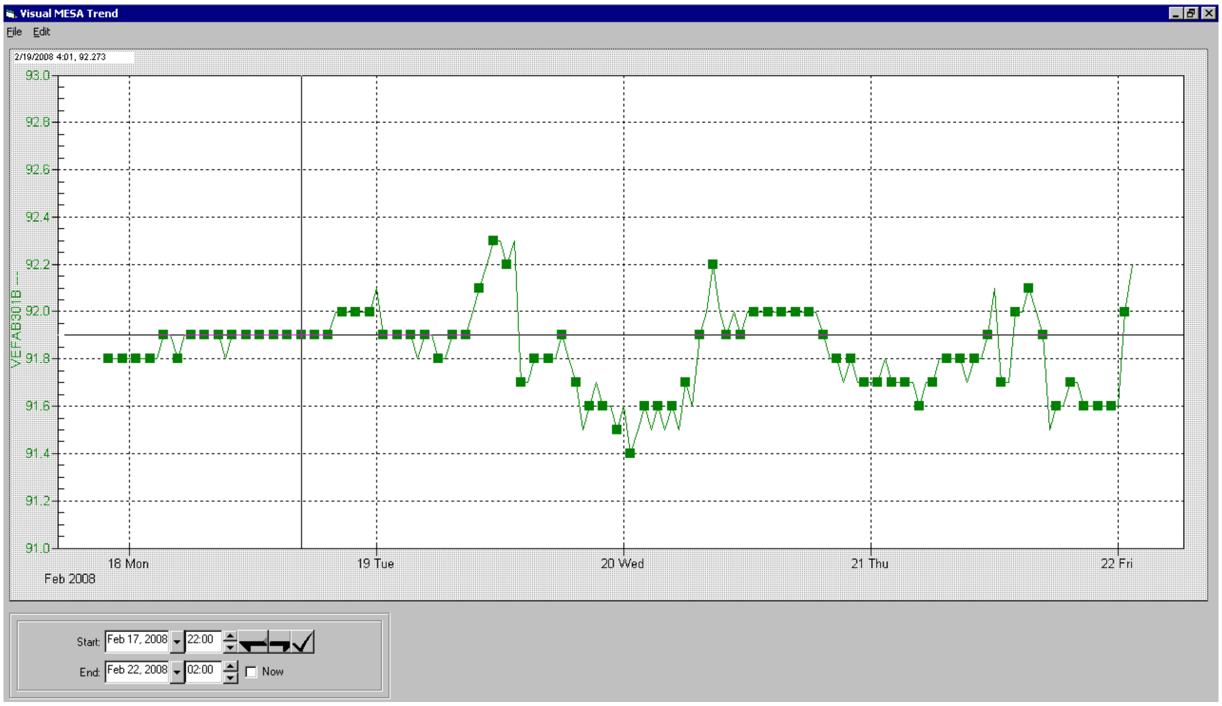

Figure 6. Calculated Boiler Efficiency Trend

Long term trends help to identify equipment that is losing efficiency and can be used to justify cleaning or replacement. A calculated boiler efficiency trend is shown in Figure 6.

Also, the header imbalances are often related to sensor failures. A sudden increase in an imbalance can trigger the search for the cause. Once a failing meter is identified by technicians alerted to the error by a changing Visual MESA header balance "balloon," the meter would be repaired or calibrated.

CONCLUSIONS

An online, “Energy Watchdog” model in use at CEPSA’s San Roque site enables operators to drive lowest cost utility system operation on a continuous basis. These savings are enabled because of a careful and detailed deployment of the Visual MESA sitewide utility optimization model, taking into account all relevant constraints, cost of fuel and power, and equipment operating parameters.

In addition to accounting for utility control system structure and performing data validation, the system user interface is tailored to client specifications so that use of the model is quickly adopted by the operations staff. In this way, the use of Visual MESA is integrated into the Standard Operating Procedures to ensure the utility system is operated according to best practices, as defined and driven by the optimization model over time.

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ISO 50001: A Global Energy Management System Standard

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ABSTRACT

ISO 50001:2011 provides benefits for any organization to establish a framework to manage and improve energy consumption. The framework of ISO 50001:2011 enables organizations to establish the systems and processes necessary to improve energy performance, including energy efficiency, use, and consumption. This standard is expected to achieve major, long-term increases in energy efficiency in industrial, commercial, and institutional facilities and to reduce greenhouse gas emissions worldwide. The following paper describes the need for the international standard, its purpose, origins, review of key standard requirements including a comparison to existing management standards and the value of third party certification.

Keywords: ISO-50001; Plan - Do - Check - Act (PDCA); Energy Performance Indicators; Certification Audit; Energy Baselines, Review, Policy, Management Commitment, Legal and Other Requirements, Energy management

ORIGINS AND DEVELOPMENT OF THE STANDARD

The recently adopted standard, ISO 50001:2011 is a specification created by the International Organization for Standardization (ISO) for an energy management system. The standard specifies the requirements for establishing, implementing, maintaining and improving an energy management system, whose purpose is to enable an organization to follow a systematic approach in achieving continual improvement of energy performance. This includes energy efficiency, energy security, energy use and consumption practices. The standard aims to help organizations continually reduce their energy use, and therefore their energy costs and greenhouse gas emissions.

Energy management system standards have been around for several years however its origins include American National Standards Institute (ANSI) first publication in 2000 and several other countries followed including development of EN 16001 in 2009 by the European Union. In 2007, ISO received a formal request to begin on an international energy management system standard from a 2007 United Nations Industrial Development Organization energy expert meeting. In 2008, ISO Project Committee 242 was formed to begin work on development of the new standard. The United States Department of Energy and ANSI assumed leadership roles on ISO Project Committee 242. The standard was released in June 2011 which was two years earlier than traditional standard development times.

National accreditation programs followed later in 2011 through to 2012. The system is modeled after the ISO 9001:2008 Quality Management Systems and the ISO 14001:2004 Environmental Management Systems. In North America, two recognized programs for energy management include ISO 50001:2011 and Superior Energy Performance both offered for accreditation under ANSI-RAB National Accreditation Board (ANAB). Accreditation requirements follow ISO 17021:2011 requirements and ISO 50003 defines the audit processes (including audit time) and auditor requirements are in development by ISO TC 242. Auditor certification to the ISO 50001:2011 National Exam in the United States is encouraged however not required.

IMPLEMENTATION OF ISO 50001:2011

Implementation of an energy management standard within an organization requires a change in existing institutional practices toward energy, a process that may benefit from technical assistance from within or experts outside the organization. It enables an organization to follow a systematic approach to achieving continual improvement of its energy performance, including efficiency, usage and consumption. The process of adopting ISO 50001:2011 is highly beneficial for organizations, especially those with reporting and transparency pressures from shareholders and other entities requesting measurement data. This management system standard will help these companies formalize accepted best practices and ensure accurate and standardized reporting. However, the ultimate benefit is in the form of sustainable energy savings that arise out of following this approach.

The standard specifies that an organization should establish, document, implement, maintain and improve an energy managements system in accordance with the standard requirements; define and document the scope and boundaries of its system; and determine how it will meet the requirements of this ISO 50001:2011 in order to achieve continual improvement of its energy performance. The standard is based on the Plan - Do - Check - Act (PDCA) continual improvement framework and integrates energy management into daily organizational practices.

This is a similar approach utilized in the ISO 9001 Quality Management Systems and ISO 14001 Environmental Management Systems standards to provide compatibility and integration opportunities.

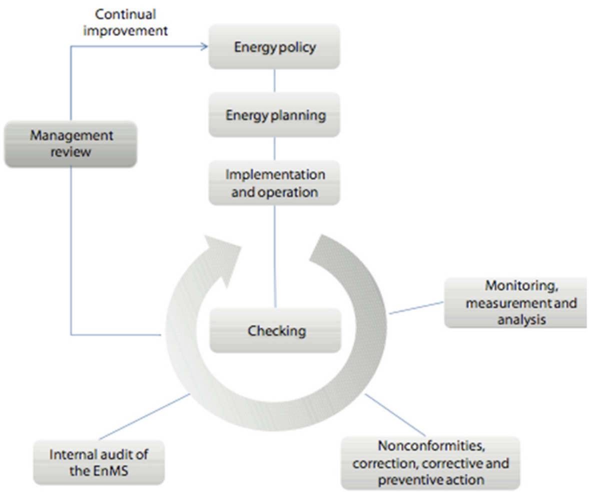

Figure1. ISO 50001:2011 2011 Structure

Plan (P): Conduct the energy review and establish the baseline, energy performance indicators, objectives, targets and action plans necessary to deliver results that will improve energy performance in accordance with the organization's energy policy;

Do (D): Implement the Energy management action plans;

Check (C): Monitor and measure processes and the key characteristics of operations that determine energy performance against the energy policy and objectives, and report the results;

Act (A): Take actions to continually improve energy performance and the Energy management system.

The requirement for documentation is dependent on the nature, size and needs of the organization. ISO 50001:2011 is considered a "data" standard and therefore has fewer firm documentation requirements than other management system standards. The few documentation requirements related to this standard will present challenges to organizations as well as auditors. There may be some difficulties related to consistent application of standard requirements if an organization takes a minimal documentation approach. Auditors will need to assess effectiveness based on evidence and data presented. There will not be manuals and procedures on which to base audit trails.

CORE REQUIREMENTS FOR COMPLIANCE

The core requirements for an ISO 50001:2011 complaint energy management system include:

- Top Management Commitment
- Definition of Scope and Boundaries
- Development and Communication of an Energy management Policy
- Identification of Energy Related Legal and Requirements
- Develop, Document and Implement Energy Review Process
- Establish Energy Baselines and Key Performance Indicators
- Establishment of Energy Objectives, Targets and Action Plans
- Implement internal and external Energy management system communication requirements
- Establish and implement operational criteria for operation and maintenance of facilities, systems, equipment and processes
- Establish process for energy performance evaluation in design of facilities, systems, equipment and processes
- Establishing energy procurement process and development of energy purchasing specifications.
- Development and Implementation of the Energy Measurement Plan, including calibration of measurement devices.
-

The required documents include:

- Scope and boundaries of the Energy management system
- Energy Policy
- Energy Review Methods and Criteria
- Energy Performance Indicators, including methodology for determination and updating
- Energy Objectives, Targets and Action Plans
- Energy Purchasing Specifications

- Energy Measurement Plan (defined vs. documented).
- Any additional documents needed by the organization

The required records include:

- Energy Review Data
- Energy Baseline Data
- Competence Awareness and Training
- Decision related to external communication
- Results of energy evaluation in design activity
- Energy Key Characteristic Monitoring and Measurement Results
- Measurement Equipment Calibration Records
- Results of compliance evaluation with legal and other requirements
- Internal Audit Results
- Records of Corrective/Preventive Action
- Management Review

Full implementation of ISO 50001:2011 management system practices and principles will require an organization to develop a system to establish, document control and record management. The organization should review capacities internally for competence, awareness and training. Defined internal audits and a process for corrective and preventive action alongside management review should also be completed.

KEY CLAUSES OF THE STANDARD

Similar to other ISO management system standards organizations can choose to have a third party audit and certify their ISO 50001:2011 management practices. This paper further examines the highlights and notable comparisons to existing management system standards.

Management responsibility.

Management responsibility is of the first requirements of ISO 50001:2011. Management must be responsible for policy and for scope and boundaries of the Energy management system and approve the energy management team. A management representative should also be assigned and additional responsibilities and authorities include the need for appropriate skills and competence. The organization should identify persons authorized by an appropriate level of management, to work with the management representative in support of energy management activities, ensure that the planning of energy management activities is designed to support the organization's energy policy. The management representative should define and communicate responsibilities and authorities in order to facilitate effective energy management. The representative should determine criteria and methods needed to ensure that both the operation and control of the Energy management system are effective and promote awareness of the energy policy and objectives at all levels of the organization.

Scope of certification.

The scope of certification is the extent of activities, facilities and decisions that the organization addresses through an energy management system, which can include several boundaries. All elements activities and facilities included in the scope must be on a metering system. The scope cannot exclude elements contained within these metering systems.

Energy policy.

The energy policy follows similar to ISO 14001:2004 management system requirements with the following adder supporting the purchase of energy-efficient products and services, and design for energy performance improvement. Energy planning is one of the few requirements of ISO 50001:2011 which requires the organization to document the process.

Legal and other requirements.

Legal and other requirements is described similar ISO 14001:2004 management system requirements. Domestically there are few energy legal requirements; other requirements may be more applicable.

Energy Review.

Energy review is one the most critical clauses of the standard. The organization must document methods and criteria for performing the energy review. It consists of the following distinct components.

- Analysis of Energy Use and Consumption
- Identification of Significant Energy Use

- Identification, prioritization and recording of energy improvement opportunities.

Two specific process requirements include identification of all energy sources and evaluation past and present energy consumption. This generally involves the energy balance process. Consumption data must be assessed utilizing a common energy measure (e.g. KWh, mmBtu) and appropriate conversion factors will need to be applied utilizing data from energy consumption and use analysis. The standard does not prescribe the method for determining significance but it does identify the criteria to be considered:

- Facilities, equipment, systems, processes and personnel that significant affect use & consumption
- Other relevant factors affecting significant energy use (e.g. weather, operational changes)
- Determine current energy performance
- Estimate future energy use and consumption

If the Energy Analysis is incomplete or not comprehensive (e.g. omission of an energy source, failure to evaluate future energy, the determination of significant energy use and subsequent energy planning requirements will be flawed. The energy analysis must be updated at defined intervals and in response to major changes in facilities, equipment, systems, or processes within the organization.

<u>Energy Baseline.</u>

The energy baseline refers to the quantitative reference for comparison of energy performance. It is calculated using a set period of time that is appropriate to energy use and consumption and is to be used to measure changes in energy performance. Adjustments to the baseline are required when energy performance indicators no longer reflect organizational energy use and consumptions or there have been major changes to the process, operational patterns, or energy systems. This can be normalized for variables that affect energy use and consumption.

<u>Energy Performance Indicators (EnPI).</u>

Indicators are a quantitative value or measure of energy performance and is to be established by the organization. For example, EnPIs can be established at various levels:

- Facility Level (Btu per units produced)
- System level (Btu per lb of steam)
- Process Level (Btu per lb of paint)

ISO 50001:2011:2011 is the only international management system standard to specifically require performance metrics.

<u>Energy Objectives, Energy Targets and Energy management "Action Plans".</u>

These requirements are similar to ISO 14001:2004 standard and include the factors to be considered when establishing objectives (responsibility, means in which objective is to be achieved and assignment of responsibility). Energy management requirements include two statements in addition to the ISO 14001:2004 requirements: one of the method by which an improvement in energy performance shall be verified and second a statement of the method verifying the results.

VALUE OF CERTIFICATION

At the end of the implementation process, an organization can choose to have the energy management system independently certified. ANSI-RAB National Accreditation Board (ANAB) accredits certification bodies in accordance to ISO 17021:2011 requirements. Certification is sought in a two system initial audit process which includes a readiness review and an assessment audit. This is followed by a minimum annual surveillance audit. Audit time determination will consider energy usage and then other factors such as size and nature of the organization's processes. This is a departure from other Management System schemes in which head count is the beginning basis for audit time determination. Total annual energy consumption in a common energy unit (MM Btu preferred) for the scope and boundaries for which certification is being sought. This includes total number and details of energy sources number of employees directly involved in energy management system and listing of significant energy uses.

Some of the benefits achieved for third party certification of this standard include:

- Reduce Increase energy efficiency
- Demonstrate a commitment to sustainability
- Support energy conservation
- Reduce greenhouse gas emissions
- Improve use of energy assets

- Formalize and refine energy procurement practices
- Reduce energy related operational costs

ANSI-RAB National Accreditation Board (ANAB) has established the following scopes of accreditation for Certification Bodies:

- Commercial Buildings
- Light to Medium Industry
- Heavy Industrial
- Transportation
- Building Complex Energy Use
- Energy Supply
- Other

Auditors will have to demonstrate competence in energy management, basic energy principles as well specific industry experience to the accreditation scopes noted above.

ISO 50001:2011 can be applied across an entire organization or within specific industrial plants or operating facilities. Implementing an energy management system certified to ISO 50001:2011 or including these principles into an existing management system will help organizations to improve their energy performance, increase energy efficiency, minimize energy use, better manage energy consumption and reduce greenhouse gas emissions**.** The ISO 50001:2011 energy management standard is based on common elements found in other ISO management system standards such as ISO 9001:2008 and ISO 14001:2004, assuring a high level of compatibility for any organization. At a very competitive time, organizations would be well-advised to look at the opportunities offered by adopting the strategic approach of ISO 50001:2011.

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SUCCESSFUL IMPLEMENTATION OF A SUSTAINABLE STEAM TRAP MANAGEMENT PROGRAM

JONATHAN WALTER BUSINESS DEVELOPMENT MANAGER TLV CORPORATION NC

ABSTRACT

Plants are typically focused on meeting safety, production and quality targets. The impact of steam traps on these goals is sometimes not fully understood, so traps may be neglected or ignored for prolonged periods. However, there may be a significant cost penalty in delaying implementation of a program to manage the steam trap population.

Plants typically embark on a trap management initiative by focusing on a survey, but may not maximize returns because they fail to execute or sustain possible improvements. There are three areas that can help ensure benefits and sustainability of a program:

1. Pre-implementation strategic planning
2. Onsite program implementation tactics
3. Ongoing program review

This paper presents an overview of these three areas.

JUSTIFICATION FOR IMPLEMENTATION

The first key to successfully implementing a steam trap management program is for the site to be sufficiently motivated to really want to implement one. The motivation for implementing the trap management program must cover all levels and groups in the organization and will typically include:

1. Cost of leaking steam (1, 2)
2. Risk of production impact (3)
3. Maintenance costs
4. Mitigation of personnel safety risks
5. Reduction of green house gas emissions

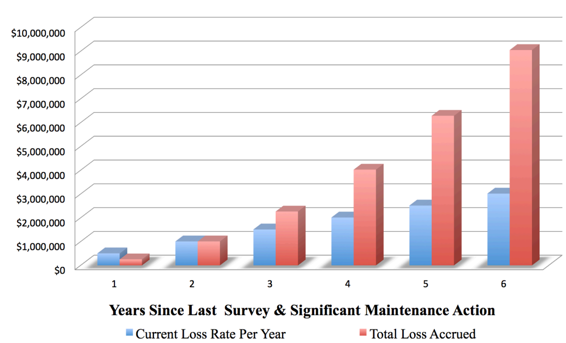

Figure 1. Annual and Accrued Financial Loss After Years of No Action

The magnitude of justification is likely to increase if the plant has not been recently managing the steam trap population. Figure 1 (above) shows an example of how annual and accumulated loss may increase in a 6,000 trap facility if a program is not in place to properly address steam trap failures. These figures are based on a steam cost of $5 per 1,000 lb, annual cost impact of $800 per cold trap, and 10% un-addressed annual trap failure rate.

PRE-IMPLEMENTATION PLANNING

Once the plant has decided to implement a program there is often a tendency to rush to do a survey with a hope of quickly replacing traps. However, it may be more prudent to spend additional time in the planning phase. The planning areas that typically have the largest impact on the success of the program are:

1. Selecting & preparing to correctly install the "best" steam traps for the site's conditions
2. Selecting the most accurate diagnosis technology & testing resources
3. Defining the program scope

How to Select and Install the "Best Trap" for the Site

An effective framework for this is an application based life cycle cost model matching trap technology to address specific plant challenges.

A trap's life cycle has four phases with four basic cost components (4):

1. A new trap is installed requiring an initial product purchase and labor installation cost
2. The trap operates correctly but will have Functional Steam Loss (FSL) measurable to international standards (5,6)
3. The trap fails and either leaks steam or creates a cold trap risk
4. The trap is repaired or replaced which incurs further product and labor costs

Figure 2 shows a 10 year life cycle comparison of four different trap models in a typical drip service. This shows that the cheapest initial purchase cost may actually be the most expensive for the plant to own.

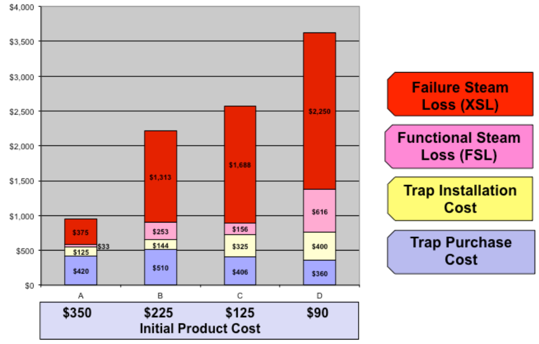

Figure 2. 10 Year Life cycle Comparison

Trap selections should be documented to create a plant standard. This should also include plant specific installation guidelines and hook up drawings. This helps with maintenance and also with outsourced projects to ensure traps are supplied and installed to the plants "best practice" requirements.

Diagnosis Accuracy

Diagnosing the operational status of the steam trap has a significant impact on the profitability and impact of the program. There are 4 potential cases for trap diagnosis:

1. Trap operation is correctly diagnosed – there is no diagnosis cost impact on the program
2. A "GOOD" trap is incorrectly diagnosed as either leaking or blocked, so the site may spend needless money purchasing and installing a replacement trap making absolutely no impact on the steam system
3. A "LEAKING" trap may be missed, leaving it in place and wasting energy
4. A "BLOCKED" trap may be missed leaving the potential risk of plant impact in place

Considering the financial penalty of the last three misdiagnoses it may be reasonable to assume that there is an average cost of $600 per diagnosis error. If 3 misdiagnosis errors are made per 100 tests then in a 1,000 trap population the plant may incur a hidden misdiagnosis penalty of $18,000 (or for a larger 6,000 trap facility a cost of $108,000). The misdiagnosis cost could be viewed as the equivalent of a "testing penalty" for each trap in the population of $18 per trap ($18,000/1,000 traps in the population). This financial impact highlights the criticality of correctly diagnosing the trap before taking costly maintenance action. This may influence the choice of testing technology if one testing method can be shown to be more accurate than another, even if it is more expensive and take more time to undertake.

Agree Survey & Replacement Parameters

It is important to determine the scope of the survey and maintenance actions before the survey starts. If the trap testing will be outsourced, then a clear scope of work is essential to ensure that a valid bid is proposed and costs are clear. Three areas of program scope that deserve special attention are:

1. Onsite data collection including
   a. Identifying applications
   b. Recording trap importance
2. Special trap testing requirements
   a. Clarifying why traps are cold or out of service
   b. Blowing strainers down
3. Trap replacement philosophy
   a. Focus on cold traps
   b. Set leakage hurdles for replacement

ONSITE PROGRAM IMPLEMENATION

If the trap management program has been well planned as described above then execution should go smoothly, so it is worth investing time upfront. There are three key areas that can influence the success of the implementation phase: Testing, Maintenance Response, and Oversight.

Testing

Determining who will perform the testing and ensuring they are adequately trained is critical to the success of the survey. Common options include site employees, maintenance contractors or testing specialists. Once the resources are determined, then it is standard practice to work through the testing logistics such as non disclosure agreements, work contracts, site access, permits, equipment approvals and licensing, etc. However, three areas are commonly overlooked and should be carefully considered:

1. Locating & identifying the trap to be tested
2. Ensuring traps can be accessed and are free from insulation
3. Process operations support to ensure an accurate and efficient survey

For large plants, the results of testing should be periodically handed over to the maintenance team, so failures can be addressed as soon as possible rather than waiting until the end of the survey and facing an overwhelming action list.

Maintenance Response

Planners may need to be involved to control materials, raise work orders, arrange scaffold access, and facilitate maintenance work. Tactics that can support this work to increase the speed and accuracy of the maintenance response will reduce the time that failed trap losses accumulate, therefore improving the return on investment of the program. This may include items such as:

1. Training
2. Use of trap selection & installation reference materials
3. Onsite validation of installations
4. Support from trap vendor
5. Recording maintenance actions in a searchable database

Oversight

Tracking maintenance response rather than simply looking at survey findings is important since no benefits actually occur until a failed trap is corrected. One way to do this is to efficiently create and review a meaningful monthly or quarterly report, which should be reviewed by the plant champions and ideally senior or corporate managers who can hold the plant accountable to action.

ONGOING PROGRAM REVIEW

When the survey is completed, the failure data should be analyzed to determine if there are any common failure modes in categories or combinations of categories such as areas, applications, trap types (or models), and pressures. The effectiveness of the maintenance response should also be reviewed to identify how to improve in the future. When three to five years of surveys have been completed, then an analysis of historical data should also be undertaken. Analysis results should be carefully reviewed by senior management who may be able to encourage program improvements, which may have further significant cost benefits for the site.

CONCLUSIONS

The successful implementation of a trap management program requires:

1. Everyone to understand the potential prize
2. Appointment of champions
3. Involvement of managers and workers in Operations, Engineering, Maintenance, Energy and Purchasing Groups
4. Selecting the best trap for an application according to life cycle costs
5. Creation of “best practice” standards supported by training and onsite validation of trap installations
6. Selecting trap diagnosis technology and testers to ensure accurate judgments
7. Specifying data to be collected that will improve the program in the long term
8. Determining replacement criteria to optimize resources and budgets
9. Updating a central database with maintenance actions to enable root cause analysis to improve the program
10. Monitoring of implementation performance
11. Conducting annual and historical data reviews to improve the program

Once the essential first step of managing a steam trap program is in place, then other opportunities to improving the steam system (8) should be explored. This may include initiatives such as improving specific steam using applications and then looking at the entire steam and condensate system balance.

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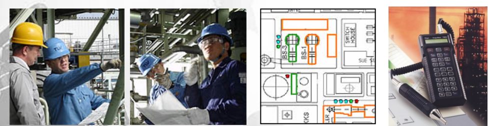
Successful Implementation of a Sustainable Trap Management Program



TLV®

Jonathan Walter

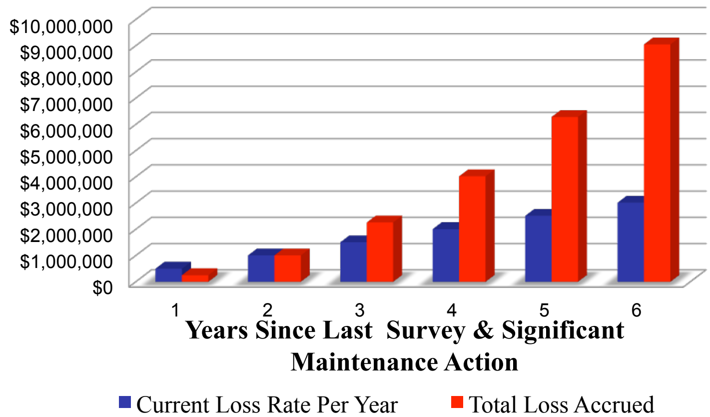
Overview

- Motivation
- Planning & Preparation
  - Trap Selection
  - Diagnostic Accuracy
  - Program Scope & Logistics
- Implementation
  - Testing
  - Maintenance Response
  - Oversight
- Sustaining & Improving the Program
  - Annual Review
  - Historical Trend Analysis

Motivation

Site Must REALLY want to do it

6,000 Trap Population



Safety Reliability Production

Motivation

Corporate Focus

Scorecard | Budget

Program Champion

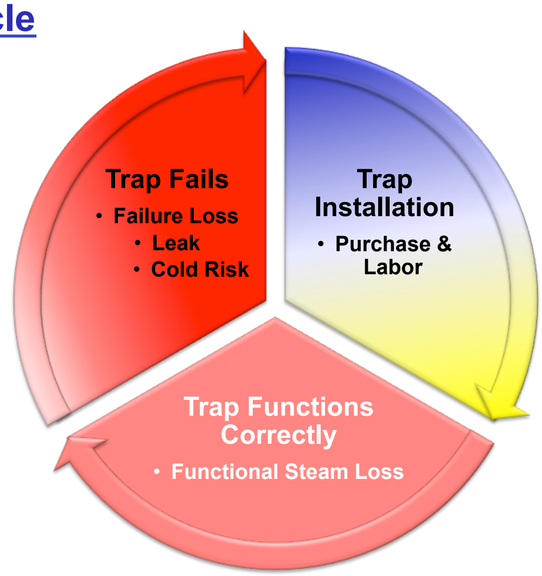
Plant Groups

Maintenance | Operations | Energy

Managers | Technicians | Managers | Operators

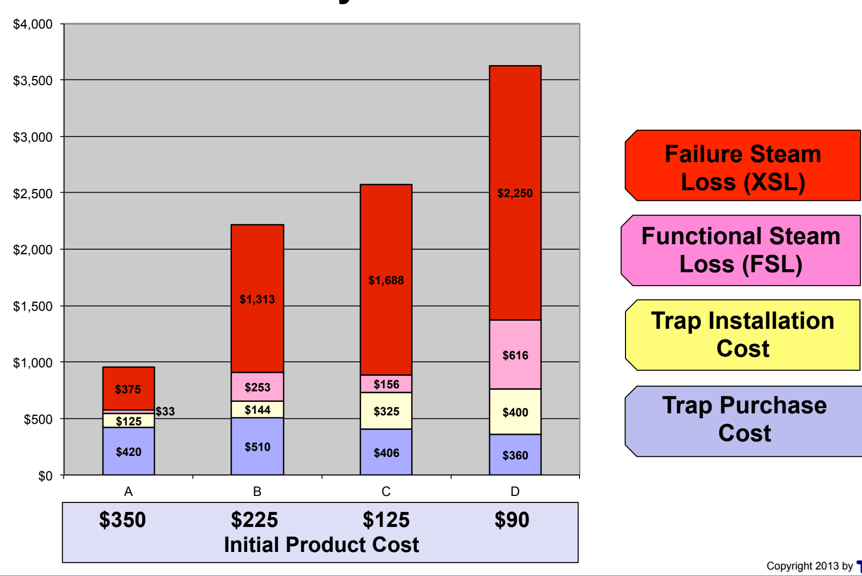
Trap Selection & Performance

Life Cycle



Trap Selection & Performance

10 Year Life Cycle Cost



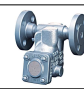
STAR (Standards & Traps Application Review)

Plant Conditions

- Applications
- Pressures
- Specific challenges
- Installed trap base
- Maintenance resources

Plants Priorities

- Maintenance
- Longevity
- Energy Efficiency
- Life Cycle Optimization
- Lowest Initial Cost

Application	Pressure Range (PMO)	Best Model	Alternate Model
Drip	High Pressure (600 psig)		
	Medium Pressure (250 psig)		
	Low Pressure (50 psig)		
Tracing	High Temp		
	Un-supported		
	Copper		

Diagnosis Accuracy Impact

Good Trap	Leaking Trap	Cold Trap
Fail	**Good**	**Good**
• Unnecessary Replacement	• Lost Opportunity Cost	• Un-identified Risk
$300	**$750**	**$800**
Trap & installation cost	1 year of Steam Leak	Cold Trap Risk

Average inaccurate diagnosis ≈ $600
Assume inaccurate diagnoses 3/100 = 3%
*1,000 trap population risks 30 x $600 = **$18,000***

(Equivalent to $18 per trap)

How much is the survey really costing?

Diagnosis Accuracy Evaluation

- What testing technology?
- Diagnosis decision: Objective or subjective?
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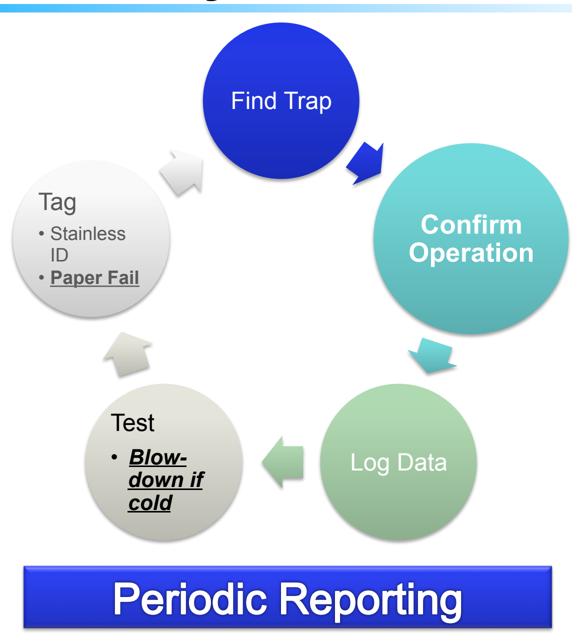
- Experience
- Survey Speed: Realistic or unbelievable?
- True cost: Survey & Accuracy Impact

On-site Survey



Summary

Engage the whole organization

- Understand the prize
- Appoint "Champions"
- Involve maintenance, operations & purchasing

Plan **ALL** aspects of the program before starting

- Consider location life cycle costs
- Select traps by application & document (STAR)
- Evaluate trap diagnosis accuracy impact
- Specify data to be collected
- Decide replacement criteria (leak level & cold)
- Determine best resources for testing & repairing traps

Execute the program

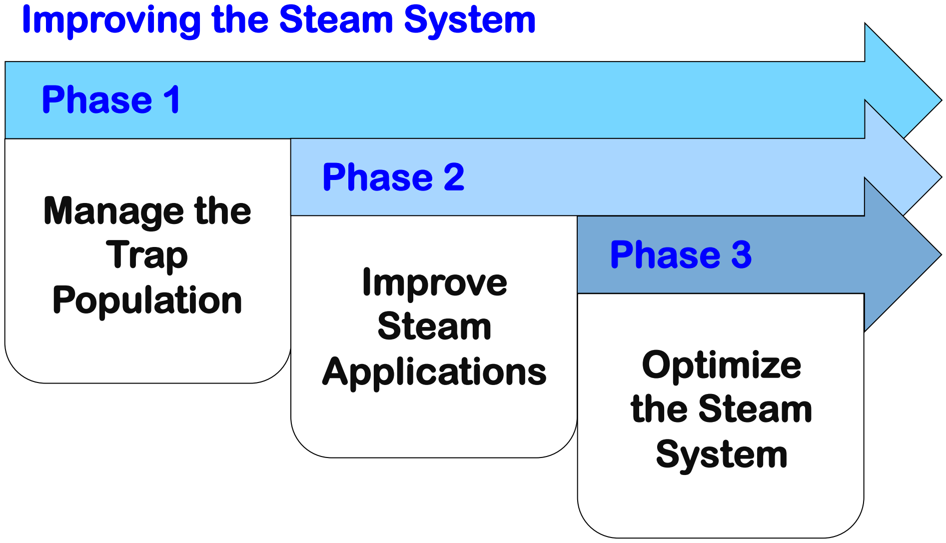
- Have operations support
- Ensure all mechanics are trained & vendor provides field support
- Pay the mortgage (leaks) and the insurance (cold traps)
- Update the database with maintenance actions for future historical & root cause analysis
- Monitor performance

Ensure ongoing improvement & sustainability

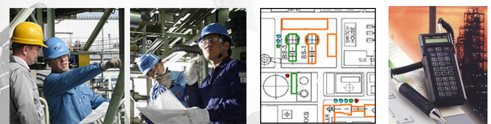
- Annual & historical analysis
- Improve the program

Additional Phases

Improving the Steam System



Successful Implementation of a Sustainable Trap Management Program



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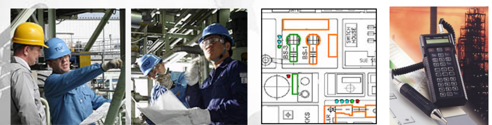

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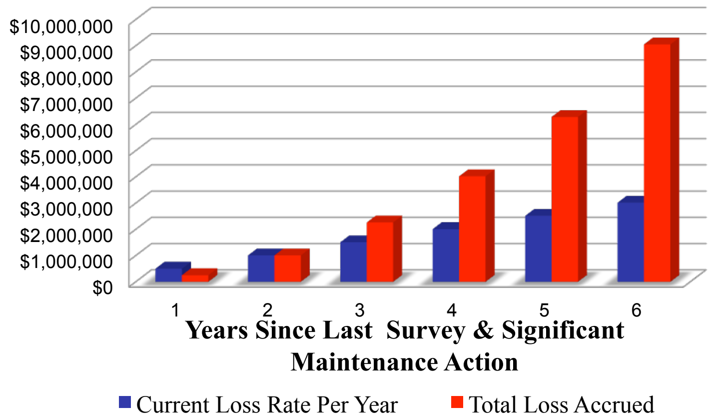

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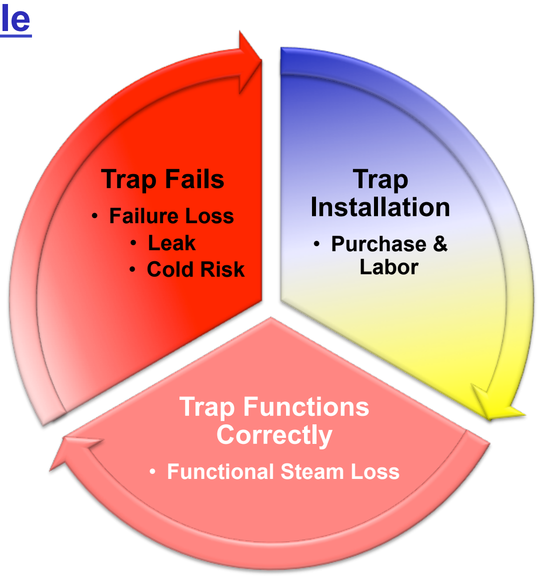

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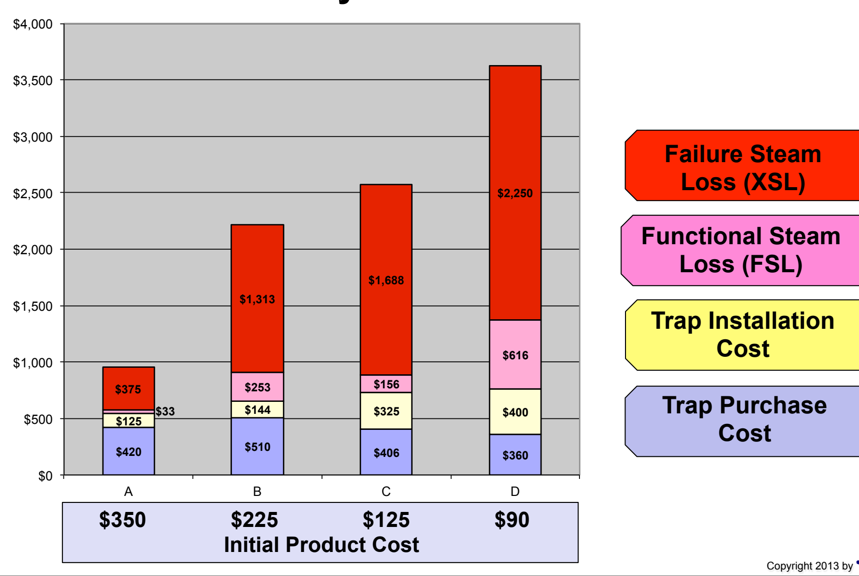

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Periodic Reporting

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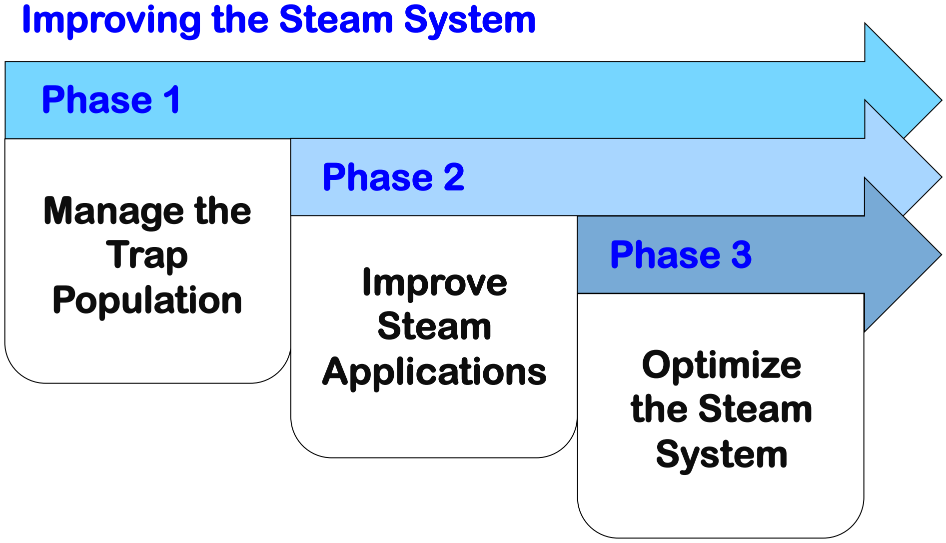

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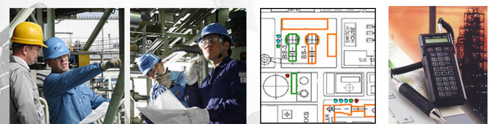

Jonathan Walter

ENERGY EFFICIENCY OPPORTUNITIES IN WINERIES FOR RETROFIT AND NEW CONSTRUCTION PROJECTS

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ABSTRACT

This paper outlines typical winemaking processes for both white and red wines and the associated major energy consuming systems. Energy efficiency opportunities in retrofit as well as new construction projects are introduced. The opportunities for small/medium wineries as compared to large and very large wineries are discussed. The presented data is based on detailed assessments of 33 wineries and evaluation of designs of 17 new wineries in Northern and Central California. Over 25 major distinct energy efficiency opportunities were identified in all assessments. Electrical consumption distribution per system type will be discussed based on the size of the winery. The energy savings results as well as the simple payback will be outlined per measure base and per facility base for the evaluated existing and new construction wineries.

INTRODUCTION

Modern wine making is an energy intensive process that involves various stages of refrigerated cooling. The fermentation, cold stabilization, and the storing/aging processes require significant levels of refrigeration. The fermentation process uses yeast to convert grape sugars to alcohol and carbon dioxide with heat released at the same time. This process greatly relies on the cooling system for heat removal. Red wine fermentations are generally controlled between 75 and 80 °F, whereas white wine is fermented between 48 and 60 °F [1]. The solubility of potassium bitartrate decreases as alcohol accumulates, and the crystal may show up in wine bottles. Hence, white wine is usually cold-stabilized at 25 to 36 °F [1] so that potassium bitartrate crystallization forms in the tank and can be removed. The post-fermentation wine is stored and aged at low temperature to prevent oxidation and other chemical reaction in the wine. White wine is generally stored at 40 to 44 °F on average, whereas red wine is generally kept between 45 and 70 °F [1]. The refrigeration systems operate at their heaviest load during the harvesting period between August and November. Since storing and aging wine continues throughout the year, the refrigeration system operates year-round. Figure 1 shows typical white and red wine production process flow diagrams.

According to the U.S. Census Bureau [2], the U.S. had 1,956 wineries in 2007, where 971 of the wineries were in California and produced about 85% of all U.S. wine. According to a Lawrence Berkeley National Laboratory (LBNL) study [1], the California winemaking industry consumes over 400 GWh of electricity annually, the second largest electricity-consuming food industry in California, after fruit and vegetable processing. Thus the wine industry is considered an effective target for application of energy efficient processes and equipment. Energy efficient opportunities can be implemented in retrofit, expansion as well as new construction projects.

The energy consumption distributions per system type are significantly different between small and large wineries. For instance, lighting energy consumption is minimal compared to the refrigeration system in a large winery, whereas the lighting and HVAC energy consumption may be higher than refrigeration system in a small winery, indicating that energy efficiency retrofit should be focused on the lighting and HVAC system as well. Technologies and equipment types for wine making are designed based on the size of winery, indicating that some energy efficiency opportunities are only targeted for certain sizes of facilities. Therefore, it is essential to distinguish the energy efficiency opportunities per winery sizes. The ASHRAE Refrigeration Handbook defines small wineries as those that crush tens of tons grapes per season, and large wineries that crush hundreds or thousands of tons of grapes per season [3]. The BEST Winery Guidebook by LBNL refers to “small/medium”

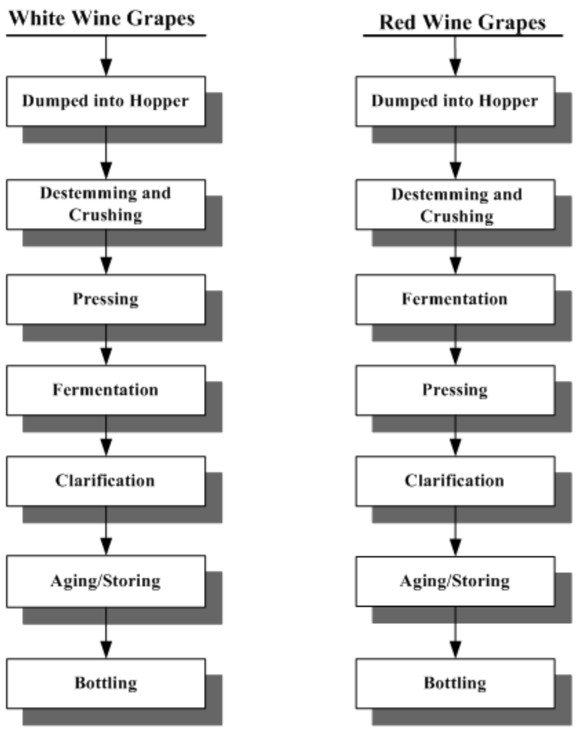

Figure 1 – Typical Wine Process Flow Diagram

refrigeration system to be less than 100 tons, and "large" with refrigeration systems of 100 tons and up [1]. Since the size of refrigeration system is designed mainly based on the amount of grape to be processed, this paper categorizes the winery sizes based on the refrigeration capacity. In this paper wineries are grouped per refrigeration capacity:

- Small/Medium Winery: refrigeration system less than 100 tons
- Large Winery: refrigeration system equal or more than 100 tons
- Very Large Winery: refrigeration system over 2,500 tons

The majority of electrical energy consumption in wine making is by refrigeration systems. Other electric using systems are crush equipment, compressed air system, bottling equipment, transfer pumps, wastewater treatment system and lighting. Figure 2 shows the electrical consumption distribution based on the weighted average energy consumption of the audited small/medium wineries, large wineries and very large wineries summarized in Table 1. This data shows that the refrigeration, compressed air and process equipment energy consumption account for 68% to 84% of overall energy consumption in large and very large wineries, whereas the lighting and HVAC energy consumption is weighted heavily in small/medium wineries accounting for about 36% of total energy consumption.

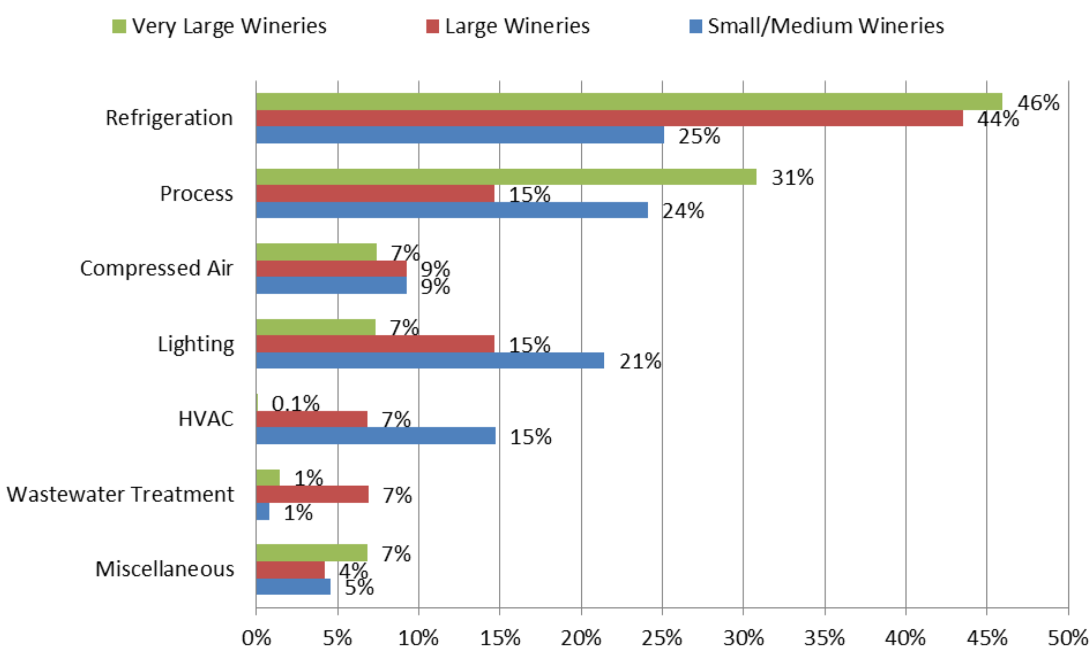

Figure 2 – Electrical Consumption Distribution

Note: For very large wineries, the electrical energy consumption of HVAC is very minimal and is included under Miscellaneous for some of the assessed facilities; also, the wastewater treatment systems were not included for half of the assessed wineries.

MAJOR ENERGY CONSUMING SYSTEMS

The major energy consuming systems for wine making can be categorized as the refrigeration system, process equipment, heating system and wastewater treatment system.

Refrigeration Systems

The audited small/medium wineries generally had one central refrigeration system to support the process cooling loads for the entire facility. The large wineries that were audited had multiple refrigeration systems that were dedicated to various applications, such as tank farms, barrel rooms, and must cooling. Most refrigeration systems were used to generate chilled glycol, except one very large winery supplied liquid ammonia to shell-and-tube heat exchangers in the tank farm to chill stored wine. The audited plants typically had ammonia refrigeration systems for large wineries and Freon refrigeration systems for small/medium sizes. Chilled glycol was generally generated at 25 to 36 °F during cold-stabilization periods [1] and higher temperature for the rest of the time. The majority of refrigeration applications are fermentation, cold stabilization and cold storage/aging.

The required fermentation temperature and period depend on the type of wine to be made. White wine is fermented at lower temperature resulting in more fruitiness taste and it requires longer fermentation period. The level of dry wine (without residual sugar) also determines the fermentation period. Generally for red wine the must is fermented between 75 and 80 °F for seven to ten days [1]. For white wine the fermentation takes seven to twenty-eight days usually between 48 and 60 °F [1]. Modern wine making utilizes stainless steel tanks as the most common fermentation vessels. Cooling is achieved by jackets, external or internal heat exchangers with chilled glycol or refrigerant circulation.

Cold stabilization chills the white wine to about 25 to 36 °F [1]to extract the potassium bitartrate since the salt solubility decreases at lower temperatures. Wine is typically maintained at this temperature for a period of 1.5 to 3 weeks [4], depending on how easy it is to crystallize the potassium bitartrate, i.e. how “stable” the wine is. The crystalized potassium bitartrate is then removed by racking.

The last wine making step is storage/aging. White wine is generally stored at 40 to 44 on average, whereas red wine is generally kept between 45 and 70 °F with 59 °F on average [1]. White wine is usually stored in tanks and consumed relative early to provide the fruity flavors. Red wine is generally aged in oak barrels for up to six months for light red wines and up to three years for robust red wines [1].

Process Equipment

Based on the audited wineries, wine making process equipment account for about 24%, 17% and 35% of the total energy consumption for small/medium, large and very large wineries, respectively. The process equipment includes de-stemmer, crush equipment, presses, clarification and must and juice transfer pumps. The harvested grapes are first de-stemmed and then crushed to form the must, a mixture of juice, skins, seeds and pulp. The juice is extracted by pressing the must before fermentation for white wine and after fermentation for red wine. Juice may be drained out from the must by filters. Larger wineries use presses to extract juice as the main method. Clarification is used to separate wine from suspended yeasts and other solids after fermentation. Racking is the most traditional technique for clarification, which is simply siphoning off the relatively clear wine. Fining and filtering are also the common clarification techniques. Large wineries commonly apply centrifuges for clarification, and very large wineries may use double stack floatation solid separation to clarify wine in far less time.

Heating System

The majority of natural gas energy consumption in wine making is process hot water usage. Hot water in wineries is mainly used for heating of tanks, cleaning, and heating wine after cold-stabilization. The audited wineries utilize hot water boilers, except the very large wineries that may use steam boilers, and hot water is generated by steam to water heat exchangers.

Wastewater Treatment

Most conventional winery wastewater treatment processes utilize ‘aerobic’ treatment, meaning that oxygen is taken in to break down the waste products. The common aerator types are brush aerator, mechanical surface aerator, and diffused air aeration system. Fine bubble diffuser system is the most efficient aeration system that has up to 20% standard oxygen transfer efficiency (SOTE) [5]. Anaerobic digesters are less energy intensive compared to aerobic systems but have higher initial investment costs.

Modern Technologies

Modern technologies are developed to improve the productivity rate and shorten the process time compared to traditional wine making processes. New technologies are generally adopted by large and very large wineries that process large amounts of grapes. Major technologies that impact the clarification, stabilization, cooling system and wastewater treatment system for winemaking are briefly outlined below.

Electrodialysis

Electrodialysis process is an alternative method for wine stabilization instead of cold-stabilization. Electrodialysis removes the tartaric acids from the wine by passing it through an electric field and collecting ions (potassium (K+), calcium (Ca++) and negatively charged tartaric acids) on anionic and cationic membranes. Electrodialysis eliminates the need for freezing and pre-heating the wine in cold-stabilization. According to an emerging technologies case study [6], for about 20,000 gallons of wine, the stabilization period for electrodialysis was 31 hours as opposed to 1,108 hours for cold-stabilization and the energy consumption reduced to be less than 1% of the energy required by cold-stabilization. However, electrodialysis resulted in a water consumption increase of about 3,000 gallons.

Clarification

Centrifuge and double stack floatation solid separation system are the modern technologies for the clarification process in large and very large wineries. Both systems can process high throughput of wine and have high clarification efficiency with low solid content output. Centrifuges are compact devices that mainly consist of one main drive and require less maintenance. Double stack floatation solid separation system uses coagulants, also known as “finings”, to clarify the wine, and it uses compressed air to induce separation between the solids and the liquid. It consists of a floatation tank, separated solid pumps, tank mixer and saturation tank. Double stack floatation solid separation system is more energy efficient than centrifuge.

High Efficiency Turbocor Chillers

Turbocor chillers are centrifugal chillers with frictionless magnetic bearing, which are controlled by variable frequency drives. Turbocor chillers are oil-free and hence eliminate the needs for oil cooling. At partial loads, Turbocor chillers are much more efficient than screw, centrifugal and reciprocating chillers. The integrated part load value (IPLV) can be as low as 0.34 kW/ton based on the operating conditions. According to manufacturer data, the largest water-cooled Turbocor chiller available has a capacity of 1,000 tons.

Anaerobic Wastewater Treatment

Anaerobic treatment processes do not use oxygen. The energy requirements and sludge production is much less than aerobic processes, thus making the process less costly and simpler. However, one of the main disadvantages of anaerobic processes is that they are much slower than aerobic processes and are only good at removing organic waste. Biogas generated from the anaerobic digesters is used to heat the digester. Excess biogas can be used for power generation. Anaerobic wastewater treatment systems are used in large and very large wineries.

ENERGY EFFICIENCY OPPOTUNITES

This section details the energy efficiency opportunities and the savings summary in retrofit as well as new construction projects. The opportunities for small/medium wineries as compared to large and very large wineries are discussed. The presented data is based on detailed assessments of 33 wineries and design evaluation of 17 new wineries in Northern and Central California. Over 25 distinct energy efficiency opportunities were identified in all assessments. Tables 1 and 2 below summarized the plant characteristics of the audited existing wineries and reviewed new construction wineries considered in this paper.

TABLE 1 - SUMMARY OF PLANT CHARACTERISTICS FOR AUDITED EXISTING WINERIES*			
Average Value	**Small/Medium Wineries**	**Large Wineries**	**Very Large Wineries**
Number of Plants	5	22	6
Annual Electrical Energy Usage (kWh/yr)	481,000	2,000,000	14,000,000
Maximum Electrical Demand (kW)	130	510	3,100
Annual Gas Energy Usage (Therm/yr)	5,900	48,000	764,000
Refrigeration Compressor Capacity	55 hp	500 hp	5,200 hp

* The values in the table have been rounded.

TABLE 2 - SUMMARY OF PLANT CHARACTERISTICS FOR NEW CONSTRUCTION*			
Average Value	**Small/Medium Wineries**	**Large Wineries**	**Very Large Wineries**
Number of Plants	6	9	2
Refrigeration Compressor Capacity	40 ton	350 hp	N/A

* The values in the table have been rounded.

Major energy efficiency opportunities are discussed in the following section and categorized per refrigeration system, process equipment, lighting, hot water system and wastewater treatment system. For each measure the application for small/medium (S/M), large (L) and very large (VL) wineries are indicated. Tables 3 and 4 summarize the number of times each measure was recommended, as well as the ranges of energy savings percentage compared to the associated system or equipment energy consumption and years of simple payback for the assessed small/medium, large and very large wineries.

Refrigeration Systems

Sequence Refrigeration Compressors (L, VL)
The refrigeration systems in large and very large wineries typically consist of multiple compressors of various types, cooling capacities and control systems. The performance of these compressors is different under the same operating point. Therefore, optimizing the sequence control of multiple compressors can result in significant electrical energy savings.

Implementing this measure could result in about 9% electrical energy savings of the associated refrigeration system energy consumption, with a simple payback of about 2 years.

High Efficiency Refrigeration Compressors and Chillers (S/M, L, VL)
The compressor performance can be evaluated at kW/ton, where kW is the compressor power consumption for providing a certain tonnage of cooling load. Under the same suction and discharge operating conditions, and providing the same amount of cooling load, the lower kW/ton indicates a more efficient compressor.

Implementing this measure could result in 6% to 42% electrical energy savings of the associated refrigeration system energy consumption, with a simple payback of 1-5 years, and up to 8 years for new construction projects.

Interconnect Multiple Refrigeration Systems (VL)
It was recommended to interconnect individual ammonia refrigeration systems into a single system with common discharge and suction headers. A single interconnected refrigeration system can be controlled to sequence and optimize the operation of compressors to minimize the number of compressors needed to run. Minimizing the number of compressors to match a refrigeration load results in energy savings and system reliability.

Implementing this measure could result in about 16% electrical energy savings of the associated refrigeration system energy consumption, with a simple payback of about 3 years.

Floating Head Pressure Control on Refrigeration Compressors (S/M, L, VL)
If the head pressure were to adjust itself based on the systems' heat rejection rate and the ambient wet-bulb temperature, the system would be operating with a "floating" head pressure. Allowing the head pressure to "float" would permit the refrigeration system to operate much more efficiently. As a rule-of-thumb, one degree (°F) reduction in saturated condensing

temperature will result in about 1.3% efficiency improvement of the compressor [7].

Implementing this measure could result in 14% to 23% electrical energy savings of the associated refrigeration system energy consumption, with a simple payback of 1-6 years.

Enable Air Economizer Free Cooling (S/M, L, VL)
Barrel rooms and case good storage rooms are air-conditioned to maintain the required room set point temperature. Red wine is generally kept between 45 and 70 °F with 59 °F on average for storage and aging [1]. When the outside dry-bulb temperature is below room set point, free outside air cooling, also known as night air cooling, can be introduced to the room instead of using mechanical cooling.

Implementing this measure could result in 6% to 42% electrical energy savings of the associated refrigeration system energy consumption, with a simple payback of 1-4 years, and up to 14 years for new construction projects.

Raise the Glycol Temperature and Refrigeration System Suction Pressure Set Points When Not Cold Stabilizing Wine (S/M, L, VL)
It is common that a winery utilizes a central refrigeration system to provide cooling for various applications, including cooling for fermentation, cold stabilization, barrel room, tank cellars and process cooling load. Cold stabilization chills the white wine to about 25 to 36 °F [1], while other applications are generally maintained at 50 °F and above. Cold stabilization is only required for short periods during the year. Refrigeration systems are more efficient at a higher suction pressure set point. Therefore, raising the glycol temperature and refrigeration system suction pressure set points when not cold stabilizing wine will result in significant energy savings.

Implementing this measure could result in 23% to 29% electrical energy savings of the associated refrigeration system energy consumption, with a simple payback of 0-2 years.

Replace the Air-Cooled Condensers with Water-Cooled Evaporative Condensers for Refrigeration Systems (S/M, L, VL)
The performance of air-cooled condensers is dependent on ambient dry-bulb temperature, while the performance of evaporative condensers (similar to a cooling tower) is dependent on ambient wet-bulb temperature. The ambient wet-bulb temperature is always less than or equal to the ambient dry-bulb temperature. Using evaporative condensers rather than the air-cooled condensers will allow the compressors to operate at a lower discharge pressure, which will reduce the energy consumed by the compressors.

Implementing this measure could result in 34% to 47% electrical energy savings of the associated refrigeration system energy consumption, with a simple payback of 3-5 years.

Insulate Wine Tanks (S/M, L, VL)
Wine tanks are used for wine fermentation, storage and stabilization. Generally for red wine the must is fermented between 75 and 80 °F for seven to ten days [1]. For white wine the fermentation takes seven to twenty-eight days usually between 48 and 60 °F [1]. White wine is generally stored in tanks at 40 to 44 °F on average [1]. For outdoor wine tanks, the surfaces of the tanks are exposed to the ambient. When the ambient temperature is higher than the tank temperature, it will increase the heat gain to the tank resulting in an increase of cooling load to the refrigeration system. Insulating the outdoor wine tanks will reduce their heat gain, which in turn will reduce the energy consumption of the refrigeration systems.

Implementing this measure could result in 65% to 97% electrical energy savings of the portion of electrical energy consumption of the refrigeration system for cooling the un-insulated wine tanks, with a simple payback of 2-5 years.

VFD Controlled Refrigeration Screw Compressor as the Trim Unit (L, VL)
Based on performance characteristics of screw compressors, a variable frequency drive (VFD) controlled screw compressor is more efficient at part-load compared to modulation valve controlled fixed speed screw compressor of the same size [8]. Also, screw compressors are most energy efficient at full load. Therefore, for refrigeration systems that consist of multiple compressors, it is more efficient to install a variable frequency drive compressor as a trim unit.

Implementing this measure could result in about 3% electrical energy savings of the associated equipment energy consumption, with a simple payback of about 1 year.

VFD Control on Condenser Fans, Glycol Circulation Pumps and Air Handler Fans (S/M, L, VL)
Since the cooling load required by the winery is determined based on seasonal grape process, different wine temperature requirement and the amount of wine being processed, optimum control of

refrigeration system components based on the actual cooling load will result in significant electrical energy savings. Variable frequency drives (VFD) can be installed on condenser fans, glycol circulation pumps and air handler fans to achieve the optimal control for the needed supply flow rate.

Implementing this measure could result in 20% to 93% electrical energy savings of the associated refrigeration system energy consumption, with a simple payback of 1-6 years.

Process Equipment

VFD on Process Equipment (S/M, L, VL)
Since winery process loads fluctuate depending on the amount of grape/wine being processed, it is recommended to install variable frequency drives (VFD) to control the speeds of process equipment, such as must transfer pumps, screw presses, destemmer and wine transfer pumps, whenever it is feasible.

Implementing this measure could result in 29% to 60% electrical energy savings of the associated process equipment energy consumption, with a simple payback of up to 5 years, and up to 11 years for new construction projects.

Double Stack Solid Separation Device (L, VL)
Double stack solid separation devices can process high throughput of wine and have high clarification efficiency with low solid content output. It consists of a floatation tank, separated solid pumps, tank mixer and saturation tank. Double stack solid separation is less energy intensive than centrifugal clarification, although centrifuges can reduce outgoing solids contents of wine to a fraction of a percent.

Implementing this measure could result in 66% to73% electrical energy savings of the associated process equipment energy consumption.

VFD Controlled Air Compressor (S/M, L, VL)
Rotary screw type air compressors are commonly used in wineries. The control methods for a screw air compressor include load/unload, inlet modulation and variable frequency drive (VFD) controls. Based on typical screw compressor performance [9], VFD is the most energy efficient control method, while inlet modulation is the least for part-load operation. When the compressor is unloading, inlet modulations controlled and load/unload controlled screw compressors still draw over 25% of the full load power.

Implementing this measure could result in 20% to 55% electrical energy savings of the associated process equipment energy consumption, with a simple payback of 1-3 years.

High Efficiency Humidifier (S/M, L, VL)
Humidification is required in barrel storage rooms for maintaining the humidification level. Energy efficient humidifiers, such as high pressure mechanical humidifier and ultrasonic humidifiers, are recommended in applications requiring simultaneous cooling and humidifying, but not when simultaneous heating and humidifying is required.

Implementing this measure could result in 76% to 95% electrical energy savings of the associated process equipment energy consumption, with a simple payback of less than about 2 years.

Lighting

High Efficiency Lighting (S/M, L, VL)
High efficiency lighting consumes less electrical energy for providing comparable amount of lighting intensity. The common high efficiency lighting opportunities include:

- Replace the High Intensity Discharge (HID) Lighting with High Intensity T5
- Replace T12 fluorescent lighting with T8 fluorescent lighting
- Replace 32-Watt T8 lamps with 28-Watt T8 lamps
- Replace HID and fluorescent lightings with LED or induction lighting

Implementing this measure could result in 25% to 83% electrical energy savings of the associated lighting energy consumption, with a simple payback of 1-6 years.

Automatic Lighting Controls (S/M, L, VL)
The two common automatic lighting controls are occupancy sensor control and daylight sensor control. When a space is unoccupied or there is sufficient daylight, the lighting can be reduced or turned off resulting in electrical energy savings. For the case of HID lighting this measure would include bi-level controllers.

Implementing this measure could result in 33% to 83% electrical energy savings of the associated lighting energy consumption, with a simple payback of 1-6 years.

Hot Water System

High Efficiency Boiler (S/M, L, VL)
Hot water in wineries is mainly used for heating of tanks, cleaning, and heating wine after cold-stabilization. High efficiency boilers consume less natural gas energy for generating the same amount of heating load.

Implementing this measure could result in up to about 6% natural gas energy savings of the associated hot water system energy consumption, with a simple payback of 1-3 years.

Recover Waste Heat from Refrigeration System to Preheat Boiler Make-Up Water (L, VL)
Discharge refrigerant from compressors (except with liquid injection oil cooling) is superheated at high temperature. Generally the rejected heat from the refrigeration system is removed by the condenser system. The available heat depends on the head (discharge) pressure set point for each particular type of compressor. The discharge temperature can be as high as 190 °F for the head pressure of 165 psia for an ammonia compressor. The waste heat from the refrigeration system can be used to preheat boiler make-up water that is generally at about 60 °F. Desuperheating the high-pressure refrigerant will also reduce the heat load to the evaporative condensers, which will reduce the energy consumption of the condenser fans if it is properly controlled.

Implementing this measure could result in 6% to 20% natural gas energy savings of the associated hot water system energy consumption, with a simple payback of 3-6 years.

Wastewater Treatment System

Install an Automated Dissolved Oxygen (DO) Control System for Aeration Control (S/M, L, VL)
The amount of wastewater generated in a winery and the biological oxygen demand (BOD) level are significantly higher during crush season than in non-crush season. In manual systems, plant operators tend to provide excess oxygen into the bioreactor to avoid violating standards, which in turn results in excess electrical energy usage by the aeration system. An automatic dissolved oxygen (DO) system will measure the level of dissolved oxygen in the wastewater using DO sensors. Control of aerators (e.g. through VFDs) can result in significant energy savings. According to the extensive literature search [10], the energy savings achievable by automatic aeration of DO control is typically 25% to 40%, but can be as high as 50%.

Implementing this measure could result in 10% to 75% electrical energy savings of the associated wastewater treatment system energy consumption, with a simple payback of 1-3 years, and up to 8 years for new construction projects.

Anaerobic Digester System (L, VL)
Most conventional wastewater treatment processes utilize ‘aerobic’ treatment, meaning that oxygen is taken in to break down the waste products. This results in a high energy consumption since oxygen has to be supplied by aeration equipment, which is probably one of the most energy intensive process in a wastewater treatment facility. ‘Anaerobic’ treatment processes do not use oxygen. The energy requirements and sludge production is much less than for aerobic processes, thus making the process less costly and simpler.

Implementing this measure could result in up to 98% electrical energy savings of the associated wastewater treatment system energy consumption, with a simple payback of about 1 year.

Other Energy Efficiency Opportunities

There are other common energy efficiency opportunities for wineries that are not described in the above sections. These measures should also be considered for energy assessments for existing and new construction facilities.

- Install Premium Efficiency Motors
- Replace Standard V-Belts with Cog-Type Belts
- Repair Compressed Air Leaks
- Replace Compressed Air Jets with High-Pressure Blower
- Reduce Air Compressor Discharge Pressure
- High Efficiency Pumps
- Insulate Chilled Water Lines
- Insulate Glycol Storage Tanks
- High Efficiency HVAC Units
- VFD Controlled Hot Water Pumps

TABLE 3 - SUMMARY OF ENERGY EFFICIENCY OPPORTUNITIES FOR AUDITED EXISTING WINERIES*

Energy Efficiency Measure	Small/Medium Wineries		Large Wineries		Very Large Wineries	
	No.	Ranges of % EES (and Simple Payback)	No.	Ranges of % EES (and Simple Payback)	No.	Ranges of % EES (and Simple Payback)
Refrigeration System						
Sequence Refrigeration Compressors					1	9% (2 yrs)
High Efficiency Refrigeration Compressors and Chillers	1	16% (5 yrs)			1	13% (4 yrs)
Interconnect Multiple Refrigeration Systems					1	16% (3 yrs)
Floating Head Pressure Control on Refrigeration Compressors	1	20% (5 yrs)	7	14-18 % (1-6 yrs)	3	18-23 % (< 1 yrs)
Enable Air Economizer Free Cooling					2	41% (1 yr)
Raise the Glycol Temperature and Refrigeration System Suction Pressure Set Points When Not Cold Stabilizing Wine			2	28 % (< 2 yrs)	2	23-27 % (0 yr)
Replace the Air-Cooled Condensers with Water-Cooled Evaporative Condenser for Refrigeration Systems	1	47% (3 yrs)			1	34% (5 yrs)
Insulate Wine Tanks			3	84-91 %£ (2-4 yrs)		
VFD Control on Condenser Fans, Glycol Circulation Pumps and Air Handler Fans	4	75-93 % (1-5 yrs)	32	32-93 % (1-6 yrs)	3	48-61 % (2-3 yrs)
Process Equipment						
VFD on Process Equipment					2	29-46 % (n/a)
VFD Controlled Air Compressor	1	40% (2 yrs)				
Energy Efficient Humidifier			1	76% (2 yrs)		
Lighting						
High Efficiency Lighting	4	43-80 % (1-6 yrs)	24	31-83 % (1-6 yrs)	2	45-49 % (2-3 yrs)
Automatic Lighting Controls	4	33-63 % (1-2 yrs)	18	15-83 % (1-6 yrs)	3	41-52 % (2-6 yrs)
How Water System						
VFD Controlled Hot Water Pumps			3	57-91 % (1-3 yrs)	1	33% (2 yrs)
Recover Waste Heat from Refrigeration System to Preheat Boiler Make-Up Water			3	8-20 % (3-6 yrs)	1	6 % (3yrs)
Wastewater Treatment System						
Install an Automated Dissolved Oxygen (DO) Control System for Aeration Control	1	75% (3 yrs)	3	10-53 % (1-2 yrs)	1	22% (3 yrs)

*This table summarizes the following results for the assessed wineries: number of times the measure was recommended, percentage of energy savings compared to the associated system/equipment energy consumption, and the simple payback periods with energy efficiency incentives (about $0.09/kWh savings, $100/kW demand reduction, and $1/therm savings).

£ The baseline energy consumption is considered to be the portion of electrical energy consumption of the refrigeration system for cooling the un-insulated wine tanks.

TABLE 4 - SUMMARY OF ENERGY EFFICIENCY OPPORTUNITIES FOR NEW CONSTRUCTION WINERIES*						
Energy Efficiency Measure	**Small/Medium Wineries**		**Large Wineries**		**Very Large Wineries**	
	No.	**Ranges of % EES (and Simple Payback)**	**No.**	**Ranges of % EES (and Simple Payback)**	**No.**	**Ranges of % EES (and Simple Payback)**
Refrigeration System						
High Efficiency Refrigeration Compressors and Chillers	3	6-42 % (1-8£ yrs)	8	12-43 % (1-4 yrs)		
Enable Air Economizer Free Cooling	2	6-42 % (4-12£ yrs)	1	6% (14£ yrs)		
Raise the Glycol Temperature and Refrigeration System Suction Pressure Set Points When Not Cold Stabilizing Wine			1	29 % (0 yrs)		
Insulate Wine Tanks			4	65- 97 %** (2-5 yrs)		
VFD Controlled Refrigeration Screw Compressor as the Trim Unit					1	3% (1 yr)
VFD Control on Condenser Fans, Glycol Circulation Pumps and Air Handler Fans	3	57-69 % (2-5 yrs)	6	20 -79 % (1-5 yrs)	1	74 % (3 yrs)
Process Equipment						
VFD on Process Equipment					2	29-60 % (5-11£ yrs)
Double Stack Solid Separation Device					2	66-73 % (0 yrs)
VFD Controlled Air Compressor	3	20-44% (2 yrs)	3	36-55% (1-3 yrs)		
Energy Efficient Humidifier			3	91-95% (0-1 yrs)		
Lighting and HVAC						
High Efficiency Lighting	5	25-54% (1-5 yrs)	8	28-71% (1-2 yrs)		
Automatic Lighting Controls			2	60% (3-4 yrs)		
High Efficiency HVAC	3	22-29% (3-14£ yrs)				
How Water System						
High Efficiency Boiler			2	6 % (1- 3 yrs)		
Wastewater Treatment System						
Install an Automated Dissolved Oxygen (DO) Control System for Aeration Control			2	22-23% (1- 8£ yrs)	1	23 % (2 yrs)
Anaerobic Digester System					1	98 % (1 yr)

*This table summarizes the following results for the evaluated new construction wineries: number of times the measure was recommended, percentage of energy savings compared to the associated baseline energy consumption, and the simple payback with energy efficiency incentives (about $0.09/kWh savings, $100/kW demand reduction, and $1/therm savings). Note that the simple years of payback periods were calculated based on the premium implementation cost compared to purchasing the baseline equipment. The baseline is considered to be common practices in California wineries.

** The baseline energy consumption is considered to be the portion of electrical energy consumption of the refrigeration system for cooling the un-insulated wine tanks.

£ Measures with long simple payback were included in the original designs by the facility.

Tables 5 and 6 summarize the overall average electrical energy and gas savings percentages as well as payback ranges from implementation of energy efficiency opportunities for the assessed small/medium, large and very large wineries.

TABLE 5 - SUMMARY OF OVERALL AVERAGE SAVINGS FOR AUDITED EXISTING WINERIES			
	Small/Medium Wineries	**Large Wineries**	**Very Large Wineries**
Electrical Energy Usage Overall Savings (%)*	18%	13%	17%
Natural Gas Usage Overall Savings (%)*	N/A	3%	1%
Payback Range (yrs)	2 - 4	1 - 6	0.5 – 4.5

*Based on total electrical and gas energy consumption of assessed facilities.

TABLE 6 - SUMMARY OF OVERALL AVERAGE SAVINGS FOR NEW CONSTRUCTION WINERIES			
	Small/Medium Wineries	**Large Wineries**	**Very Large Wineries**
Electrical Energy Usage Overall Savings (%)*	26%	38%	55%
Natural Gas Usage Overall Savings (%)*	22%	6%	2%
Payback Range (yrs)[#]	1 - 4	0.5 - 4	< 1

*Based on baseline electrical and gas energy consumption of energy efficiency opportunities outlined in Table 4.
[#] Payback was evaluated based on implementation cost premium.

CONCLUSIONs

Wine making is an energy intensive process, and the wine industry consumes over 400 GWh of electricity annually, the second largest electricity-consuming food industry in California. Therefore, the wine industry becomes an effective target for energy efficiency opportunities in both existing and new construction facilities.

The energy savings results presented are based on detailed plant-wide energy audits of 33 wineries and design reviews of 17 new wineries in Northern and Central California. Energy savings are discussed for small/medium, large and very large wineries categorized based on the size of the refrigeration system capacity. The electrical energy distribution data shows that the refrigeration system consumes about 45% of overall energy consumption in large and very large wineries. The lighting and HVAC energy consumption in small/medium wineries is about 36% of the total energy consumption, which is more than the 25% share of the refrigeration systems. Therefore, it indicates that energy efficiency retrofit should be focused on the lighting and HVAC system as well in small/medium wineries.

Over 25 major distinct energy efficiency opportunities were briefly discussed. Overall results of our findings are:

- For the audited wineries, on a facility-wide basis, up to 18% of the total electrical energy consumption and 3% of the total natural gas consumption can be conserved through energy efficiency measures. Payback periods for these facilities are between 0.5 years and 6 years.
- For the evaluated new construction wineries, on a project-wide basis, up to 55% of the total baseline electrical energy consumption, and 22% of the total baseline natural gas consumption can be conserved through energy efficiency measures. The baseline is considered to be common practices in California wineries. Payback periods for these facilities are between 0.5 years and 4 years.

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POTENTIAL FOR ENERGY, PEAK DEMAND, AND WATER SAVINGS IN CALIFORNIA TOMATO PROCESSING FACILITIES

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ABSTRACT

Tomato processing is a major component of California's food industry. Tomato processing is extremely energy intensive, with the processing season coinciding with the local electrical utility peak period. Significant savings are possible in the electrical energy, peak demand, natural gas consumption, and water consumption of facilities.

The electrical and natural gas energy usage and efficiency measures will be presented for a sample of California tomato plants. A typical end-use distribution of electrical energy in these plants will be shown. Results from potential electrical efficiency, demand response, and natural gas efficiency measures that have applications in tomato processing facilities will be presented. Additionally, water conservation measures and the associated savings will be presented.

It is shown that an estimated electrical energy savings of 12.5%, electrical demand reduction of 17.2%, natural gas savings of 6.0%, and a fresh water usage reduction of 15.6% are achievable on a facility-wide basis.

INTRODUCTION

According to the University of California Vegetable Research & Information Center, canned tomatoes processed in California comprise over 90% of the total tomato consumption of the United States and approximately 35% of the total tomato consumption of the world (7). In 2011, the amount of California processed tomatoes was approximately 12 million tons, with the main areas of cropland focused in Fresno, Yolo, and Kings County (14). While farm prices for processed tomatoes are fairly stable when compared to other agricultural commodities, processers carry much more risk and price volatility (1).

For tomato processors, energy costs comprise approximately 6% of a facility's total expenses (15). Thus, energy efficiency is a critical component in maintaining a tomato processor's profitability in the global market. BASE Energy, Inc. has performed detailed energy audits, calculation assistance, and wastewater treatment assessments at several major California tomato processing plants. The Industrial Assessment Center (IAC) at San Francisco State University has also performed detailed energy audits at a few California tomato processing plants. Together, this represents over 30% of all the tomato processors in California, forming a strong basis for energy savings and water conservation potential. The presented data are mainly based on the results of the facility-wide audits.

PROCESS

Tomato processing occurs from late July to early October, with most processing seasons lasting between 90 and 100 days (approximately 2,300 hours per year). The most common end forms of processed tomatoes are paste and diced tomatoes, although purée and whole tomatoes are also processed. Other major materials used in this process include packaging containers and fresh water. Figure 1 shows a typical tomato process from raw material receiving until final product storage. Please note that this is considered "in-container processing", while "aseptic processing" has the cooking, sterilization, and cooling stages prior to packaging (12).

Bulk Dump (*All Tomatoes*)

Tomatoes are trucked in from the fields to the facility. Samples from the trucks are inspected based on their quality and aesthetic appeal prior to dumping. A typical plant will receive approximately 400 trucks per day during the season. The highest quality tomatoes are designated to become whole or diced tomatoes, while the remaining tomatoes are designated for the paste and purée lines.

The raw tomatoes are washed out of the truck trailers into water flumes, which serve two purposes: the flumes will transport the tomatoes to either the peeling area or the crushing area, and they will clean the tomato surfaces of excess debris (stones, insects, vines, etc.). Typically, there will be multiple stages of flumes, with the last stage chlorinated to disinfect the tomato skins.

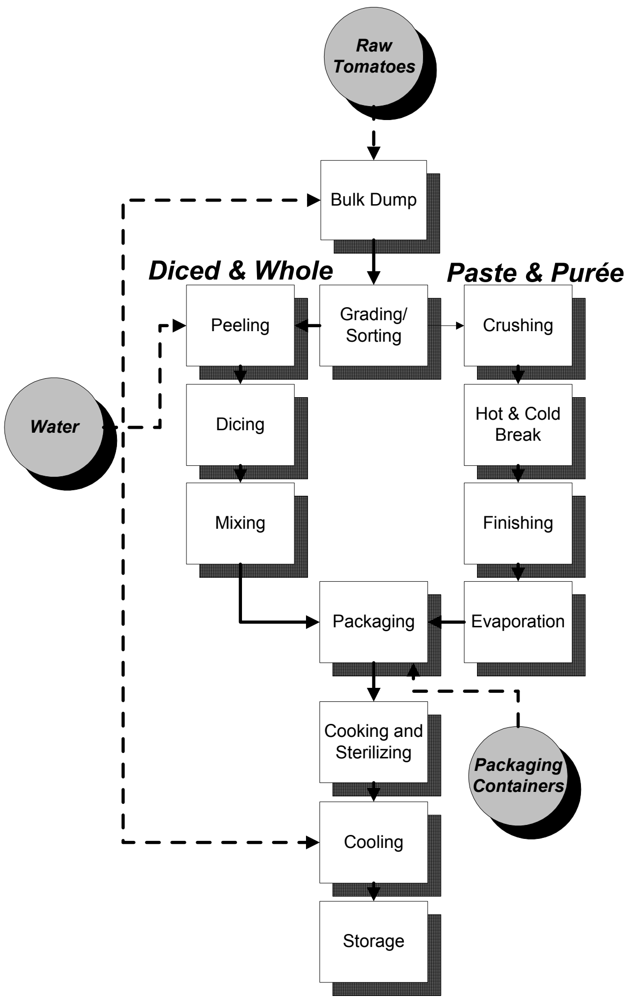

Figure 1 - Typical Tomato Canning Process

Grading/Sorting (*All Tomatoes*)

Grading and sorting are typically performed differently at each facility. The main goal of sorting is to remove sub-par tomatoes from the diced & whole lines to be sent to the paste & purée lines.

Typical practices include using skilled operators to visibly inspect the tomatoes, pneumatic ejectors with photosensitive sensors to sort the tomatoes based on color, rotary screens to sort the tomatoes based on size, and other types of specialized sorting equipment.

Peeling (*Diced & Whole Tomatoes*)

There are three main methods used for peeling tomatoes: mechanical, chemical, and steam. A fourth method, infrared peeling, is currently in the research and development stages at U.C. Davis.

Mechanical peeling involves either placing a rotating tomato through stationary blades or by letting it tumble across abrasive rollers. This is the least used method, as it will typically involve a significant loss of product (25%, compared to 8-18% with steam) (9).

Chemical peeling involves preheating the tomatoes with injected steam, before a caustic solution (Typically sodium hydroxide, 12 - 18% solution, 185– 212 ^{o}F) (8) strips the skin from the tomatoes, and the tomatoes are rinsed before continuing to the next stage of the process. The finish of the tomatoes is the best with chemical peeling, and this method will typically remove more of the peel when compared to steam (8). The main drawback to chemical peeling is that the caustic solution waste stream is difficult to treat, representing a very high pH solution that needs to be neutralized.

Steam peeling involves feeding the tomatoes into a rotating cage, while low pressure steam (24 – 27 psig) (8) strips the skins from the tomatoes. Steam peeling is the most common type of peeling used by tomato processors in California. With steam peeling, the total tomato yield is typically greater than caustic peeling, but less skin is removed (8).

Infrared peeling is in the research and development stage at University of California, Davis as a part of a grant from the California Public Interest Energy Research (PIER) program (13). Infrared peeling is a non-water and non-chemical process. Natural-gas fuelled infrared heaters heat the skins, a vacuum chamber cracks the skins, and mechanical rollers separate the skins from the rest of the tomato. It has been shown in a laboratory setting that IR heating reduced the product loss by 9% and resulted in a firmer product when compared to chemical peeling (11), and is expected to have lower energy usage when compared to steam peeling (13).

Typically, all peeled tomatoes will be checked for blemishes, discolorations, or poor peeling one more time before being sent to the next stage of the process.

Dicing (*Diced Tomatoes*)

Whole tomatoes will be sent to dicers, which are rotating blades in predetermined arrangements to cut the tomatoes into nearly any sized cubes. The diced tomatoes are sent to shaker tables to remove excess juice before being sent to the mixing and filling lines.

Mixing (*Diced & Whole Tomatoes*)
Diced and whole tomatoes are typically mixed with preservatives, such as citric acid for acidity control and calcium chloride for product firming, prior to being canned.

Crushing (*Paste & Purée*)
Whole tomatoes designated for paste and purée production are sent to crushing machines, which turn the tomatoes into a coarse pulp. The pulp is then sent to either a hot break or a cold break, depending on the desired finished product.

Hot Break & Cold Break (*Paste & Purée*)
Hot breaks and cold breaks deactivate enzymes in the tomatoes, both of which are significant consumers of steam. A hot break will hold the tomato pulp at 210 ^{o}F. This deactivates pectic enzymes, inhibits breakdown of pectin in the product, and results in a thicker, more consistent paste. A cold break will hold the tomato pulp at 150 ^{o}F, which will destroy pectin and result in a thinner, brighter product. After the hot or cold break, the tomato pulp is sent to the finishing lines.

Finishing (*Paste & Purée*)
The finishers essentially act as screens, removing skins, seeds, and pulp from the product. The screen size will determine the end finish of the product, and sizes typically range from 0.25" (very coarse, for thick sauce) to 0.02" (very fine, for soup and juices) (10).

Evaporation (*Paste & Purée*)
Evaporation is used on tomato pastes and purées to increase the percent of sugar content, or percent soluble solids, designated by ^{o}B (degrees Brix). Raw juice will enter the evaporators at 5 – 7 ^{o}B, and leave the evaporators at various paste concentrations. The USDA classifies light concentration as 24 – 28 ^{o}B, medium concentration as 28 – 32 ^{o}B, heavy concentration as 32 – 39.3 ^{o}B, and extra heavy concentration as greater than 39.3 ^{o}B (17). Typically, there will be pre-evaporators for low ^{o}B tomato paste, and thicker pastes will be sent to higher density evaporators. Generally, the evaporators are kept under vacuum (18).

There are three main types of evaporators: Multiple-Effect evaporators, Thermal Vapor Recompression (TVR), and Mechanical Vapor Recompression (MVR).

Multiple-effect evaporators operate by pumping the product in a counter-flow arrangement from input steam through multiple tanks, or effects. Higher pressure steam is input to the final evaporation stage (highest ^{o}B product) and enters each subsequent effect at lower pressures (and lower ^{o}B product). In each effect, product will be recirculated or sent to the next higher density effect. In practice, evaporators will typically be between 2 effects and 5 effects, with the ideal steam economies ranging from one unit of steam evaporating 2 units of water from tomatoes (2-effect) to one unit of steam evaporating 4 units of water (4-effect) (6).

TVR evaporators operate by using a steam ejector to mix the tomato water vapor exiting the evaporator with high-pressure steam from the boilers before reintroducing it into the evaporator. Steam is condensed out of the evaporator itself to maintain a mass balance in the system. The steam economy for a double-effect TVR evaporator is approximately 4 units of water evaporated from the tomatoes for every 1 unit of steam input to the system (6).

MVR evaporators operate by compressing the tomato water vapor exiting the evaporator before recirculating the higher pressure steam back into the evaporator. The compressor can be either steam driven, if the facility has a use for the low pressure steam that would exit the turbine, or electrically driven through a motor. The steam economy for MVR systems can be as high as 20 units of water evaporated from the tomatoes for every one unit of steam into the system (6). MVR provides the most heat recovery from the evaporated tomato vapor, but is also more capital intensive to implement when compared to TVR (18).

Packaging (*All Tomatoes*)
Processed tomatoes are canned or aseptically sealed in other containers to preserve their freshness throughout the year. The cans are typically made of tin, with an enamel lining to protect the can from the acidity of the tomatoes. Other types of packaging include glass and plastic bags or jars. Containers are usually cleaned before packaging by hot water, steam, or blasts of pressurized air (9).

For all tomatoes, mechanical filling lines will volumetrically measure the amount of product into the packaging material to over 90% filled (9), exhaust the air to create a vacuum, and mechanically or thermally seal the package. Whole and diced tomatoes are usually topped with tomato juice or very thin purée prior to the filling/exhausting/sealing unit. In some cases, nitrogen gas is added to the container prior to sealing to displace any oxygen remaining in the container.

Cooking and Sterilizing (*All Tomatoes*)
Packaged tomato products are not stored in refrigerated warehouses. Thus, the U.S. Department of Agriculture requires that the canned products be sterilized to prevent bacterial growth within the cans (16). Cooking and sterilization can occur either before or after the packaging process.

Aseptic in-line sterilization typically occurs before flash cooling. Steam is injected into the line carrying the tomato paste or purée, rapidly raising the temperature and sterilizing the tomatoes. Aseptic sterilization can also be performed through the use of tube-in-tube heat exchangers.

In-container sterilization occurs by submerging the packages into ambient or low-pressure (about 3 psig) steam baths. The exact temperatures and durations of sterilization depend on the product and geometry of the package.

Cooling (*All Tomatoes*)
There are several methods for cooling, depending on the process. Flash cooling systems occur after the evaporation stages, tube-in-tube cooling systems occur after the sterilization stage, and submerged cooling tower water or chilled water systems occur after the packaging stage. Flash cooling systems provide a higher quality product and do not have significant capacity constraints, but tube-in-tube systems provide more reliable sterilization (12).

For flash cooling systems, the product is flash cooled after evaporation by injection into a vacuum chamber. This rapidly lowers the product temperature to approximately 98 ^{o}F – 105 ^{o}F, and slightly increases the solids content of the paste or purée.

Tube-in-tube systems are typically single units which perform the heating/sterilization in earlier tubes, with cooling in the later tubes.

Storage (*All Tomatoes*)
Packaged tomatoes are stored in ambient temperature warehouses, and shipped to various customers throughout the year on request.

ENERGY USAGE
BASE and the Industrial Assessment Center at San Francisco State University have performed integrated energy audits of seven tomato processors in California. Figures 2 through 4 show the level of annual electrical energy consumption, peak electrical demand, and annual natural gas energy consumption for each plant.

As shown in these figures, there is significant variation in the electrical energy consumption between the plants mainly due to the production capacity. However, there is little variability between the electrical energy consumption and peak demand for each plant, which shows that each plant operates at maximum capacity throughout the season. Figure 5 shows that Plants A and B are more natural gas energy intensive, relative to their electrical energy consumption, when compared to the other plants. We suspect that this is mainly due to the use of steam turbines to drive large pumps for the evaporators.

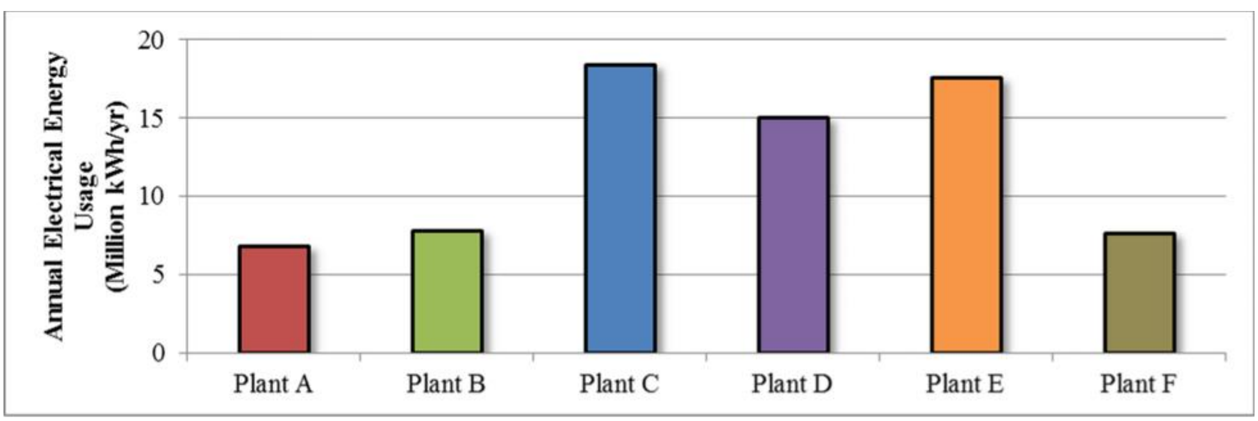

Figure 2 - Annual Electrical Energy Consumption for Various Plants

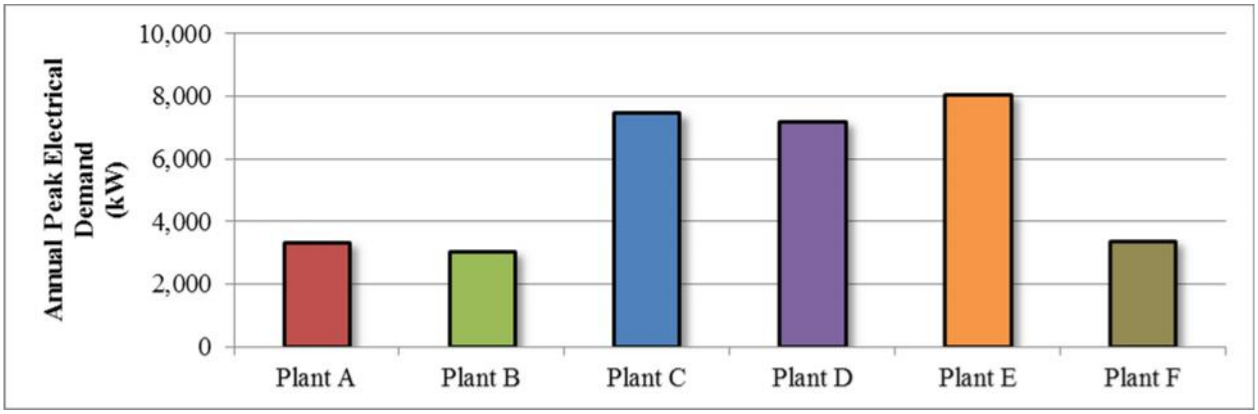

Figure 3 - Peak Electrical Demand for Various Plants

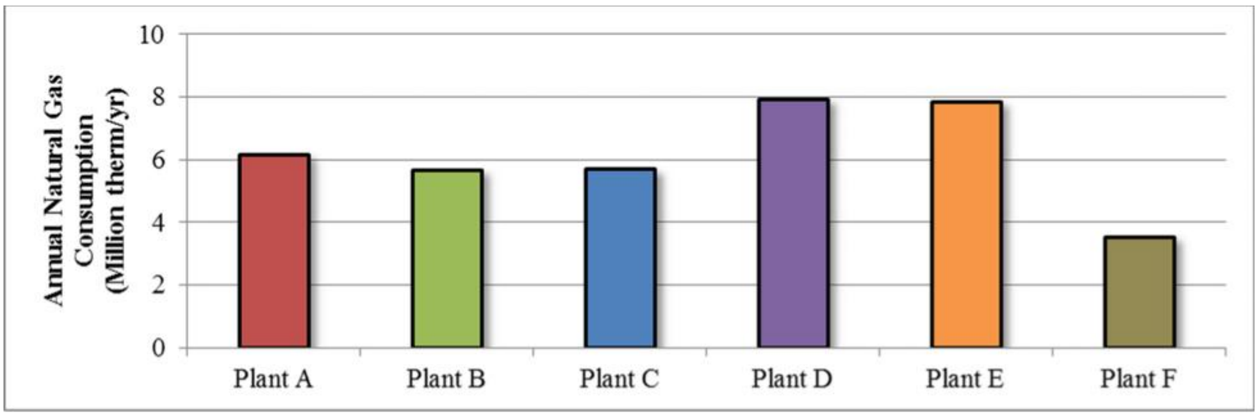

Figure 4 - Annual Natural Gas Consumption for Various Plants

Tomato processors are seasonal in operation, and typically operate over a 90 – 100 day period. Figures 5 through 7 show the monthly profile of electrical energy consumption, peak demand, and natural gas consumption, respectively. These figures show that production begins ramping up at the end of July, operates at full capacity throughout August and September, then finishes production in mid-October. Figure 8 shows a typical electrical demand profile for a week while the processing facility is in season. This figure shows that the electrical demand is nearly constant while the facility is processing tomatoes; the demand varies by only 5%.

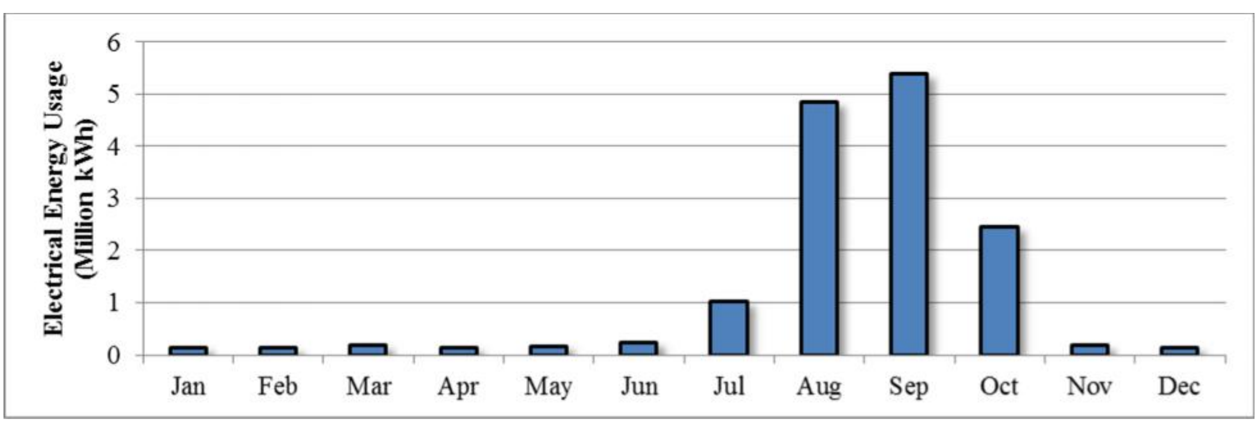

Figure 5 - Monthly Electrical Energy Consumption for a Typical Plant

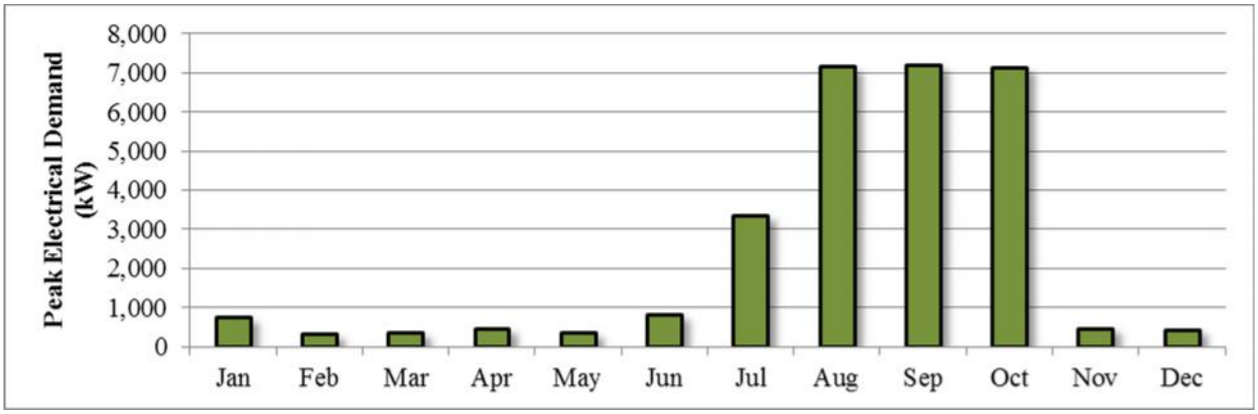

Figure 6 - Monthly Peak Electrical Demand for a Typical Plant

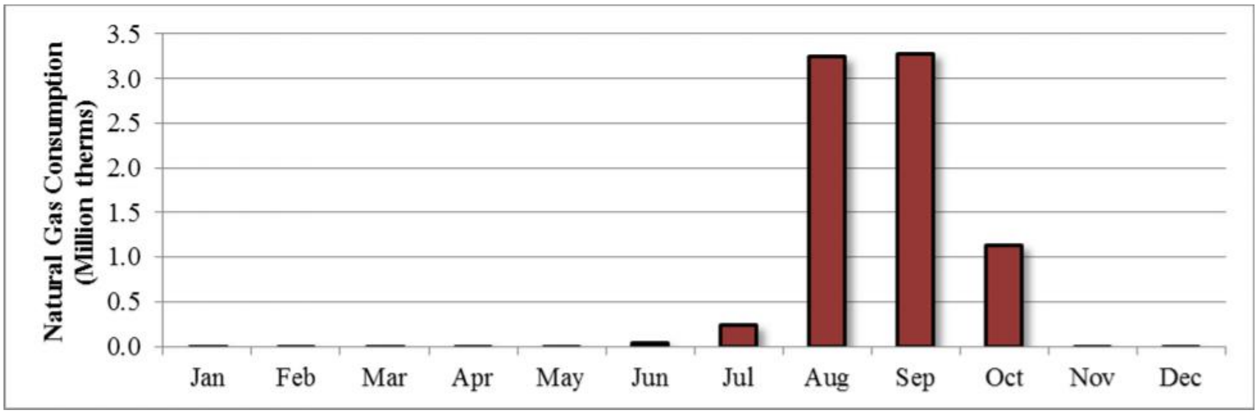

Figure 7 - Monthly Natural Gas Consumption for a Typical Plant

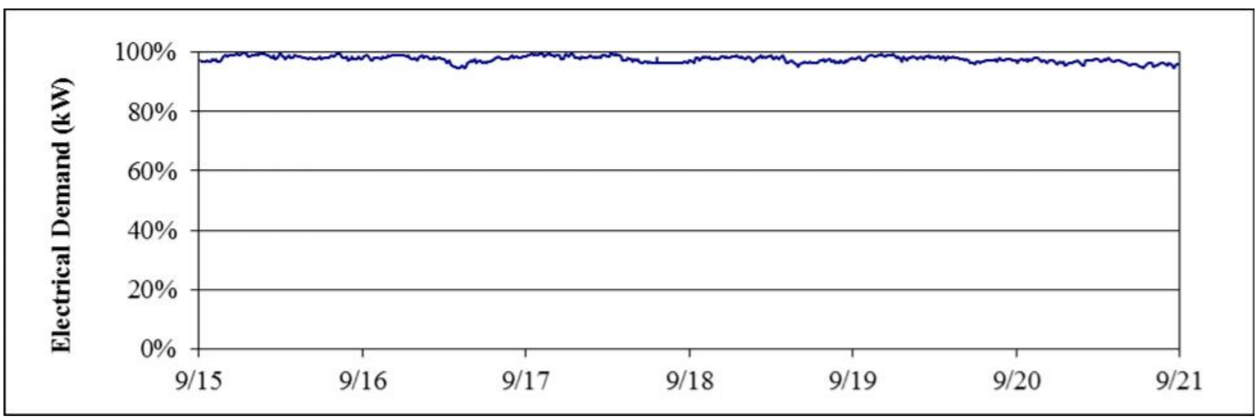

Figure 8 – Weekly Electrical Demand Profile for a Typical Plant

Figure 9 shows the typical distribution of electrical energy consumption in a tomato processing plant. The cooling towers, hot breaks, and evaporators are the most significant consumers of electrical energy in the plant. This is mainly due to paste/purée recirculation in the evaporators and product cooling. Other significant consumers are the steam boiler combustion blowers, boiler feedwater pumps, facility lighting, and air compressors. Table 1 summarizes the range of electrical energy consumption for major end uses in the audited tomato processing facilities.

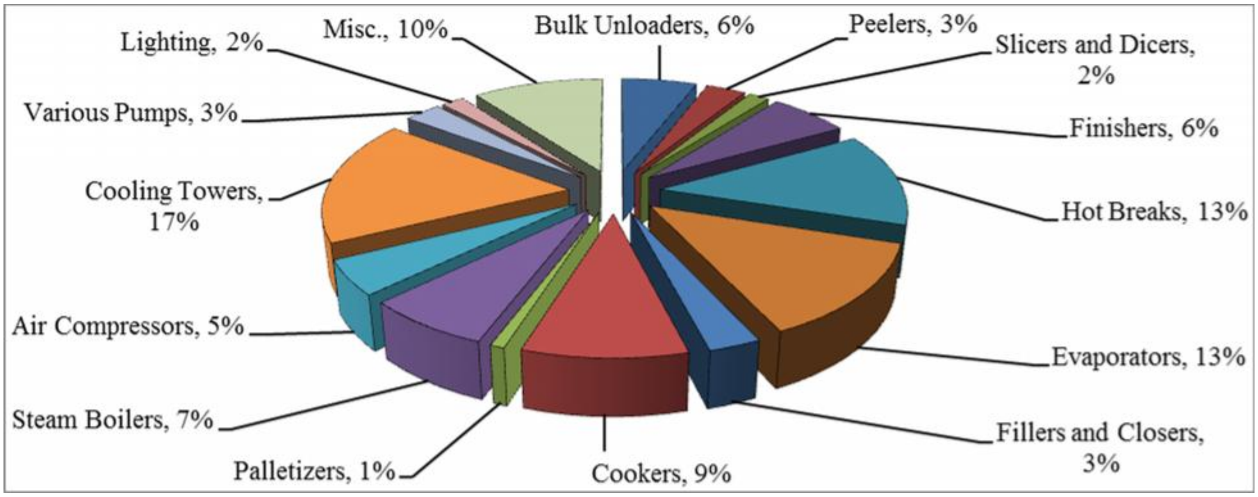

Figure 9 - Distribution of Electrical Energy Consumption in a Typical Plant

Table 1 - Range of Major Electrical Energy End-Uses

Evaporators & Breaks	19.5% - 47.0%
Lighting	1.8% - 11.5%
Boilers	3.5% - 17%
Compressed Air	3.0% - 3.5%
Cooling Towers	11.4% - 17.4%

The vast majority (95 – 98%) of natural gas consumption in tomato processing plants is in the steam boilers. The heat energy from the steam is also significantly greater than the heat required at the source (10,339 Btu of natural gas consumed at source for each kWh consumed on site) to generate the electrical energy used at the plant (3). For the plants audited, natural gas energy is 75 – 90% of the total energy usage at the plant. The major consumers of steam energy are the evaporators and hot/cold breaks, cookers, sanitizing equipment, and CIP operations.

OPPORTUNITIES IN ENERGY EFFICIENCY

Tomato processing facilities are extremely production oriented. On-site engineers typically do not have time to optimize the performance of their equipment during the short harvest season for tomatoes; thus, many opportunities for energy efficiency are available for both electrical and natural gas consuming equipment. This section will describe various identified measures, as well as the relative amount of savings compared to the total system consumption. All inspections were performed during the processing season.

Table 2 at the end of this section summarizes each measure, the relative system energy savings that can be achieved in a tomato processing facility, and the expected simple payback period for these measures. A brief description of the recommended energy efficiency measures for tomato processing facilities follows.

Steam Systems

Steam boilers at a tomato processing facility are the largest energy consuming equipment by a large margin. Therefore, any comprehensive energy efficiency audit should include this equipment. Tomato processors typically use several large water-tube boilers producing steam from 150 psig up to 500 psig. Combustion efficiencies for these boilers range from 72% - 86%, based on flue gas analyses performed by site personnel.

Repair Steam Leaks and Failed Steam Traps

Steam leaks and failed steam traps are fairly easy to identify, and represent a significant loss of thermal energy and potentially a safety risk if left unchecked. Steam leaks should be tagged at the beginning and end of the harvest season and repaired to reduce the natural gas consumption of the steam boilers.

On average, diligently repairing steam leaks can save 0.5% of the steam boiler's natural gas consumption, but can be up to 2.1% for sites with a significant number of leaks. Lawrence Berkley National Laboratory (LBNL) estimates that natural gas savings up to 10% can be achieved by implementing a steam leak repair program. This is an extremely low-cost measure to implement, with payback periods less than a year.

Return Condensate to the Main Condensate Return

There are various reasons that condensate may not be returned to the steam boilers. Failed steam traps may cause condensate to build up in the lines, and bypass valves or relief valves will be opened by maintenance personnel to prevent water-hammering (liquid plug of condensate hammering against a pipe bend at high velocity). Returning condensate also saves water, as well as boiler makeup water treatment costs and blow down losses.

Typically, tomato processors will already have extensive condensate return systems installed, but there may still be opportunities for condensate return. Natural gas savings for the steam boilers range from 0.02% of the total system consumption to as high as 3.6% for plants with a significant number of condensate points that drain to the wastewater system. Tomato processing facilities are fairly compact, and condensate return distances between the major steam users and the boiler room will not be very long; payback periods for this measure are typically less than a year.

Install an O_2 Trim System on the Boilers

Water tube boilers can operate at excess air levels up to 79% during part load conditions. Too much excess air will result in inefficient operation of the boiler. Excess air can be introduced to the combustion chamber through infiltration, a decrease in the ambient air temperature (increasing air density), fuel and air linkage misalignments, air leaks, and defects in the combustion blower dampers or burner management systems (2).

Installing an O_2 trim system can reduce the natural gas consumption of the steam boilers up to 0.8%. This measure also results in combustion blower electrical energy savings. The implementation of this measure is usually low-capital, and will pay back in less than a year.

Reduce the Operating Pressure of the Boilers

High pressure steam (380 - 420 psig) is usually needed to run backpressure steam turbines for pumping applications. Some boilers may produce a much higher pressure steam than what it is required by the processes, which reduces heat transfer rate and efficiency inside the boilers.

Reducing the discharge pressure of the steam boilers from 500 psig to 450 psig to better match the turbine demand and avoid pressure reduction in a pressure reducing valve (PRV) can result in a 1% increase in efficiency for the system. It is relatively simple for a boiler technician to adjust the pressure setpoint of the boiler system, and the payback for this measure is less than a year.

Insulate Various Hot Surfaces

Due to the steam usage intensity of tomato processors, there are many equipment surfaces that could benefit from the installation of insulation. This equipment includes condensate tanks and lines, deaerator tanks, boiler feed lines, boiler ends, product tanks feeding into the evaporators, hot or cold breaks, and sterilizers, cookers, heat exchangers, and others. Typically, fiberglass blankets are used as the insulation type, but there have been recent developments in commercially available thin-film spray-on insulation for surfaces up to 400 ^{o}F.

Application of insulation on uncovered surfaces can save 0.2% to 1% of the steam boilers' natural gas consumption. Simple payback periods for this measure range from 1 year to 2.6 years, depending on the difficulty of insulation application and temperature of the surface.

Replace or Repair Failed Economizers on the Boilers

Over time the economizers on boilers will fail, and boiler feedwater will be bypassed. Repairing these economizers can save a significant amount of energy.

Repairing failed boiler economizers can save up to 2.7% of the boiler's natural gas consumption, with a typical simple payback period of approximately 2 years.

Convert Existing Evaporator into an MVR System

A Mechanical Vapor Recompression (MVR) evaporator is the most efficient and most capital intensive type of evaporator. Steam from the evaporated tomato paste is recompressed and sent to earlier stages in the evaporator.

Installing an MVR system can save 5% to 11% of the boilers' natural gas consumption. It requires a significant capital investment, but typically has a simple payback of 2.2 to 5.5 years.

Install an Additional Effect on the Evaporator

Evaporator stages, or effects, operate at a lower pressure than the previous effect so that the evaporated tomato vapor heat can be used. Each additional effect on an evaporator increases the steam economy of the system.

Installing an additional effect on the evaporator can save approximately 3.7% of the boilers' natural gas consumption. This is a capital intensive measure, with a simple payback of approximately 10 years.

Electrical Systems

Tomato processors are large consumers of electrical energy. Due to their seasonal operation at the end of summer and the concentration of facilities in Fresno, Yolo, and Kings County (hot climate), tomato processors contribute significantly to the local utilities' peak electrical demands. There are many opportunities for electrical energy savings in nearly every stage of the process.

Repair Compressed Air Leaks

Compressed air is used in instrumentation throughout the plant. During production, lines can come loose at the fittings or form holes, forming leaks. Compressed air leaks can represent significant losses of energy.

Implementing a compressed air leak repair program at the beginning and end of the season can save up to 10% of the compressors' energy consumption. The annual cost savings for this measure will exceed the cost required to implement an inspection and repair program.

Use VFD-Controlled Air Compressors as Trim Units

Rotary screw air compressors are used to provide instrumentation compressed air at tomato processing facilities. In some cases, compressed air is also used in mechanical conveyance, air knife dryers, and the wastewater system. Often, one or more air compressors will be operating at part load, which is inefficient for screw compressors. It is recommended to install air compressor controls so all constant-speed compressors are nearly 100% loaded, and only the VFD-compressor part-loads as the trim unit.

Controlling the VFD compressor as the trim unit can save up to 4% of the electrical energy of the compressed air system. Implementation costs for this type of control system is low, and payback periods are less than a year.

Replace Compressed Air with Blower Air

Compressed air is used in some applications, such as package flattening, drying, or mechanical conveyance, when high pressure blower air would be an acceptable and an efficient alternative. Compressed air is typically produced at about 120 psig, while the air pressure for certain applications can be as low as 3 psig. Rotary lobe blowers can easily produce this pressure of air.

Implementation of this measure can save up to 2.3% of the compressed air energy usage, with a simple payback period of approximately 3.3 years.

Install Variable Frequency Drives on Water and Product Pumps

Water is used for many different purposes at a tomato processing facility; unloading flumes, product washing, equipment cleaning processes, heating and cooling circulation, and makeup water to cooling towers and boilers. Often, these pumps will be oversized and throttled or bypassed in order to control the flow and pressure. Installing Variable Frequency Drives (VFDs) and pressure or level sensors on these pumps can save a significant amount of energy and peak demands.

Installing VFDs on pumps at tomato processing facilities can save 16% to 80% of the electrical energy and up to 80% of the peak demand of these pumps. Simple payback periods range from less than a year to 6.4 years, depending on how far each pump is throttled or bypassed.

Install VFDs on Cooling Tower Fans

Cooling towers are used extensively in tomato processing facilities for cooling product exiting the peelers, evaporators, and sterilizers. Reducing the fan flow through a VFD when the ambient wet-bulb temperature is below design conditions can save significant amounts of energy.

Implementation of this measure can save 42% to 63% of the cooling tower fan energy consumption. There is no demand savings for this measure, as the utility peak period coincides with the peak ambient wet-bulb and dry-bulb temperatures. Implementation of this measure can be fairly capital intensive, and payback periods range from 1.8 years to 4.1 years.

Install VFDs on the Boiler Combustion Blowers

Typically, the airflow rate for boiler combustion blowers will be controlled by inlet vanes or dampers. Removing or completely opening the vanes/dampers and controlling the blower flowrate with a VFD will result in significant energy savings.

Energy savings for this measure range from 44% to 73% for the combustion blowers, with peak demand savings from 33% to 44% of the damper controlled boiler combustion blowers. Simple payback for this measure ranges from less than a year to 1.6 years.

Replace Hydraulic Drives with Electric Drives

Hydraulic pumping systems are an inefficient method of pumping and application for speed control. Often, hydraulic systems would be used so the equipment they were actuating would be simple to wash down without causing electrical shortages. However, this is no longer necessary because of totally enclosed stainless steel "wash-down" motors. Replacing hydraulic drives with electric drives can result in a significant amount of electrical energy and peak demand savings.

Installing electric drives in place of hydraulic drives can result in an electrical energy savings and peak demand reduction up to 57% compared to the hydraulic drive consumption. Simple payback periods are approximately 1.2 years.

Install High Efficiency Lighting

Typical processing areas will be lit with high-bay high-wattage metal halide lamps. Other support areas may be lit by inefficient T12 lighting. Replacing these lamps with T5, T8, light-emitting diode (LED), or induction lighting can result in significant electrical energy savings and reduce the peak electrical demand. Additionally, full spectrum high efficiency lighting can possibly reduce the occurrence of manual sorting errors (5), and increase productivity, decrease accidents, and morale among night shift workers (4).

High efficiency lighting can save from 38% to 80% of the fixtures electrical energy consumption and peak demand. Depending on the hours of operation, simple payback periods range from less than a year up to 4.7 years.

Install Lighting Controls

Office buildings and warehouses at tomato processing facilities will often be unoccupied for extended periods of time, or have sufficient daylight available where the lights will not be needed.

Installing lighting motion sensor and daylight sensor controls can save 24% to 75% of the fixture's energy consumption and reduce the peak demand by up to 75%. Simple payback periods for this measure range from 1.0 years to 3.2 years.

Use Steam Turbines Instead of Electric Drives

Often at tomato processing facilities, steam will be generated at a much higher pressure and temperature than what some processes, such as the tomato paste evaporators, can use. This steam will be throttled to a lower pressure through the use of a pressure reducing valve (PRV). Often, there are large electrically driven pumps near these processes that can be replaced with steam backpressure turbine driven pumps, both producing mechanical work and lower pressure steam. This measure is especially effective for evaporator circulation pumps, because the mechanical work and low pressure steam is used in the same piece of equipment.

Savings for this measure can be from 28% to 47% of the evaporator process electrical energy consumption and peak demand. Implementing this measure will slightly increase the natural gas consumption of the boiler system. Simple payback periods for this measure are approximately 5 years.

Table 2 - Summary Energy Efficiency Measures and Typical Savings for Tomato Processors

Energy Efficiency Measure Description	**Typical Range of System Energy Savings Comparison**	**Typical Range of Simple Payback**	**No. Facilities Recommended**
Steam Boilers			
Repair Steam Leaks and Failed Steam Traps	0.5% - 2.1%	< 1 year	5
Return Condensate to the Main Condensate Return	0.02% - 3.6%	< 1 year	3
Install an O_2 Trim System on the Boilers	0.8%	< 1 year	2
Reduce the Operating Pressure of the Boilers	1.0%	< 1 year	1
Insulate Various Hot Surfaces	0.2% - 1.0%	1 – 2.6 years	2
Replace Failed Economizers on the Boilers	2.7%	2 years	1
Convert Existing Evaporator into an MVR System	5% - 11%	2.2 – 5.5 years	2
Install an Additional Effect on the Evaporator	3.7%	10 years	1
Electrical Systems			
Repair Compressed Air Leaks	10%	< 1 year	1
Use VFD-Controlled Air Compressors as Trim Units	4%	< 1 year	1
Replace Compressed Air with Blower Air	2.3%	3.3 years	1
Install VFDs on Water and Product Pumps	16% - 80%	1 year – 6.4 years	2
Install VFDs on Cooling Tower Fans	42% - 63%	1.8 years – 4.1 years	3
Install VFDs on Boiler Combustion Blowers	33% - 44%	1 year – 1.6 years	2
Replace Hydraulic Drives with Electric Drives	57%	1.2 years	1
Install High Efficiency Lighting	38% - 80%	4.7 years	5
Install Lighting Controls	24% - 75%	1 year – 3.2 years	5
Use Steam Turbines Instead of Electric Drives	28% - 47%	4.6 years – 5.1 years	2

OPPORTUNITIES IN DEMAND RESPONSE

Most tomato processing facilities in California are concentrated in Fresno, Yolo, and Kings County. Additionally, because the tomato harvest season is in late summer, the peak demand of these facilities coincides with the local utility peak demand.

Tomato processors are so highly production oriented that it is difficult to enact demand response programs. However, in some cases there are site-specific measures that can be used to reduce the facility's load on the grid. Table 3 on the next page summarizes these measures and the relative site demand reduction that can be achieved. A brief description of the recommended demand response measures for tomato processing facilities follows.

Turn Off Warehouse Lights

Most tomato processors have large ambient temperature warehouses to store the seasonal product year-round until a customer places an order. If the warehouses have skylights, the lighting can be turned off during a peak demand response event. Turning off the warehouse lighting can reduce a tomato processor's peak demand by approximately 0.3% with negligible implementation costs.

Charge the Forklift Batteries During the Off-Peak

Often, a facility will have multiple forklifts to transport product to and from the warehouses. Charging the forklifts during the off-peak utility period can reduce the peak demand, as well as save costs by consuming energy during a low-rate period. Charging the forklifts during the off-peak period can reduce a tomato processor's peak demand by approximately 2%. The facility may need to purchase additional chargers, batteries, and timers in order to implement this measure. Note that some processors will use propane-fuelled forklifts; this measure only applies to battery-powered forklifts.

Shut Down Packaging Lines

Some tomato processors have multiple packaging lines, and it would be feasible to shut down one or more lines during a demand response event. This process may include conveyors, product pumps, sanitation and cooling equipment, and filler/sealer units. In some plants, shutting down a packaging line could reduce a facility's peak demand by 11% with negligible implementation costs.

OPPORTUNITIES IN WATER CONSERVATION

During the harvest season, tomato processors are significant consumers of water. Most producers will pump water from the aquifer, use the water internally, then discharge the effluent to land application. The facilities audited consumed between 129 and 532 million gallons per year. Table 4 summarizes the recommended water conservation measures. Please note that the measures listed in this table may be applied to multiple areas in a facility. A brief description of the recommended water conservation measures for tomato processing facilities follows.

Repair Water Leaks

Valves, hoses, and water storage tanks can all spring leaks due to normal wear and tear. Implementing a maintenance program to repair these leaks can significantly reduce the amount of fresh water that a facility purchases from the city or pumps from the aquifer. Repairing water leaks can save approximately 0.7% of a facility's water consumption.

Prevent Overflow of Cooling Tower Water

Cooling tower makeup water pumps may be improperly controlled and cause significant overflow rates by continuously supply water to the cooling tower sump after it has already been filled. Installing a level control system on the cooling tower makeup water pump can save up to 1.7% of a facility's total water consumption. Implementation of this measure will often pay back within a year.

Cascade Water in the Flume System

Water jets are used to unload tomatoes from trucks, which are then conveyed into the processing facility by a series of flumes. Water can be recovered from the last stages of the flume, filtered, and sent to former stages counter-current to the flow of the product. Recovering water from one flume and using it in another flume can save between 1.3% and 3.8% of a facility's total fresh water consumption, and will typically pay back in less than a year.

Reuse Single Pass Cooling Water

In tomato processing facilities, pump seal cooling water and product cooling water is often drained. It is recommended to reroute this water back into the cooling tower or flumes to offset fresh makeup water. Reusing single-pass cooling water can save between 1.7% and 5.0% of a facility's total fresh water consumption. This measure will pay back between one year and 4.8 years, depending on the amount of collection points.

Recycle Evaporator Condensate

If the condensate from the evaporated tomatoes is relatively pure, condensate water can be used in the cooling towers, unloading flumes, and other low-grade facility applications (9).

Table 3 - Summary of Demand Response Measures and Typical Demand Reduction for Tomato Processors

Demand Response Measure Description	Typical Range of Site Demand Reduction	Typical Range of Simple Payback
Turn Off Warehouse Lights	0.3%	< 1 year
Charge the Forklift Batteries During the Off-Peak	2.0%	< 1 year
Shut Down Packaging Lines	11.3%	< 1 year

Table 4 - Summary of Water Conservation Measures and Typical Savings for Tomato Processors

Energy Efficiency Measure Description	Typical Range of Site Water Savings	Typical Range of Simple Payback
Repair Water Leaks	0.7%	< 1 year
Prevent Overflow of Cooling Tower Water	1.7%	< 1 year
Reuse Flume Water in Former Stages	1.3% - 3.8%	1 year – 4.8 years
Reuse Single Pass Cooling Water	1.7% - 5.0%	1 year – 4.8 years
Recycle Evaporator Condensate*	N/A	N/A

*There is no range of savings or payback period for this measure, because it is referenced from the Lawrence Berkeley National Laboratory (LBNL).

CONCLUSIONS

Tomato processing is an extremely energy intensive industry, with approximately 6% of the total costs of operation spent on energy. California tomato processors supply 35% of the world's packaged tomato consumption. Thus, it is important to help reduce this bottom line for tomato processors in California through the use of conservation practices.

It is possible to reduce the electrical energy consumption, peak demand, natural gas energy consumption, and water consumption significantly and cost effectively. On a facility-wide basis, up to 12.5% of the total electrical energy consumption, 17.2% of the total peak demand, and 6.0% of the total natural gas consumption can be conserved through energy efficiency and conservation measures, as well as demand response measures. This represents a total cost savings of approximately $480,000 per year. Additionally, water conservation measures can result in a 15.6% facility-wide reduction of fresh water usage, representing approximately $30,000 per year in electrical energy costs. If all energy conservation and water conservation measures are considered together, payback periods for these facilities are between 1.2 years to 3.6 years.

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Optimized Design of a Furnace Cooling System

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***Abstract*—This paper presents a case study of manufacturing furnace optimized re-design. The bottleneck in the production process is the cooling of heat treatment furnaces. These ovens are on an approximate 24-hour cycle, heating for 12 hours and cooling for 12 hours. Pressurized argon and process water are used to expedite cooling. The proposed modifications aim to minimize cycling by reducing cooling time; they are grouped into three fundamental mechanisms. The first is a recommendation to modify current operating procedures. This entails opening the furnace doors at higher than normal temperatures. A furnace temperature model based on current parameters is used to show the reduction in cooling time in response to opening the furnace doors at higher temperatures. The second mechanism considers the introduction of forced argon convection. Argon is used in the process to mitigate part oxidation. Cycling argon through the furnace during cooling increases convection over the parts and removes heat from the furnace envelope. Heat transfer models based on convective Nusselt correlations are used to determine the increase in heat transfer rate. The last mechanism considers a modification to the current heat exchanger. By decreasing the temperature of the water jacket and increasing heat exchanger efficiency, heat transfer from the furnace is increased and cooling time is shortened. This analysis is done using the Effectiveness-NTU method.**

I. Introduction

In the midst of global climate change and a greater awareness of consumer based economics, there is a drive to reform industrial consumption habits. Energy geared towards industrial applications is projected to rise by approximately 0.3% per year from 2010 to 2035; this amounts to approximately 3.34 quadrillion BTU's over the next 25 years [1]. There is a need for industrial facilities to make better use and exert greater control over the energy they use. The following analysis represents an endeavor to re-evaluate the dynamics of heat transfer for a key piece of industrial equipment, a sintering furnace. The goal is to optimize furnace operations to relieve an operations bottleneck for a tungsten carbide drill nozzle production facility. In light of plans to mitigate the bottleneck by purchasing an additional $1.6M furnace and increase production by 17%, the following has the potential to increase production capacity while bypassing plans to make greater use of electrical power.

The furnace is on an approximate 24 hour cycle; sintering drill nozzle parts for 12 hours and cooling for the following 12 hours. In order to identify factors that contribute to the lengthy process cycle time, the furnace energy flow was investigated. This furnace was designed with maximized insulation to allow for an efficient heating cycle; furnace materials were chosen to contain the thermal energy required to sinter the parts. These materials, although beneficial during heating, serve as major barriers that inhibit heat from being removed during cooling. In order to lessen the effects of these thermal barriers, concepts were generated to increase convective heat transfer and utilize an existing heat exchanger system more effectively. Computational and mathematical modeling of heat transfer through the system allowed for calculation of the predicted effects for various concepts.

II. Background

The plant is currently operating six sintering furnaces with an average cycle time of 24 hours. The first half of this cycle is a precisely regimented heating recipe that has been designed to achieve desired drill nozzle material properties. Temperatures within each furnace reach up to 2,588°F. The vessel is purged with hydrogen and pressurized with argon at 250 psi to prevent oxidation of parts. The second half of the process cycle, characterized by a lengthy cooling process, is unconstrained and can be modified to improve furnace cooling without compromising part quality. The solutions presented in this report utilize a variety of approaches to increase heat transfer during the furnace cooling process, providing an opportunity for the facility to achieve the necessary increase in production capacity without purchasing an additional furnace.

A. *Furnace Description*

The manufacturing facility currently utilizes six large sintering furnaces. Two of these furnaces can accept 300 kg of parts per load, while the other four hold 500 kg. For reference, the vessel walls of the 300 kg furnaces have an interior length of 72 in. and an inner diameter of 44.75 in. Three-dimensional diagrams describing the furnace is presented in Fig 1 and 2. Each furnace is composed of two sections: the inner and outer chamber. The inner chamber is separated from the outer chamber by a rigid package made from low-density carbon fiber insulation. Inside the inner chamber are two removable platforms for the parts to sit on. While the parts are inside the furnace, a dense and rigid graphite radiation shield is placed over each platform in order to evenly distribute thermal energy that is radiated from heating elements. The platforms and the radiation shields can be removed from either of the exterior doors on the opposite sides of the furnace.

The heating elements are located in the inner chamber, with temperatures in this section reaching 2,588°F (1420°C) at the end of the heat treatment process. Thermocouples lay between the heating elements along the side walls of the package to record the temperature within the region. The outer chamber remains relatively cooler due to the insulating

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properties of the graphite packing. The inner and outer chamber both contain a pressurized argon atmosphere by the end of the heat treatment process to mitigate part oxidation. The argon used is currently vented out of the furnaces and into the atmosphere after each use, but plans exist to implement a recapture system to re-cycle the gas through the system multiple times.

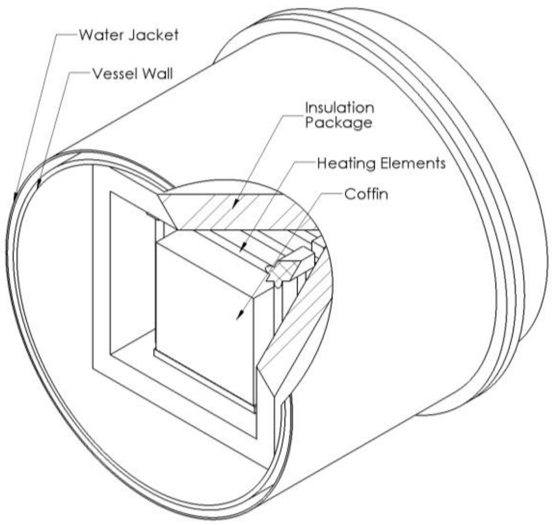

FIGURE 1. FURNACE SCHEMATIC.

The outer chamber wall is made of stainless steel and cannot be exposed to extreme temperatures due to the threat of structural failure. This constraint prevents the inner door from being opened immediately after the heating cycle ends. Therefore, upon the start of the cooling process, the inner door remains sealed and the only means of heat transfer from the inner chamber to the outer chamber is via conduction through the graphite packing. Plant protocols currently call for the inner door to be opened when the temperature of the inner chamber is below 1,166°F (630°C) to avoid endangering the structural integrity of the stainless steel pressure vessel wall. The inner chamber temperature that corresponds with this process is displayed in Fig. 3. The outer chamber wall also contains a water jacket with a 40 gal/min flow rate that receives heat from within the furnace and disposes of it through the use of a shell and tube heat exchanger.

III. SOLUTION DESCRIPTIONS AND ANALYSES

The solutions developed to improve the furnace cooling operation can be separated into three main sections: modified operational procedures, free and forced convection improvements, and water cooling system modifications. These solutions are described and analyzed within their own respective sections.

A. *Modified Operational Procedures*

1) *Concept*

A means to reduce cooling time would be to investigate furnace cycle operations to find improvements that can be made without altering the furnace pressure vessel. A proposed modification in operating procedure to allow the

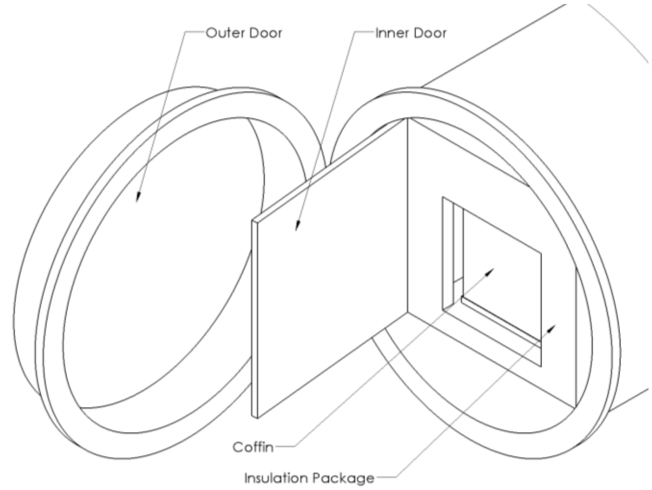

Figure 2. Door Diagram

outer and inner doors to be opened at higher temperatures is explored.

2) *Analysis*

A mathematical model for a cooling cycle was developed from thermocouple sensor data used by the company to monitor furnace operations. The cooling cycle exhibited two periods of exponential decay; before and after the opening of the inner door. The exponential temperature decay for the two time periods follows:

$$T_1(t) = (T_{1,i} - T_{surr})e^{-\tau_1 t_1} + T_{surr} \tag{5a}$$

$$T_2(t) = (T_{2,i} - T_{surr})e^{-\tau_2 t_2} + T_{surr} \tag{5b}$$

The subscripts 1 and 2 indicate the periods before and after the inner door is opened. The subscript i refers to initial values. T is the temperature of the inner chamber, τ is the time constant, t is the time of cooling for the period and T_i is the initial temperature when the cooling cycle begins. T_{surr} is the surrounding temperature outside the furnace. The total cooling time, t_{tot}, is calculated from the final times, t_f, using (6).

$$t_{tot} = t_{1,f} + t_{2,f} \tag{6}$$

The total time can be derived from the above equations as function of the inner and outer door opening temperatures using (7).

$$t_{tot} = -\frac{\ln\left(\frac{T_{2,i}-T_{surr}}{T_{2,f}-T_{surr}}\right)}{\tau_1} - \frac{\ln\left(\frac{T_{2,f}-T_{surr}}{T_{2,i}-T_{surr}}\right)}{\tau_2} \tag{7}$$

T_{surr} was set at 73 °F as an average temperature value for the facility. The first period was completed in 6.58 hr as the inner chamber of the furnace cooled from 2,588°F to 1,166°F, at which time the inner door was opened. The second period was completed in 3.07 hr cooling from this inner door opening temperature to the outer door opening temperature of 302 °F. From this $T_{1,i}$ = 2,588 °F, and $T_{2,i}$ = 1,166 °F. To calculate τ_1 and τ_2, T_1 = 1,166 °F at t_1 = 6.58 hr and T_2 = 302 °F at t_2 = 3.07 hr. For this, τ_1 was calculated to be 0.1266 hr^{-1}, and τ_2 was 0.5091 hr^{-1}.

Equations (5a) and (5b) can thus be given as:

$$T_1(t) = (2588 - 73)e^{-.1266t_1} + 73$$

$$T_2(t) = (T_{2,i} - 73)e^{-.5091t_2} + 73$$

This can be input into (7) to find t_{tot} as follows:

$$t_{tot} = -\frac{\ln\left(\frac{T_{2,i}-73}{2515}\right)}{.1266} - \frac{\ln\left(\frac{T_{2,f}-73}{T_{2,i}-73}\right)}{.5091}$$

$T_{2,i}$ (inner door opening temperature) and $T_{2,f}$ (outer door opening temperature) can be input to calculate the time saved if either of them were altered. For the sintering cycle examined, t_{tot} = 9.65 hr. From this, the percent decrease in cooling time, $\%_{t,d}$, as function of $T_{2,i}$ and $T_{2,f}$ can then be derived as shown in (8).

$$\%_{t,d} = \left[\frac{t_{tot} + \frac{ln\left(\frac{T_{2,i}-T surr}{T_{1,i}-T surr}\right)}{\tau_1} + \frac{ln\left(\frac{T_{2,f}-T surr}{T_{2,i}-T surr}\right)}{\tau_2}}{t_{tot}}\right] \times 100 \qquad (8)$$

3) Recommendation

Currently, the plant opens the outer pressure-bearing door when the interior chamber temperature is 302 °F (150 °C). To reduce the time of a sintering cycle, the plant should investigate opening the furnace and removing the parts at a higher temperature than current facility operations call for. Recommendations from the furnace manufacturer suggest opening the furnace door at an inner chamber temperature of 392 °F (200 °C). Keeping all other conditions constant, implementing this action into (8) would reduce the cooling cycle time by approximately 10.16 percent by ending the normal cycle earlier. The main challenge is ensuring part property integrity. Fig. 3 presents a temperature vs. time diagram showing the time savings for this action.

Operation of the interior doors should be investigated to ensure they are opened at an optimal time in the process. This can be done either by making sure the door is opened as soon as the chamber reaches the allowable temperature limit or by testing for higher temperature limits. Opening the inner door allows hot argon to be released in the cooler outer chamber. Heat would then be drawn out faster by contact with the water jacket surrounding the outside wall, which is where the highest rate of heat transfer occurs. Many of the proposed concepts yield improvements once the inner door is opened.

One recommendation, supported by the furnace manufacturer, is for the facility to carefully experiment with opening the inner door at incrementally higher temperatures, up to 1,292 °F (700 °C) for internal chamber temperature. The limiting factor is the outer chamber steel wall temperature limits; it cannot surpass 200 °F (93 °C), a constraint set by the manufacturer to avoid structural failure. A motivation to pursue this concept would be the possible time savings for each cycle. By opening the inner chamber door when the interior is 126 °F hotter (700 °C), the percentage decrease in cooling time, calculated using ($\%_{t,d}$), would be 11.36 percent. If this is combined with opening the outer door at 392 °F, percentage decrease in cooling would be 17.18 percent.

B. Free and Forced Convection Improvements throughout Furnace

1) Concept

Another means to reduce cooling time is to increase convective heat transfer within the furnace. Concepts under this category include both free and forced convection. The two areas of focus for improving free convection are the radiation shield and the inner chamber door.

2) Analysis

Preliminary analysis and calculations have been made to determine the impact of increased convection. This was done by creating a theoretical spherical mass of tungsten carbide that was subjected to both free and forced convection by means of computational modeling. In one situation, the mass was modeled as if it was suspended alone in stagnant argon, undergoing free convection. In the second situation, the mass was subjected to a cross flow of argon at a nominal velocity. The two theoretical cases were then compared to estimate the advantage that may be created by the introduction of convection. The crucial numbers in this calculation are the convection coefficients that are found using the Nusselt number, as shown in (9).

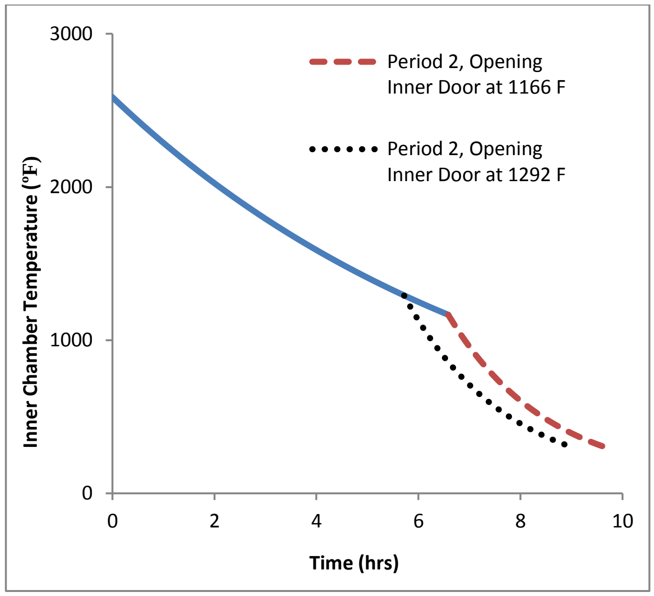

Figure 3. Cooling Time improvements from opening inner door at higher temperatures.

$$\overline{Nu} = \frac{\bar{h}D}{k} \qquad (9)$$

Where $\overline{Nu}$ is the Nusselt number, $\bar{h}$ is the convection coefficient, D is the hydraulic diameter of the tungsten carbide mass, and k is the thermal conductivity of the argon gas. The Nusselt number for a free convective flow going across a spherical surface is shown in (10).

$$\overline{Nu}_{Free} = 2 + \frac{0.589 * Ra_D^{1/4}}{[1+(\frac{0.469}{\text{Pr}})^{9/16}]^{4/9}} \qquad (10)$$

Where Ra_D is the Raleigh number and Pr is the Prandtl. The Raleigh number with a characteristic length of D (diameter) for a spherical object is as shown in (11).

$$Ra_D = \frac{g\beta(T_1 - T_2)D^3}{\alpha v} \quad (11)$$

where g is the gravitational constant, β is simplified to the inverse of the average absolute temperature of the argon gas, T_1 and T_2 are the warmer and cooler temperatures of the system being evaluated respectively, α is the thermal diffusity, and ν is the kinematic viscosity. For forced convection, the Nusselt number for a flow going across the surface of a sphere is as shown in (12).

$$\overline{Nu}_{Forced} = 2 + (0.4Re_D^{\frac{1}{2}} + 0.06Re_D^{\frac{2}{3}})Pr^{0.4}(\frac{\mu}{\mu_s})^{\frac{1}{4}} \quad (12)$$

Where Re_D is the Reynolds number for the gas, μ is the dynamic viscosity of the gas at the warmer temperature (T_1), and μ_s is the dynamic viscosity of the gas at the cooler temperature (T_2). The Reynolds number can be expanded to be dependent on the velocity of the gas flow, the characteristic length of the object (the diameter specifically for this situation), and the kinematic viscosity as shown in (13).

$$Re_D = \frac{VD}{\nu} \quad (13)$$

To combine the effects of both forced and free convection, (14) is used.

$$Nu_{Total}^n = Nu_{Free}^n + Nu_{Forced}^n \quad (14)$$

Where typically n = 3 for most cases [4]. Once the proper Nusselt numbers and convection coefficients are calculated, comparative times for the two theoretical cases can be found using the lumped capacitance model, as shown in (15).

$$\frac{\rho Vc}{hA_s}\ln\left(\frac{T_i - T_\infty}{T - T_\infty}\right) = t \quad (15)$$

Where ρ is the density of the material, V is the volume, c is the heat capacity, and A_s is the surface area of the material. T_i, T_∞, and T represent the initial starting temperature of the cooling cycle, the ambient temperature around the material, and the desired temperature to end with, respectively. For the comparative model used, the tungsten carbide mass was assumed to have a diameter of 1.345 ft. based off of its density and expected furnace load. The temperatures in the lumped capacitance model were assumed to be 2,588°F for the initial temperature, 194 °F for the ambient temperature (as the outer chamber walls cannot exceed 200°F), and 302 °F for the desired part temperature to be taken out. The results from the comparison of the free convection only model to that with forced convection introduced, presented a 10% improvement in reduced cycle time when a 1.64 ft/s flow of argon was introduced.

The physical constraints of the pressure vessel thermal requirements poses a difficulty in opening the inner doors at a temperature above 392 °F (200 °C). Much of the gain associated with cooling the sintering furnace comes about after opening the inner doors, where most of the heat lies. One expects any increase in heat transfer proportionality to bode well for cooling, thus decreasing the amount of time required for full cycle part sintering. Fig 4 entails the decrease in cooling time after the inner chamber doors have opened. It currently takes the facility approximately 2 hours to reach the required temperatures to maintain material integrity. By doubling the convection, cooling time decreases by half; from two hours to one hour and by increasing the convection coefficient by approximately 5 times the current value, cooling time can be decreased to approximately 0.5 hours.

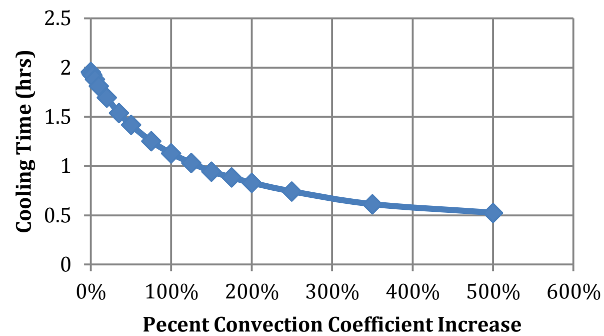

Figure 4. Graph entailing decrease in cooling time with precent increase in the convective coefficient.

If one were only able to double the convection coefficient, the savings would amount to 355 hours per year (10 days off for holidays), or 14 more loads per year. Realized throughout all 6 ovens, 84 more loads per year are possible.

3) Recommendations

As there are no heating elements at the front and back faces of the inner chamber, fluid flow could be improved by increasing the open area of the radiation shield faces at these locations, since radiation has no effect here. This will not compromise quality as long as the parts remain optically blind to the radiation directly from the heating elements. This can be accomplished by increasing the size of the existing holes or removing larger sections of the back and front faces.

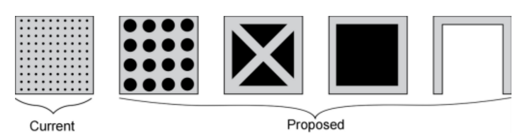

Figure 5. Current and Proposed Modifications to Radiation Shield Front and Back Faces

This will allow more airflow, and thus convection, cooling the inner chamber more quickly, and reaching the temperature in which the inner door can be opened sooner. Modifying the radiation shield will also increase free convection after the inner door is opened, further decreasing the length of the entire cooling process. A diagram of the possible coffin modifications can be found in Fig. 5.

In addition to free convection and conduction, several methods of creating forced convection have been considered to increase heat transfer. The first method is the continuous cycling of argon gas into and out of the furnace during the cooling process. This would create flow within the furnace and also allow further cooling of the gas outside the furnace. The cooler gas could then be brought back into the system to continue cooling the system. The temperature and pressure constraints of the current venting and introduction systems will have to be considered for whether the hotter argon can be handled by the current system, or if a new system needs to be developed. The current argon recapture system, or an updated version, could be easily integrated as part of this concept, as it would be utilized in retrieving the hot argon out of the furnace during the appropriate time.

The second proposed forced convection method is the installation of a fan in the inner chamber of the furnace to increase argon flow. There are similar sintering furnaces currently on the market that include fans for efficient cooling of equipment. Another possibility is to install the fan in the outer chamber of the furnace. It should be noted that a fan in the outer chamber would not be significantly effective until the opening of the inner chamber door.

The final method of creating forced convection is by movement of the interior door in an oscillating motion to produce a flow from the interior portion to the exterior. This motion could be automated to allow for the motion to occur repeatedly for long periods of time. This automation equipment could also act as the autonomous mechanism to open the inner door on time described in the *Modified Operational Procedures* section.

C. *Water Cooling System*

1) *Concept*

The water-cooling system, displayed in Fig. 6 includes the heat exchanger, the furnace water jacket, and cooling towers. Surrounding the wall of the pressure vessel is a water jacket where process water absorbs thermal energy from within the furnace. This process water exits the furnace and enters into a two-pass shell-and-tube heat exchanger at a temperature of $T_{h,i}$ where it exchanges thermal energy with plant water flowing from a cooling tower. This process water then exits the heat exchanger at a temperature of $T_{h,o}$ and returns to the furnace to complete the cycle. In Fig. 6, $T_{c,i}$ and $T_{c,o}$ are the temperatures of the plant water entering and exiting the heat exchanger respectively.

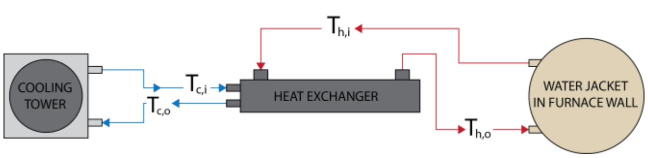

Figure 6. Water Cooling System

The water cooling system would be modified to decrease the temperature of the process water being sent into the furnace's water jacket, $T_{h,o}$. This colder water would be used to maintain the stainless steel wall of the pressure vessel below the required 200 °F during experimenting with opening the inner door at higher temperatures.

2) *Analysis*

The heat exchanger was analyzed using "The Effectiveness-NTU Method" to determine its performance within the water cooling system. This method begins by determining the maximum possible heat transfer rate, q_{max}, for a set of inlet fluid temperatures into a heat exchanger using (16) [4].

$$q_{max} = C_{min}(T_{h,i} - T_{c,i}) \tag{16}$$

$T_{h,i}$ is the inlet temperature of the hotter fluid, while $T_{c,i}$ is the inlet temperature of the colder fluid. Thermocouples were used to measure inlet temperature values. $T_{h,i}$ values ranged from 84-96 °F and $T_{c,i}$ values ranged from 70-72 °F. The larger range of $T_{h,i}$ values is attributed to the different temperatures within the furnace over its cooling cycle, while $T_{c,i}$ is kept fairly constant due to the work of the cooling towers. C_{min} is the minimum value taken from the heat capacity rate of the two fluids [4]. A fluid's heat capacity rate, C, is the product of the mass flow rate, $\dot{m}$, and the fluid's heat capacity, c_p [4].

$$C = \dot{m}c_p \tag{17}$$

With c_p being the same for both fluids ($c_{p,water}$ = 1.1498 BTU/(lb·°F), the C_{min} value was decided by the mass flow rates ($\dot{m}_h$ = 5.564 kg/s and $\dot{m}_c$ = 16.69 kg/s).This resulted in C_{min} = C_h = 6.397 BTU/(s·°F) and C_{max} = C_c = 19.19 BTU/(s·°F).

The actual heat transfer rate, q, is defined from (18) using a calculated effectiveness, ε, a function of NTU and C_r for the heat exchanger [4].

$$q = \varepsilon q_{max} = \varepsilon C_{min}(T_{h,i} - T_{c,i}) \tag{18}$$

C_r is defined as C_{min}/C_{max} and results in a value of 0.33 [4]. The effectiveness is a function of NTU and C_r.

The number of transfer units, NTU, is calculated using (19).

$$NTU = \frac{UA_{he}}{C_{min}} \tag{19}$$

U is the overall heat transfer coefficient, and A_{he} is the area of the tubes within the heat exchanger. A representative U value of 0.06360 BTU/(s·ft²·°F) for water to water heat exchange was used in the analysis [4]. Area was calculated to be 42.21 ft². The NTU value was found to be 0.4828.

Finding the effectiveness for a two pass shell-and-tube heat exchanger is broken into two steps. The theoretical effectiveness for one pass, ε_1, has to be found first (20)

$$\varepsilon_1 = 2\left\{1 + C_r + (1 + C_r^2)^{1/2} \times \frac{1+e^{[-(NTU)_1(1+C_r^2)]^{1/2}}}{1-e^{[-(NTU)_1(1+C_r^2)]^{1/2}}}\right\}^{-1} \tag{20}$$

Where $(NTU)_1$, the number of transfer units for one pass, is defined using (21).

$$(NTU)_1 = \frac{NTU}{n_p} \tag{21}$$

Where n_p is the number of passes and equals two. $(NTU)_1$ was found to be 0.2414. With this, ε_1 was found to be 0.2070. The equation to calculate the effectiveness for a multiple pass shell-and-tube heat exchanger is (22).

$$\varepsilon = \left[\left(\frac{1-\varepsilon_1 C_r}{1-\varepsilon_1}\right)^n - 1\right]\left[\left(\frac{1-\varepsilon_1 C_r}{1-\varepsilon_1}\right)^n - C_r\right]^{-1} \tag{22}$$

The effectiveness for the heat exchanger was found to be 0.3620.

3) Recommendation

With the heat exchanger showing a low effectiveness value of 0.3620 and the cooling tower limited in its ability to only cool the fluid to ambient temperature, it is recommended that the facility consider the installation of a chilled water cooling system in place of the current setup.

IV. Conclusion

In order to increase production capacity of the plant's sintering furnace through a decrease in cooling time, three solutions have been proposed. The first is a modification of current operating procedures. By opening the furnace's inner chamber door at 392°F rather than 302°F, a time savings of 10.16% can be realized, thus decreasing sintering time and increasing annual production capacity. The introduction of forced argon has the potential to increase heat transfer by increasing convection between the furnace walls and tungsten carbide drill parts. By doubling the convective coefficient a savings of approximately 355 hours can be realized, increasing the number of loads per year. Decreasing the encompassing area of the radiation heat shield further enhances heat transfer, thus allowing greater flow of argon over the sintered parts. The final concept proposes a modification to the heat exchanger. It has been shown that the current shell and tube heat exchanger has an effectiveness of 0.36. By increasing the effectiveness of the heat exchanger and lowering the temperature of the water jacket over the furnace. A larger amount of heat can be extracted and dissipated, decreasing cooling time.

V. Acknowledgments

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Design and Predictive Control of a Net Zero Energy Home

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***Abstract*—This paper analyzes two methods to reduce residential energy consumption for a Net Zero home in Austin, Texas. The first method seeks to develop a control algorithm that actively engages environmental conditioning. The home must preserve user-defined comfort while minimizing energy consumption. An optimization function governed by user input chooses the degree to which various comfort-defining systems are active, optimizing comfort while maintaining minimal energy usage. These systems include a geothermal heat pump and ceiling fans to effect convection, humidity, and dry bulb temperature. The second method reflects an analysis towards augmenting traditional home systems with modern and efficient counterparts. Electrochromic glass is used to attenuate heat transfer from outside the home envelope. A thermal chimney passively removes heat from the home while increasing convection. Replacing conventional incandescent bulbs with compact fluorescent and LED illumination reduces lighting energy waste.**

I. Introduction

The United States consumes over 15% of the world's power, while its population only makes up 5% of the world's total. Furthermore, the majority of the US's energy comes from non-renewable fossil fuels [10]. Economic stressors within the past 30 years have driven recognition for efficient energy usage. Environmental awareness of burning fossil fuels and the drive towards energy independence has many innovating on energy savings methods. Within the United States, residential applications account for 22% of total electrical consumption [10]. Residential buildings are major consumers of energy and although energy consumption per home has decreased, the increased number and size of residential structures have offset efficiency gains [1].

While many endeavors seek to produce homes that mitigate grid energy consumption, the latest realization of this is the Net Zero home; usually reserved to mean a residential dwelling that consumes as much grid energy as it produces (through wind driven power generation or photovoltaics). To satisfy this condition, it becomes necessary to use non-traditional technologies that accomplish the same task as any traditional home system while decreasing the electrical energy consumed to accomplish it. Using LED or compact fluorescent lighting in place of incandescence, or implementing geothermally based heat pumps rather than traditional air conditioning to cool. The need arises for an array of technologies, working together, over time, that replace traditional home operations while running on the minimal power supplied through off grid sources over the course of a year. In part, the following depicts an analysis of four such technologies; lighting, electrochromic glass, thermal chimney and a geothermal heat pump. Using energy efficient lighting can directly impact electrical consumption by producing the same amount of light as traditional incandescent bulbs with less energy. Incandescent bulbs are inherently inefficient as most of the energy they consume goes towards heat generation. Compact fluorescent (CFL) and light emitting diode (LED) bulbs use more of their energy towards lighting. Electrochromic glass and thermal chimneys effect electrical consumption by inhibiting heat transfer that would otherwise have to be dispelled by a home air conditioner. Geothermal heat pumps us the thermal constancy of the earth as a reservoir to control in home air temperature.

Standard home electrical consumption is allocated to various systems; plug loads, appliances, lighting, etc. Space conditioning, commonly referred to as HVAC (Heating, Ventilation and Air Conditioning), accounts for 29% [1] of a traditional homes electrical consumption. No single system consumes more energy than that of space conditioning. To further the Net Zero endeavor, it behooves one to focus on this system, as it has the potential for a large portion of the electrical savings.

HVAC is no stranger to the drive towards electrical efficiency. The system is a notorious over consumer of electricity as it takes copious amount of energy to drive exit air temperature to desired levels. Many have sought to relegate its power use by implementing technologies to recover some of the unused energy. Realizing energy recovery ventilation for Net Zero homes in tropical climates has been shown to increase system efficiency by up to 31% while the use of heat recovery ventilation in polar climates has been shown to increase Net Zero HVAC efficiency by up to 63% [8]. Some have shown that implementing model predictive control algorithms in buildings can save 25% of a buildings electrical use [17].

In many cases, one finds HVAC overuse. Setting thermostat set points below an optimal threshold or driving a system unaffected by occupancy, much of the energy spent to condition space is unwarranted. To limit HVAC overuse, a predictive control algorithm is developed to meet homeowner

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thermal requirements while minimizing electrical consumption. The controller will balance several systems, including a geothermal heat pump and ceiling fans. Over time, the algorithm will predict comfort independent of user input by recording space and environmental conditions during previous user defined inputs, thus extrapolating optimal conditions.

II. Predictive Modeling

The typical homeowner would agree that comfort is of upmost concern in a home. If the indoor temperature is too hot, they turn on the air conditioner; too cold and they turn on the heater. Approximately 30% of the energy spent in a home is geared towards modulating thermal comfort [1]. The American Society of Heating, Refrigeration, and Air-Conditioning (ASHRAE) define thermal comfort as "*that condition of mind that expresses satisfaction with the thermal environment*" [17]. Although many might consider temperature the sole feature responsible for their comfort, a number of factors influence a person's perception of comfort. These factors can be separated into two groups: personal factors and environmental factors. Personal factors include metabolic rate and clothing level, which vary from person to person. Environmental factors include air temperature, radiant temperature, air speed, lighting and humidity. By defining comfort as a function of these environmental variables, it becomes possible to reach an optimal balance between energy consumption and thermal comfort. Instead of turning on an air conditioner, driven to cool the dry bulb air temperature to a particular set point, energy can be saved by increasing the set point while increasing convection through a ceiling fan. Through the implementation of an optimization algorithm designed to vary the factors effecting environmental thermal comfort while minimizing electrical consumption, home energy usage can be decreased while satisfying a resident's thermal comfort. Furthermore, by storing these variables, homeowner comfort can be predicted, thus decreasing user driven consumption imbalance.

A. *Model Parameters*

A model of the home, represented in Matlab®, is used for calculating the thermal load on the home. This allowed for algorithm implementation; driving active systems and optimizing energy usage. To initialize, housing dimensions and environmental conditions needed to be considered.

B. *Home Dimensions*

The walls of the home were divided into four sections, represented by the four cardinal direction each wall faces. These wall sections were divided further into different segments for simplicity. This reduced the number of windows per segment, simplified wall protrusions blocking the sun, and kept the outline of each wall segment within the same plane. The segments were defined in three-dimensional space, placing the origin at the left bottom back corner of the segment as shown in Fig. 1. The critical points that were defined included the four corners of the entire segment, the four corners of each window, and the four corners of the overhang. As shown in Fig. 1, the four corners of the segment and the four corners of the window are all in the same plane. The four corners of the overhang, as shown in Fig. 1 have two points that do not lie in the same plane as the rest of the wall segment. These points are needed to simulate the shading provided at different sun angles. These critical points were put into vectors within Matlab® structures labeled by segments within the different walls.

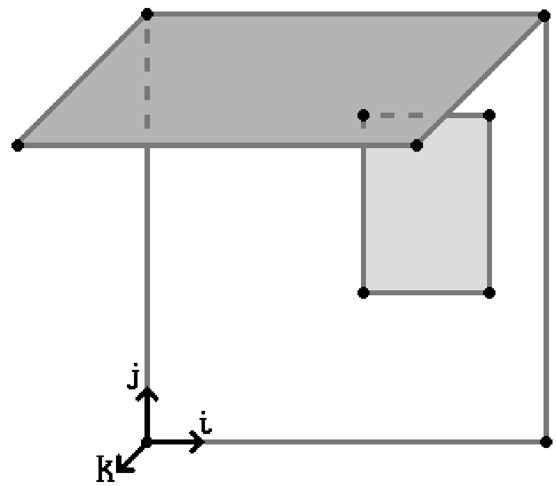

Figure 1. Example of a wall segment and the critical points used to model the home.

C. *Weather Considerations*

Two weather factors play largely into the thermal load on the home: cloud cover and outdoor temperature. Cloud cover is inherently difficult to predict. Rather than trying to predict the hour-by-hour amounts of cloud cover, averages are taken from historical data. This data is taken from a Typical Meteorological Year (TMY) for Austin, Texas. More information on this can be found in the following sections. The outdoor temperature is also predicted from historical data. Data from a TMY gives the high and low temperatures for each day of the year. It is then assumed that these high and low temperatures occur at 5:00 pm and 5:00 am, respectively, on each day of the year. The temperature is then determined by linearly interpolating between these high and low temperatures based on the time of day.

D. *Thermal Model*

The model was created to calculate the thermal load on the home as a function of several different factors. These are ambient outdoor conditions (ambient air temperature, temperature of surroundings, solar angle, solar irradiance) and the indoor conditions (ambient air temperature, temperature of surroundings).

E. *Solar Radiation*

Solar radiation is a dominant factor in calculating the thermal load upon a structure. In order to account for this factor, three components are needed: solar position, solar irradiance, and amount of shading.

The position of the sun in the sky can be calculated using well-known relations between time of day and solar angles.

Matlab® was used to calculate the angle of the sun at any time of day on any day of any year. The results from this code correlated with accepted solar position tables from the US Naval Observatory. The largest deviation from the accepted values was 0.2 degrees [17].

Solar irradiance values are based on averages from the National Renewable Energy Lab archive. This data was recorded in Austin, Texas over several years. The data is averaged over each month to create a single typical day of irradiance for each month. For example, the predicted solar irradiance at 1 PM on March 1st is the same as the solar

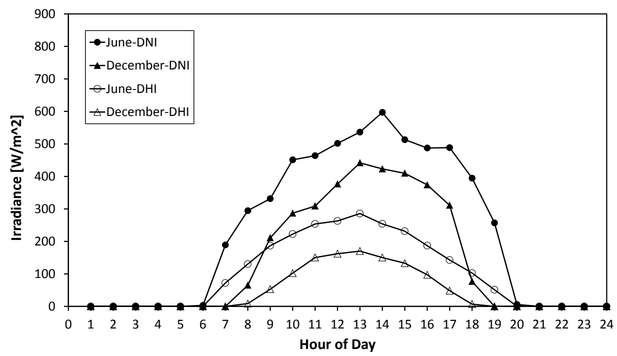

Figure 2. Monthly averaged solar irradiance data for Austin, Texas.

irradiance at 1 PM on March 31st. On April 1st, however, the irradiance at 1 PM would be different. This method does not account for unusually sunny or unusually cloudy days. A comparison of the hourly irradiance for December and June is shown in Fig. 2.

Irradiance data gives two components of irradiance that are typically measured, Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DHI). DNI is the component of irradiance due the direct beam of the sun's light. DHI is the irradiance due to all reflected and scattered radiation. Around noon on bright summer day, DNI is around 900 W/m^2 while DHI is around 100 W/m^2. Around noon on an overcast winter day, DNI could be as low as 200 W/m^2, while DHI could be as high as 400 W/m^2. These values represent extreme cases and are not represented in the average values shown in Fig. 2.

The shaded area of the wall is calculated using an intersection of planes method. The sun’s position is viewed as a vector and the different sections of the overhang are each viewed as a line. The plane formed by combination of these can be calculated, and the intersection of this plane with the plane of the wall and/or window forms the shading line. A graphical depiction of this method can be seen in Fig. 3. A code was developed to calculate these areas for the walls of the house as a function of solar angle.

Knowledge of these three factors will be used in determining the heat transfer through the walls and windows in the following sections.

F. Wall Heat Transfer

With knowledge of the indoor and outdoor temperatures along with the incoming solar radiation, a heat flux balance can be conducted on the walls. On the outside surface of the wall, there exists radiation exchange with the surrounding surfaces, convection with the ambient air, conduction through the wall, and incoming solar radiation. The same conditions exist on the inside wall, with the exception of incoming solar radiation. On the surface of the wall, only a portion of the incident solar radiation is actually absorbed. The heat flux due to the solar radiation is given by

$$\dot{q}''_{sol} = \alpha[A_{wall}(DHI) + A_{wall,unshaded}(DNI)\cos(\theta)] \qquad (1)$$

where $\dot{q}''_{sol}$ is the total incoming solar irradiance, α is the absorbance of the wall, A_{wall} is the total area of the wall, $A_{wall,unshaded}$ is the unshaded area of the wall, and θ is the angle between the incoming radiation and the surface that is being struck.

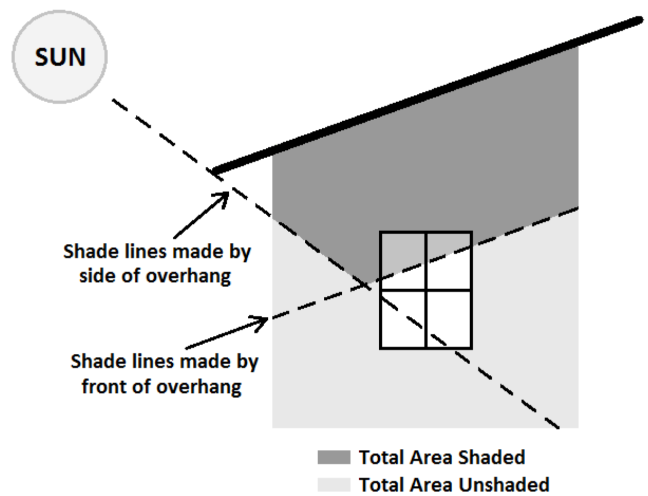

Figure 3. Depiction of the shading method used. The intersection of the dashed lines forms the shaded areas of the wall and window.

The absorbance α is an empirically determined constant and was assumed to be 0.45, which is a typical value for lightly colored building materials. The angle θ can be obtained from the solar angle. The entire wall area was multiplied by DHI because it was assumed that the entire wall was struck by diffuse radiation. The unshaded area was multiplied by DNI, with the factor $\cos(\theta)$ representing the projected area of the wall into the path of the direct radiation.

The heat balance for the outside surface of the wall can be stated as:

$$\dot{Q}''_{sol} + \varepsilon_o\sigma\left(T^4_{surr,out} - T^4_{wall,out}\right) + h_o\left(T_{amb,out} - T_{wall,out}\right) = -\frac{(T_{wall,in} - T_{wall,out})}{R_{bulk,wall}} \qquad (2)$$

Likewise, the heat balance for the inside surface of the wall can be stated as:

$$\varepsilon_i\sigma\left(T^4_{wall,in} - T^4_{surr,in}\right) + h_i(T_{wall,in} - T_{amb,in}) = -\frac{(T_{wall,in} - T_{wall,out})}{R_{bulk,wall}} \qquad (3)$$

where ε_o or ε_i is the dimensionless emissivity of the outside or inside wall, σ is the Stefan-Boltzmann constant, $T_{surr,out}$ or $T_{surr,in}$ is the temperature of the surroundings on the outside or inside of the wall, h_o or h_i is the convective heat transfer coefficient outside or inside the home, $T_{amb,out}$ or $T_{amb,in}$ is the ambient temperature outside or inside the home, and $R_{bulk,wall}$ is the bulk thermal resistance of the wall. The values for ε_o and ε_i were assumed to be 0.9, as is typical for building components [4]. $T_{surr,out}$ and $T_{surr,in}$ were assumed to be equal to $T_{ambient,out}$ and $T_{ambient,in}$. The recommended value for h_o is 34 W/m^{2}K while the recommended value for h_i is 8.3 W/m^{2}K. [4].The value used for $R_{bulk,wall}$ was 1.5 m^{2}K/W, which is a typical value for well-insulated walls. [4]. Any of these properties can be easily modified in the Matlab® .

Equations (2) and (3) can be solved simultaneously to obtain the outside and inside wall temperatures. Once these are known, the total heat transfer through the wall can be calculated using

$$\dot{Q}_{wall} = -\frac{(T_{wall,in} - T_{wall,out})}{R_{bulk,wall}} A_{wall} \tag{4}$$

where $\dot{Q}_{wall}$ is the rate of heat transfer into the home due to the wall and A_{wall} [m^2] is the total area of the wall.

G. Window Heat Transfer

The heat transfer analysis of the windows is broken into two parts: conduction and solar heat gain (SHG). In order to analyze the conductive heat transfer, an overall heat transfer coefficient is assumed to take into account convective, radiative, and conductive` resistances of the window. The heat transfer due to conduction through the window is thus calculated by

$$\dot{Q}_{win,conduction} = -\frac{(T_{ambient,out} - T_{ambient,in})}{R_{bulk,win}} A_{win} \tag{5}$$

where $\dot{Q}_{win,conduction}$ is the heat transfer through the window due to conduction, $R_{bulk,win}$ is the bulk thermal resistance of the window, and A_{win} is the total area of the window. A value of 0.3 m^{2}K/W was assumed for $R_{bulk,win}$, which is typical for aluminum framed, double pane windows [6].

The windows are different from the walls in that windows transmit a certain portion of the incoming solar radiation. The amount transmitted can be quantified by an empirically determined, dimensionless value called the Solar Heat Gain Coefficient (SHGC). This value can range from 0.2 for high-quality triple pane windows to 0.9 for single pane, inexpensive windows [6]. A value of 0.5 was assumed for these windows, which is typical for double pane windows. Then, the heat transfer through the window due to solar radiation is given by

$$\dot{Q}_{win,SHG} = SHGC[A_{win}(DHI) + A_{win,unshaded}(DNI)\cos(\theta)] \tag{6}$$

where $\dot{Q}_{win,SHG}$ is the total SHG through the window and $A_{win,unshaded}$ is the unshaded area of the window. This equation is similar to (1).

Adding the conduction and SHG components of window heat transfer thus yields

$$\dot{Q}_{win} = \dot{Q}_{win,conduction} + \dot{Q}_{win,SHG} \tag{7}$$

where $\dot{Q}_{win}$ [W] is the total heat transfer through the window.

H. Effect of Thermal Load on Temperature within the Home

Knowledge of the heat transfer through the walls and windows allows for calculation of the total thermal load on the home.

The summation of (4) and (7) can be added to yield

$$\dot{Q}_{total} = \dot{Q}_{wall} + \dot{Q}_{win} \tag{8}$$

where $\dot{Q}_{total}$ is the total heat transfer into a room. Equation 8 represents a room with only one window and one wall; this equation can be expanded to include any number of walls or windows.

In this home, a geothermal heat pump will provide air conditioning and heating. The heat pump will remove a portion of the thermal load on the room, although it may not always be practical for the heat pump to remove the exact amount of the thermal energy. In winter, for example, it may be permissible to not completely restore the heat that is being lost and thus allow the temperature to drop by some amount. In summer, cooling the home below the desired temperature earlier in the day may allow for a lower overall energy usage. The following relation can be expressed to relate the different sources of heat transfer in the home:

$$\dot{Q}_{net} = \dot{Q}_{total} - \dot{Q}_{heat\ pump} \tag{9}$$

where $\dot{Q}_{net}$ is the net heat transfer into the room and $\dot{Q}_{heat\ pump}$ is the amount of heat added or removed by the heat pump. The sign conventions of the three terms in (9) can be found in Table I.

To this point, all the discussion of thermal load analysis has been time independent; the equations presented apply only for a single instant in time. The problem of controlling the thermal conditions within the home, however, is clearly a

TABLE I. SIGN CONVENTIONS FOR THE THREE VARIABLES FROM (9).

Variable	**Sign**	
	Positive	***Negative***
$\dot{Q}_{net}$	Heat entering home (temperature rise)	Heat leaving home (temperature fall)
$\dot{Q}_{total}$	Heat entering home (hot day)	Heat leaving home (cold day)
$\dot{Q}_{heat\ pump}$	Heat being removed from home (cooling)	Heat being added to home (heating)

dynamic one. Therefore, a time-dependent relationship is needed between the thermal load on the home and the ambient temperature of the air within the home. This relationship can be stated as

$$\frac{dT}{dt} = \frac{\dot{Q}_{net}}{mc_p} \tag{10}$$

where $\frac{dT}{dt}$ is the time rate of change of the temperature of the air, m is the mass of the air, and c_p is the specific heat of the air. The mass m can be calculated using

$$m = \rho V \tag{11}$$

where ρ is the density of air and V is the volume of some given area. The density of air was assumed to be 1.2 kg/m^3. The volume of any area in the home can be calculated from knowledge of the home dimensions. The value of c_p was assumed to be 1 kJ/kgK. Equation (10) can be applied to any specific zone or room of the home. This equation allows for the calculation of the change in temperature, dT, over some selected time step, dt. In the optimization code, this will allow for the specification that the temperature at the end of the optimized time step does not exceed the bounds set forth by the comfort constraints.

The RHS of (10) represents an instantaneous time rate of change. In order to approximate (10) for discrete time steps, a first-order Euler approximation is used, so that

$$\Delta T = \frac{\dot{Q}_{net}}{mc_p}\Delta t \tag{11α}$$

where ΔT [K] is the change in temperature and Δt [s] is some selected time step. Equation (11) can be applied to any specific zone or room of the home. In the optimization code, this will allow for the specification that the temperature at the end of the optimized time step does not exceed the bounds set forth by the comfort constraints.

III. Optimization

A cost function for the energy usage for each active system was determined so that the total energy usage of the home could be modeled.

A. Geothermal Heat Pump

A Bosch TA049 geothermal heat pump was specified in the design. In the specifications of the TA049, Bosch provides the coefficient of performance (COP) for heating and energy efficiency ratio (EER) for cooling of the TA049 for various coolant and intake air temperatures. Since the heat pump will be configured with a vertical ground loop of 90 meters, the ground temperature is nearly constant year-round. The model coolant temperature was thus assumed to remain 20°C throughout the year [3], thus COP or EER of the heat pump model only depends on the intake air temperature. This temperature was assumed to be the same temperature as the air inside the home.

A function that determines the amount of power used by the heat pump for a given amount of heat to be added or removed is required so that the heat pump's power use under various conditions can be modeled. Bosch supplies the heat pump's EER and COP at specific conditions [6]. However, a continuous function is simpler to process and gives more information than discrete points. A cost function was found by plotting the manufacturer's COP and EER data against the ratio of intake air temperature and coolant temperature. The heat pump was assumed to run at partial load since the manufacturer states that it will achieve maximum efficiency in this state. Fig. 4 and 5 show the COP and EER data plotted as a function of intake air temperature to coolant temperature ratios, alongside the regression curves.

The regression line in Fig. 4 is given by

$$COP = 19.3(TR) - 13.5 \tag{12}$$

where *TR* is the dimensionless ratio of the heat pump intake air temperature over the heat pump's coolant temperature.

Typical fan power usage data versus air velocity produced by the fan. The regression shown gives the power usage fan directly as a function of the air velocity [9].

The COP can be used to find the power usage of the heat pump in heating through the relation

$$\dot{W}_{heat\ pump,heating} = \frac{\dot{Q}_{heat\ pump}}{COP} \tag{13}$$

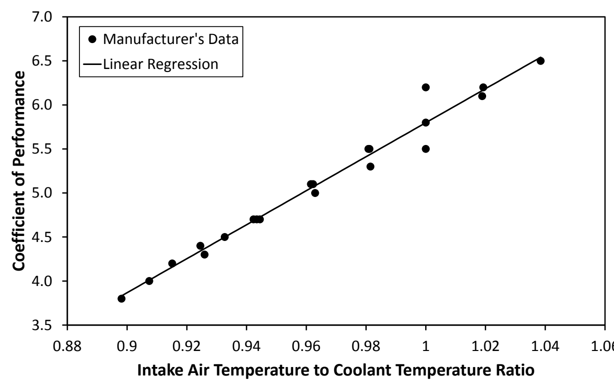

Figure 4. Bosch TA049 geothermal heat pump COP data with linear regression. Through knowledge of the intake air temperature to coolant temperature ratio, the COP can be obtained. This data applies only when the heat pump is in heating mode [6].

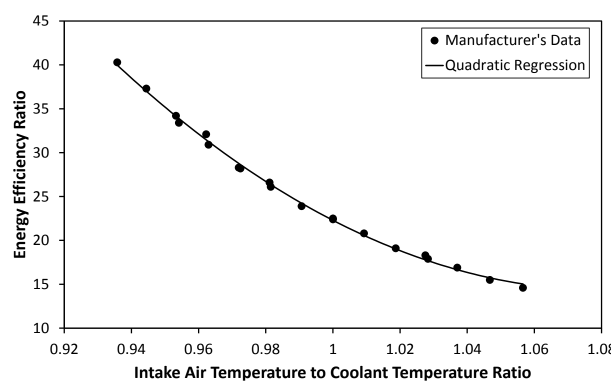

Figure 5. Bosch TA049 geothermal heat pump EER data with quadratic regression. Through knowledge of the intake air temperature to coolant temperature ratio, the EER can be obtained. This data applies only when the heat pump is in cooling mode [6].

where $\dot{W}_{\text{heat pump,heating}}$ is the power required by the heat pump when it is heating the home.

Fig. 5 shows the heat pump's EER versus the intake air temperature to coolant temperature ratio. The regression curve in Fig. 5 is given by

$$\text{EER} = 1216.8\text{TR}^2 - 2630.8\text{TR} + 1436.3. \qquad (14)$$

Similar to (13), the power usage of the heat pump in cooling is given by

$$\dot{W}_{\text{heat pump,cooling}} = 3.412\frac{\dot{Q}_{\text{heat pump}}}{\text{EER}} \qquad (15)$$

where $\dot{W}_{\text{heat pump,cooling}}$ is the power required by the heat pump when it is cooling the home. The conversion factor of 3.412 arises from the fact that the EER is defined in terms of Btu/hr divided by Watts.

B. Ceiling Fans

The velocity of the air, coming from the ceiling fans was modeled similar to the heat pump. Performance data in the form of air speed as a function of input power was plotted and a second order polynomial was fit to the data, as shown in Fig. 6. The fan was assumed to have a continuously variable speed setting and air speed was assumed to be the speed found three to four feet offset from the center of the fan.

The power usage of the fan is given directly by the quadratic regression in Fig. 6. This regression equation is

$$\dot{W}_{\text{ceiling fan}} = 41.0\text{V}^2 - 12.9\text{V} + 1.05 \qquad (16)$$

where $\dot{W}_{\text{ceiling fan}}$ is the power usage of the ceiling fan and V is the velocity of the air produced by the fan. This velocity was assumed to be that which would be felt about three feet away from the center of the fan and about nine feet below the fan [9].

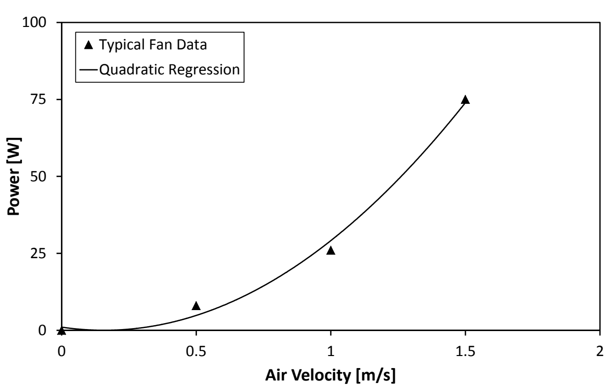

Figure 6. Typical fan power usage data versus air velocity produced by the fan. The regression shown gives the power usage fan directly as a function of the air velocity [9].

C. Computer Model Method

The Computer Model Method is a method by which the Predicted Mean Vote (PMV) and Predicted Percent Dissatisfied (PPD) indices are used to determine the extent to which comfort will be provided based on a specific set of expected clothing level [clo], activity level [met], air temperature, radiant temperature, air speed, and humidity. The PMV model "uses heat balance principles to relate the six key factors for thermal comfort…to the average response of people on the [thermal sensation index]". The correlation is based on the determination of a sweating rate and skin temperature that is necessary for ideal comfort conditions. The skin temperature and sweating rate are given below as

$$T_{sk,req} = 308.87 - (0.156)q_{met,heat} \qquad (17)$$

$$q_{sweat,req} = 0.42(q_{met,heat} - 5.401) \qquad (18)$$

where $T_{sk,req}$ is the average skin temperature in K, $q_{met,heat}$ is the metabolic heat loss in W, and $q_{sweat,req}$ is the sweating heat loss in W. The metabolic heat loss is given as

$$q_{met,heat} = M - \dot{w} \qquad (19)$$

where M is the rate of metabolic generation per unit DuBois surface area in W/m^2 and $\dot{w}$ is the human work per unit DuBois surface area in W/m^2.

A general heat transfer equation is then used to relate the rate of metabolic heat generation to the heat loss or gain to the body as a result of convective, radiative, and evaporative heat transfer at the ideal comfort level. This thermal load on the body is given as

$$L = q_{met,heat} - f_{cl}h_c(T_{cl} - T_a) - 3.96f_{cl}({T_{cl}}^4 - {T_r}^4) - 0.00305$$
$$(5733 - 6.99 * q_{met,heat} - P_a) - 0.42(q_{met,heat} - 58.15) \qquad (20)$$
$$(-0.0014M(34 - T_a) - 0.00017M(5867 - P_a)$$

where T_{cl} is the average surface temperature of the clothed body in K, f_{cl} is ratio of the clothed surface area to the DuBois surface area, T_a is the air temperature in K, h_c is the convection heat transfer coefficient in W/m^2-K, T_r is the mean radiant temperature in K, and P_a is the water vapor pressure. The heat transfer components within the equation are as follows: metabolic heat generation, convective heat transfer, radiative heat transfer, heat transfer through diffusion through skin, heat loss by sweating, dry respiration heat transfer, and latent respiration heat transfer.

In the thermal load equation, the temperature of the clothing is not known. This temperature can be determined as a function of the required skin temperature, the air temperature, the mean radiant temperature, and thermal resistances, as follows:

$$\frac{T_{sk,req} - T_{cl}}{R_{cl}} = f_{cl}h_c(T_{cl} - T_a) + 3.96f_{cl}({T_{cl}}^4 - {T_r}^4) \qquad (21)$$

where R_{cl} is the effective thermal resistance of the clothing in m^2-K/W. The ratio of the clothed surface area to the Dubois surface area and the convective heat transfer coefficient were approximated by Fanger to be

$$f_{cl} = f(x) = \begin{cases} 1 + 1.29 * I_{cl},\ I_{cl} < 0.078 \\ 1.05 + 0.645 * I_{cl},\ I_{cl} \geq 0.078 \end{cases} \qquad (22)$$

$$h_{cl} = max\begin{cases} 2.38(T_{cl} - T_a)^{0.25} \\ 12.1 * \sqrt{V} \end{cases} \qquad (23)$$

where I_{cl} is the thermal insulation of the clothing in m^2-K/W and V is the air velocity.

In order to correlate the thermal load on the body with comfort, a large number of people about their thermal comfort based on the thermal comfort parameters. The responses were categorized according to the thermal sensation index, which can be seen below in Table II.

The relationship between the PMV and the thermal load is given as

$$PMV = (0.303e^{-0.036M} + 0.028)L \tag{24}$$

This equation relates the thermal comfort levels felt by the individuals sampled to the actual thermal conditions within the environment.

The PPD is related to the PMV as a qualitative index that determines the level of dissatisfaction with the thermal

TABLE II. ASHRAE THERMAL SENSATION SCALE [17]

Numerical Indicator	Condition
+3	hot
+2	warm
+1	slightly warm
0	neutral
-1	slightly cool
-2	cool
-3	cold

conditions, based on the assumption that a vote of +3, +2, -2, and -3 represents thermal discomfort. A graphical representation of the empirical relationship can be seen in **Error! Reference source not found.** below.

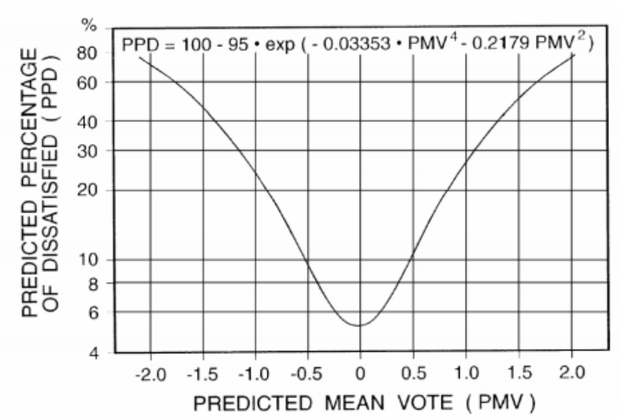

Figure 7. Predicted percentage dissatisfied (PPD) as a function of predicted mean vote (PMV) [17].

The ASHRAE accepted range for general thermal comfort includes a PPD less than 10% and a PMV range of -0.5 to 0.5. A version of the code utilized in implementing the PMV-PPD data into Matlab can be found in ASHRAE 55.

D. Optimization Scheme

The description of the optimization is broken into four parts: the objective function, the constraints of the optimization, the usage of multiple time steps, and the implementation of the optimization.

1) Objective Function

The objective function for this optimization is the power usage of the active systems. Clearly, the goal of the optimization is to minimize this function. The objective function is the sum of the power cost functions, which is given by

$$\dot{W}_{\text{total}} = \dot{W}_{\text{heat pump}} + \dot{W}_{\text{ceiling fan}} \tag{25}$$

where $\dot{W}_{\text{total}}$ [W] is the total power usage of the active systems of the home, and $\dot{W}_{\text{heat pump}}$ and $\dot{W}_{\text{ceiling fan}}$were developed in the preceding section. Thus, the two variables that are being optimized are the power input to the heat pump and the power input to the fans.

2) Constraints

As stated in the introduction, the minimization of energy usage in a home is subject to the constraint that the occupants of that home remain comfortable. This requirement is expressed mathematically through the following relationship:

$$\text{PPD} \leq 10\% \tag{26}$$

where the PPD is the ASHRAE standard for comfort that was discussed previously. The PPD function is a function of all six of the comfort factors. However, only three of the factors can be directly controlled in this project: the air temperature, the mean radiant temperature, and the air velocity. The mean radiant temperature is assumed to be equal to the air temperature.

The remaining three factors are held constant. The relative humidity is assumed to be 50%. The clothing insulation value is assumed to be 1 clo (0.155 m^{2}K/W). The metabolic rate is assumed to be 1 met (58.2 W/m^2).

An additional constraint follows from (9): the net heat gain on the home (the portion contributing to a temperature change) must be equal to the total heat gain on the home minus the amount of heat added or removed by the heat pump.

3) Multiple Time Steps

In order to predictively control the active systems in the home, the predictive thermal model must be used to look ahead to the future. In other words, the optimization will take into account the present time step as well as future time steps. This is accomplished by optimizing the heat pump and fan power inputs at multiple time steps. The factor that relates consecutive time steps is the temperature change within the home. This temperature change is given by (11α). When optimizing multiple time steps, the initial temperature of one time step will be the final temperature of the previous time step using less than 1%.

E. Data Storage and Retrieval

One of the most important features of the proposed system is the data storage and retrieval (DSaR) of user preferences. To better predict the comfort parameters of the next time interval, the team proposes to combine predictive weather data and tabularized user data. The information can be quickly sorted, updated regularly and can adapt to the preferences of the user.

The function of the program any time that the user is uncomfortable, the algorithm will take note of the current outdoor conditions based on time and ambient conditions and then store this data and average the current indoor conditions with the ones that have been previously logged. The purpose of grouping based on outside weather conditions is for ease of access for data retrieval.

The first act of the DSaR is simple. The data will be sorted into bins, as illustrated in Fig. 8, with the primary identifiers being the current time of day, followed by the ambient outside temperature, outside humidity, and indoor temperature.

This will ease data mining procedures since the data can easily be related by these three factors. Within each temperature bin, the information that will be stored will be: internal air temperature, internal humidity, lighting color, mean radiant temperature, internal air speed, and light intensity. The general principle is that for a given set of conditions on any day, the user will feel approximately comfortable if the external and internal temperatures match up with previously “comfortable” days. (e.g. if it is 21°C in the Fall, we make no differentiation with the same temperature in the Spring) By not differentiating between two similar days, the data mining will be less intensive, the data storage will be much more manageable, and the amount of time that it takes to fill bin information will be much lower.

The second component of the DSaR will be averaging the current user preferences with historical user preferences. A consideration using a weighted average or a method utilizing the recursive least squares estimation, also commonly known as a forgetting exponential are possible methods. By incorporating one of the previously listed methods, the goal is that the code will update historical user preferences to more accurately reflect the most recent inputs.

The final component of the DSaR will be the retrieval of data in the most efficient way possible. The first step when accessing data will be to locate the bins that are within a preset time interval, and then look at each bin within that time slot until the appropriate ambient conditions are found. (i.e. if it is 6 am and 5°C outside, then we will locate the bin representing the sixth hour of the day with the corresponding temperature range and have the desirable indoor conditions).

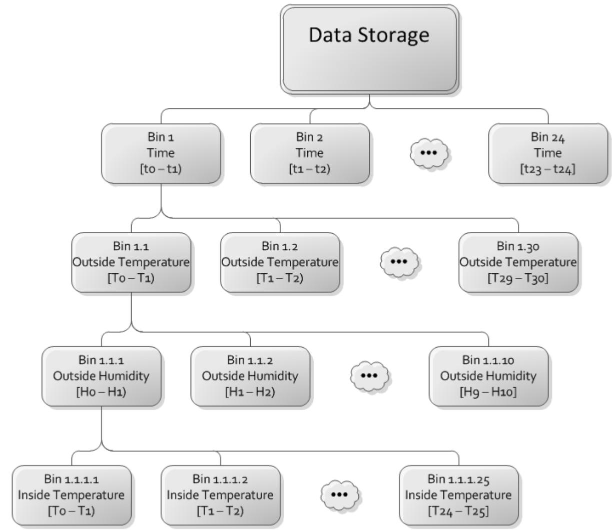

Figure 8. Visualization of data storage scheme utilizing a discrete set of bins.

Given that the time slots are divided by hour, the appropriate time bin is determined by rounding down the time inputted. The appropriate bins based on the ambient temperature ranges and the humidity are then determined by dividing the inputted parameter by the range per bin, and then rounding the result down. This allows for the immediate determination of the location of user preferences based on the ambient conditions specified.

F. Performance Analysis

The thermal model that was developed provided results that were on the expected order of magnitude. While there is no way to exactly verify the results for this particular home, general acceptable ranges for heating loads are known, and the values found here fall within those ranges. Fig. 9 shows the heat transfer for the west side of the home for four dates that are significant from a solar perspective. The slow increase that begins around hour 8 is due to the increase in diffuse radiation (DHI) as the sun comes up. Then, later in the afternoon, the sun drops below the shading overhangs so that the wall can see direct radiation (DNI). This accounts for the spike in the afternoon.

Fig. 10 shows the comparison of the heat transfer through the windows and the heat transfer through the walls. The sample day shown is the winter solstice. Note that the heat transfer through the windows is an order of magnitude higher than that through the walls. Therefore, special attention should be given to reducing the heat transfer through the windows.

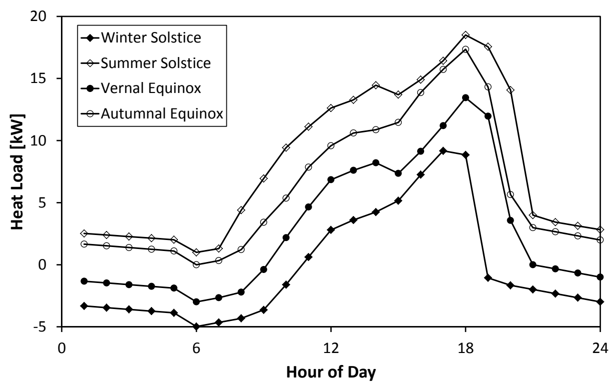

Figure 9. Comparison of the heat transfer on the west side of the home on the summer and winter solstices and the vernal and autumnal equinoxes.

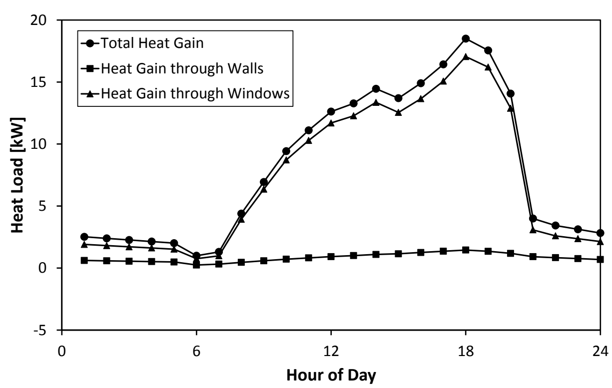

Figure 10. Comparison of the heat transfer through the walls and heat transfer through the windows. Total heat transfer is also shown, though it often overlaps closely with the window heat transfer.

IV. Component Analysis

An array of mechanical features was analyzed for cost and consumption feasibility. Features were chosen such that minimal electrical use was required to maintain a comfortable thermal environment while staying within 7% of home cost. This budget should cover any additional costs directly associated with energy saving features of the home (e.g. since windows are required for construction of the home despite energy efficient techniques, the budgeted cost associated with the use of energy saving electrochromic glass would be the differential cost of the energy saving technology over traditional technology).

A. Energy Analysis

The overall heating and cooling loads are directly related to the temperature differences between the inside and outside of the home, in addition to building material properties. To produce design concepts that reduce the heating load on the home a thermal analysis was performed using the United States Department of Energy (DOE) program, eQuest [7].

A number of variables and assumptions needed to be satisfied to perform the analysis. Home dimensions and specifications were provided by Altumaxis (Dick Clark Architecture, 2012). A comparative image between the model provided by Altumaxis in Google SketchUp and the eQuest model is shown in Fig. 11

Figure 11. Comparisons between the eQuest generated model and the Altumaxis SketchUp model

The variables and specifications required were:

- Location (Austin, Texas)
- Utility rates
- Analysis year (data to be used)
- Number of floors (above and below grade)
- Building area (room dimensions)
- Overall building specifications
    - Door dimensions/frame type/material/placement
    - Window dimensions/frame type/material/placement
        - U-factor
        - Shading Coefficient
        - Visible transmittance
    - Ground exposure
    - Foundation
    - Overhang specifications
    - HVAC system requirements

while creating the physical model in eQuest, the following assumptions were made:

- Flat roof
- Modeling was to be done with only 1 HVAC system in place

these assumptions allowed the energy analysis to be performed while maintaining the basic structure of the residency.

Using the climate data for the region and the specified variables, eQuest output overall electrical consumption broken down into predetermined categories. For the home in consideration, the results are shown in Fig. 12 and 13.

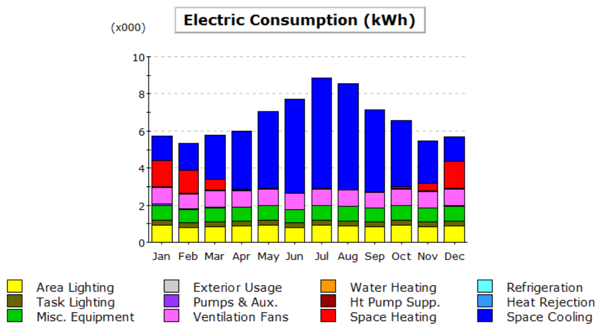

Figure 12. Bar graph of the electrical consumption through eQuest

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	1.32	1.47	2.39	3.15	4.12	5.04	5.95	5.69	4.41	3.57	2.30	1.31	40.75
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	1.41	1.22	0.57	0.05	0.00	0.00	-	-	0.01	0.07	0.41	1.43	5.18
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.39
Vent. Fans	0.88	0.80	0.88	0.85	0.88	0.85	0.88	0.88	0.85	0.88	0.85	0.88	10.39
Pumps & Aux.	0.08	0.07	0.04	0.00	-	-	-	-	-	0.00	0.03	0.08	0.31
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	0.80	0.71	0.76	0.77	0.80	0.73	0.80	0.78	0.75	0.80	0.75	0.78	9.23
Task Lights	0.27	0.24	0.25	0.26	0.27	0.24	0.27	0.26	0.25	0.27	0.25	0.26	3.07
Area Lights	0.92	0.80	0.85	0.88	0.92	0.81	0.92	0.88	0.84	0.92	0.84	0.88	10.46
Total	5.73	5.34	5.78	6.01	7.03	7.70	8.85	8.52	7.14	6.55	5.46	5.66	79.77

Figure 13. Numerical representation of the eQuest electrical consumption by category

B. Lighting

For residential applications, lighting accounts for 11% of the total energy use [10]. Energy efficient lighting can reduce consumption and take part in creating a Net Zero building design. Analysis of efficient lighting was based on energy savings and return on investments compared to traditional incandescent light bulbs. 10% of the energy that goes through traditional incandescent bulbs is converted to light while the other 90% is wasted as heat [1]. Compact fluorescent lamps (CFLs) and Light Emitting Diodes (LEDs) were analyzed in comparison with incandescent lamps.

To determine the most energy efficient bulb, energy consumption for each type of bulb is needed. To do this, the amount of lighting required for each room in the main home and guest house was calculated using (27).

$$L = (A)(FC) \tag{27}$$

where L represents the required illumination. A represents the area , and FC represents the area normalized illumination in foot candles. The appropriate illumination varies with the type of work the room is being used for. Bedrooms for general use require 14 ft · cd whereas areas such as kitchens, where more light is needed require 24-50 ft · cd for appropriate lighting.

The number of bulbs were calculated by dividing the total illumination needed for each room and the illumination emitted by the type of bulb used

$$T = \frac{L}{S} \tag{28}$$

where T represents the total number of bulbs required for a room and S represents the illumination emitted by the bulb.

The energy consumption can be calculated by multiplying the number of bulbs required by the power rating and the operating hours of the bulb in a year as shown in (29).

$$C = (T)(W)(H) \tag{29}$$

where W represents the power and H the operating time. The low life span of incandescent bulbs was taken into account in the maintenance cost.

The energy savings of CFLs and LEDs were calculated using their respective energy consumption values relative to that of the incandescent bulbs.

TABLE III. CALCULATIONS FOR INCANDESCENT, CFL AND LED BULBS FOR THE MAIN AND GUEST HOUSES

	Incandescent	**CFL**	**LED**
Total Energy (kWh/yr)	28,486	6,484	4,106
Energy Cost ($)	2,848	648	410
Energy Savings (kWh/yr)	0	22,002	24,380
Cost Savings ($/yr)	0	2,200	2,438
Cost per bulb ($/bulb)	0.65	7.61	14.21
Total Cost ($)	308	658	1,300
Payback Period (yrs)	-	0.3	0.5

Analysis yielded cost savings of $2,200 for CFL bulbs and $2,438 for LEDs with a payback period of 4 months and 6 months, respectively. LEDs have a longer payback period due to the relatively high cost per bulb. Specifically, the LED (E27 9W 900LM) used for this analysis cost $14.21/bulb in comparison with $7.24 (65R30/FL 130V) for the incandescent and $0.65 for the CFL (GE 60A-120V) [11].

C. Electrochromic Glass

Electrochromic glass (ECG) can vary opacity when a voltage is applied. The degree to which opacity is reached depends upon the voltage applied. Through the change in opacity, the glass can save cooling and lighting costs. The primary benefit of electrochromic glass comes in reducing the solar heat gain through windows.

EGC material costs are higher than typical housing windows because of component complexity and manufacturing effort involved. Costs range from $50/ft^2 to $85/ft^2 [10]. If implemented with every window (1,421 ft^2) in the main house, the material cost alone would range $71,000-$121,000.

The list of assumptions for analysis are as follows.

- The standard window is a double-pane clear glass U-factor=0.60, SHGC=0.60

- The U-factor indicates the total rate of heat flow from conduction, convection, and radiation through a window due to the difference between indoor and outdoor temperatures [3]

- Electrochromic glass is a triple pane, krypton filled with constant maximum tinted state values of: U-factor=0.13, SHGC=0.04 [14]
- Electricity rates remain constant throughout the year
- All cooling and heating loads use electrical sources
- Based on historical averages, the months with average temperatures below the users "comfort temperature" of 68°F were analyzed as cooling months, and above the comfort zone, as heating months [14].
  - Cooling months: April through October
  - Heating months: November through March
- Installation costs for the glass types are identical and the material cost is the primary cost concern.

If working under these assumptions, the net annual cost savings and a simple payback period of installing electrochromic glass can be calculated.

Using the ASHRAE tables [4] for daily total solar radiation [W/m^2], the radiative heat transfer through the window can established.

$$Q_{summer} = \sum_{i=1}^{n} a_i * b_i \tag{30}$$

$where:\ n =$ number of months above comfort temperature

$a =$ solar incident daily total (from ASHRAE table)

$b =$ number of days in the respective month

To determine if a month is either a heating or cooling month, historic data at the location in question is necessary. As assumed in this instance, anything above the desired comfort level is a cooling month and anything below a heating month. Heating and cooling temperatures are shown in Table IV.

TABLE IV. AVERAGE MONTHLY TEMPERATURES IN AUSTIN, TEXAS FROM 1981-2012

	Jan.	***Feb.***	***March***	***April***	***May***
Avg. Temp	51.5°F	55°F	61.7°F	69.1°F	76.5°F
	Jun.	***Jul.***	***Aug.***	***Sep.***	***Oct.***
Avg. Temp	82.2°F	84.9°F	85.7°F	80	71.2°F
	Nov.	***Dec.***	***Ann.***		
Avg. Temp	61°F	52.5°F	69.3°F		

Using annual summer and winter solar heat flux, the cooling load decrease, and heating load increase due to implementing electrochromic glass can be approximated. Here, it is assumed that the electrochromic glass does not change variably throughout the day but remains at either a constant clear state or tinted state depending on cooling or heating requirements.

Cooling load decrease ($CL\downarrow$):

$$CL^{-} = \underbrace{449}_{\text{Annual heat flux incident}} * \underbrace{38.981}_{\text{Total area (in meters) on the north face}} * \underbrace{(0.6 - .04)}_{\text{Difference in SHGC}} = 9794\frac{\text{kWh}}{year} \tag{31}$$

Heating load increase ($HL\uparrow$):

$$HL^{-} = \underbrace{101}_{\text{Annual heat flux incident}} * \underbrace{38.981}_{\text{Total area (in meters) on the north face}} * \underbrace{(0.6 - .39)}_{\text{Difference in SHGC}} = 823.838\frac{\text{kWh}}{year} \tag{32}$$

Using the accepted rate of \$0.119kWh, for Austin, Texas, the monetary savings between the cooling and heating load annually becomes \$1,02.

$$\begin{gathered} Total\ Expenditure\ difference = \\ (9794\frac{\text{kWh}}{year} - 823.838\frac{\text{kWh}}{year}) * .114\frac{\$}{kWh} = \$1,022 \end{gathered} \tag{33}$$

This process was repeated for each exterior cardinal direction face. To determine an overall cost-benefit comparison, the price of electrochromic glass can be compared to the material and construction cost of standard double pane window, for the entire home. The maximum amount of the material cost for 1421ft^2 of double pane clear window, with an aluminum frame estimates to \$27,214 with a maximum installation cost around \$13,456.

Assuming the installation cost for each of the materials are the same, the cost of 1421ft^2 of electrochromic material is between \$71,000 and \$120,000. Table V summarizes the cost comparison between standard, double paned window and ECG.

The evaluation of the increase in price per square foot of the electrochromic glass has a substantial effect in the annual savings: around \$3,400. In addition, evaluating the amount it saves proves that the increase in price reveals a low return on investment.

TABLE V. PRICE COMPARISON BETWEEN ELECTROCHROMIC GLASS AND A DOUBLE PANE CLEAR WINDOW, RESULTING IN A RETURN ON INVESTMENT ANALYSIS.

Main House Glass Cost Comparison		
	Electrochromic Glass	***Double pane clear window***
Installation Cost	$10,815 (Cost of Insulated Windows, 2013) (Cost of Casement Windows, 2013)	$10,815 (Cost of Insulated Windows, 2013) (Cost of Casement Windows, 2013)
Material Cost (min/max)	$71,057	$24,360 (Cost of Insulated Windows, 2013) (Cost of Casement Windows, 2013)
	$120,797	$27,214 (Cost of Insulated Windows, 2013) (Cost of Casement Windows, 2013)
Total Cost (min/max)	$81,872	$35,175
	$131,612	$38,029
Price Difference	$93,583	
Annual Savings with Electrochromic	$3,373.73	
Payback Period	27.7 years	

D. Thermal Chimney

A thermal chimney is a method of passively inducing ventilation. It uses the sun to heat air and creates an updraft in a chimney. This is done using a vertical shaft that absorbs solar energy and heats the air within. The heated air rises due to a change in density and pulls air from the home into the chimney. This process creates an air current throughout the home by using nothing more than solar energy.

Air flow through the home will reduce ventilation which would otherwise be provided by the HVAC system. The thermal chimney can also be coupled with geothermal piping to cool or heat inner home with ambient air from outside the house. As air travels through ground pipes, it will cool (or heat, depending on the season) as it passes through the ground. The ambient ground temperature in Austin is roughly 71°F year round. Thus, when the outside temperature is below 71°F it will be heated and when it is above it, the air will be cooled. When using this method, it is important that the home be well sealed. It is desirable to have the replacement air come from geothermal piping, as it would reduce the load on the HVAC system. If, however, there is too much of a pressure gradient, the air will fill the home through inadequate sealing, rendering geothermal piping useless.

The ground is used as a heat sink where the ambient air temperature can normalize before entering the home. If the ambient air is warmer than the ground temperature, such as in summer, the cooler ground removes heat from the air and thus reduces the load on the air conditioner. This process works oppositely in the winter when ambient air is warmed by the ground before either entering the home or the space heating unit.

The velocity through the thermal chimney can be found from (34)

$$v = \sqrt{\frac{2g\left(\rho_{inside} - \rho_{outside}\right)h}{\frac{fl\rho_{outside}}{d_h} + \rho_{outside}\sum k_i}}, \tag{34}$$

where v is the velocity of the air through the duct work, g is the gravitational constant, ρ_{inside} is the density of air inside the home, $\rho_{outside}$ is the density of air inside the thermal chimney, h is the height of the chimney, f is the friction factor associated with fluid flow through a pipe, l is the length of pipe in the system, d_h is the hydraulic diameter of the duct work through which the air flows, and $\sum k_i$ is the sum of the minor head loss coefficients in the duct work.

A thermal chimney that could conceivably be implemented in the home was found to have a volumetric flow rate around 600 CFM, 46% the flow rate of a 4-ton air conditioning system. This flow reduces the load on the fan in the air conditioner and further reduces the energy necessary to cool the home. In this analysis the ambient air temperature was conservatively assumed to be 95°F and the ground temperature was based off of the average well water temperatures in Austin, Texas. The ground temperature was assumed to be 72°F and the house was assumed to be perfectly sealed. The calculations in these conditions showed the heat transfer from the air to be nearly 1.8 tons.

E. Geothermal Heat Pump

Part of ensuring a building is Net Zero is ensuring heating and cooling methods are efficient and save energy. One of the most efficient ways of providing heating and cooling is using a geothermal heat pump. Geothermal heat pumps use the ground to maintain a comfortable indoor temperature. the Pipes circulate through the ground (up to 500 feet deep for vertical pipe systems), where the earth's temperature maintains a relatively constant value (between 45-75°F). During winter months the fluid flowing through the underground pipes will be warmer than the air temperature, thus heating the air in the home. Conversely, in the summer months, the earth's crust is at a cool temperature, cooling the air in the home to a more comfortable level.

The geothermal system energy usage was compared to an electric HVAC system of the same tonnage to complete the analysis. The Bosch TA049 (4-ton) geothermal system was compared to the Goodman GSZ130481A/ARF48601. A separate, but similar analysis was done for heating and cooling due to slightly different conditions of use. For this analysis, the systems were assumed to run 24 hours per day, seven days per week.

To determine the cooling use for the systems, it was observed that the specification sheets for both systems had information for an outdoor ambient temperature of 85°F, an indoor dry bulb of 80°F, and a wet bulb of 67°F. At this temperature, the Bosch system uses 1.88 kW at 1300 CFM (the low setting), and 3.1 kW at 1700 CFM (the high setting) (Bosch Guide Specifications: TA Series Two Stage R-410A, 2011). The Goodman system gave information for 1400 CFM (2.81 kW) and 1800 CFM (2.9 kW) (Product Specifications: GSC13, 2011). Using linear extrapolation, it was determined the Goodman system would require 2.89 kW at 1300 CFM and 3.01 kW at 1700 CFM. Assuming the low setting would run 80% of the time and the high setting would run 20%, in a 24-hour period the Bosch system would use a total of 50.976 kWh. Conversely, from a similar analysis, the Goodman system would require 69.89 kWh in one day. The Bosch TA035 geothermal system and the Goodman GSZ130361B/ARF364216 were similarly compared. The numbers are presented below in Table VI.

A similar analysis was done to determine the heating usage. The Bosch and Goodman specification sheets had information for an indoor dry bulb temperature of 70°F and outdoor ambient temperatures of 25, 30, 40, 50, and 60°F. After looking at the average monthly temperatures for Austin, the lowest average was in the 50°F range, so only the 50°F and 60°F settings were used. The Goodman systems only had data for a nominal flow rate, so that was used for the entire 24-hour period. Daily usage for the heating systems was determined in the same way as for the cooling systems, considering the split between the high and low setting. The numbers are presented in Table VII.

TABLE VI. KILOWATT USAGE OF A GEOTHERMAL AND ELECTRICAL AIR COOLING SYSTEM.

	4-ton		3-ton	
	Bosch TA049	***Goodman GSZ130481A ****	***Bosch TA035***	***Goodman GSZ130361B****
1000 CFM	-	-	1.32 kW	2.8 kW
1200 CFM	-	-	2.37 kW	3.02 kW
1300 CFM	1.88 kW	2.89 kW	-	-
1700 CFM	3.1 kW	3.01 kW	-	-
24-hour Usage	50.976 kWh	69.89 kWh	36.72 kWh	68.32 kWh

Two 4-ton systems and one 3-ton systems are going to be used. Thus, in a 24-hour period the 4-ton geothermal systems will consume 102 kWh per day for cooling and 211 kWh per day for heating and the 3-ton will consume 37 kWh per day for cooling and 80 kWh per day for heating. In 24 hours, cooling will consume 139 kWh and heating will consume 291 kWh. To calculate the yearly averages, the months were split into heating and cooling months depending on if the average temperatures fell above or below the desired temperature of the resident (68°F). Heating months (January, February, March, November, and December) totaled 151 days and cooling months (April, May, June, July, August, September, and October) totaled 214 days. In one year, the geothermal system will use 73,671 kWh, assuming the system is running 24 hours a day, 7 days a week. By the same analysis, the Goodman system will consume 121,109 kWh every year.

In Austin, the electric rates vary throughout the year. From October through May electric rates are $0.096 per kilowatt hour. The remaining months charge $0.114 per kilowatt hour. The total yearly cost of the Bosch geothermal system is $7,377. Similarly, the Goodman system will cost $12,083 per year. The energy and cost tabulations are displayed below in

Installing a geothermal system cost approximately $7,000 per ton of cooling with a 30-percent tax credit through 2016. Based on this estimate, the main house geothermal installation would cost approximately $77,000 and the guest house would require approximately $28,000. However, after receiving a geothermal proposal from American Geothermal in Austin, Texas, the geothermal system would cost around $42,941; this estimate includes the tax credit and a spray foam rebate. The cost of installing the Goodman GSZ13 series ranges from about $2,750 to $10,000. If the installation of the Goodman system was $20,000, this installation would be almost $23,000 less expensive than the

TABLE VII. KILOWATT USAGE OF A GEOTHERMAL AND ELECTRICAL HEATING SYSTEM

<table>
<tr><td rowspan="3"></td><th colspan="4">4-ton</th><th colspan="4">3-ton</th></tr>
<tr><th colspan="2">Bosch TA049</th><th colspan="2">Goodman ARF48601</th><th colspan="2">Bosch TA035</th><th colspan="2">Goodman ARF364216</th></tr>
<tr><td>50°F</td><td>60°F</td><td>50°F</td><td>60°F</td><td>50°F</td><td>60°F</td><td>50°F</td><td>60°F</td></tr>
<tr><td>1000 CFM</td><td>-</td><td>-</td><td rowspan="2">-</td><td rowspan="2">-</td><td>1.47 kW</td><td>1.48 kW</td><td rowspan="2">2.9 kW</td><td rowspan="2">3.03 kW</td></tr>
<tr><td>1200 CFM</td><td>-</td><td>-</td><td>2.37 kW</td><td>2.51 kW</td></tr>
<tr><td>1300 CFM</td><td>1.96 kW</td><td>2.01 kW</td><td rowspan="2">3.73 kW</td><td rowspan="2">3.87 kW</td><td>-</td><td>-</td><td rowspan="2">-</td><td rowspan="2">-</td></tr>
<tr><td>1700 CFM</td><td>3.02 kW</td><td>3.11 kW</td><td>-</td><td>-</td></tr>
<tr><td>24-hour Usage (kWh)</td><td>52.1</td><td>53.5</td><td>89.5</td><td>92.8</td><td>39.6</td><td>40.46</td><td>69.6</td><td>72.72</td></tr>
</table>

TABLE VIII. ENERGY AND COST TABULATIONS FOR THE MAIN HOUSE AND GUEST HOUSE HVAC CONFIGURATIONS.

	Main House			
	Bosch		***Goodman***	
	kWh	***Cost***	***kWh***	***Cost***
Total	73,671	$7,377	121,109	$12,083

geothermal system. However, because of the yearly cost savings that come with using the Bosch system, the installation difference would be made up in approximately five years. The payback period for using the geothermal system in the Dorsey residence would be around nine years. Table IX below summarizes the energy and cost savings of using a geothermal heat pump in the Dorsey residence.

TABLE IX. SUMMARY OF SAVINGS ANALYSIS

Savings Summary	
Energy Savings	47,437 kWh/year
Cost Savings	4,706 kWh/year
Implementation Cost	$42,941
Payback Period	9 years

V. CONCLUSION

While some may regard the Net Zero home as a novelty of the time, the drive to undermine wasted energy is at the heart of the concept. Technologies that make efficient use of energy and electricity seem to be the only way to bring about a balance between utility and purpose. It may be that few scenarios call upon Net Zero homes as a viable option, but the concept brings about ramifications extending to typical residential home use. Since HVAC is a major contributor to electrical usage in any home, methods to control and mitigate its electrical usage while maintaining thermal comfort has to the potential to undermine inefficient cooling. While laymen many consider dry bulb temperature the only variable in thermal comfort, several variables contribute to an individuals thermal comfort. Radiant heat, convection, humidity, lighting, clothing, metabolic rate, gender, etc. can all impact comfort. To reduce electrical usage of an HVAC system, a controller designed to balance these variables while optimally consuming electricity is needed. It has been shown that by modeling heat transfer into a home from the environment, one is able to quantify the amount of power required to maintain a s environment. Several systems working in conjunction, including a geothermal heat pump, ceiling fans and HVAC system dampers can be controlled to produce an adequate level of comfort while reducing electrical usage.

In addition to a comfort driven control algorithm, several systems were analyzed and chosen based on their ability to reduce either heat transfer into the home or electrical usage. Using energy efficient CFL's or LED based illumination can save up to 40,000 kWh/yr and a cost saving of $4,000 per year in comparison to traditional incandescent bulbs. Geothermal heat pumps can lessen. An analysis in the amount of electrical consumption saved, as compared to traditional HVAC systems yielded a savings of 47 MWh per year. A thermal chimney designed to evacuate heat passively has the potential of reducing the load on the HVAC system by 1.8 tons.

VI. ACKNOWLEDGMENTS

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Steam System Data Management

What Does It Include

Safety In Motion

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The Real Genius Behind Technology Is People

WAL-TECH VALVE

SAFETY INNOVATION RELIABILITY

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Introduction

Darrell Roberts

- **Who Am I**
    - Darrell Roberts, CEO Wal-Tech Valve, Inc.
- **Background**
    - Maintenance Field For 41 Years
        - Fabrication Training (Six Year Training)
        - Welding Certifications
    - Retired From Chevron After 25 Years
        - ❖ Established A Steam System Program
        - ❖ Planner For Routine Maintenance Work
        - ❖ Planner For Steam System Improvements

- Wal-Tech Valve, Inc.
    - Purchased Wal-Tech Valve, Inc. In 2007
    - Implemented Safety, Quality Control, And Management Processes
    - Established A Steam System Department
    - Improved Computer Systems And Software

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Introduction

Steve Rowell

- **Who Am I**
  - Steve Rowell, IT Manager, Wal-Tech Valve, Inc.
- **Education**
  - Computer Science Associates Degree
  - Air Conditioning/Refrigeration Course
  - Pipe Fitting Training (Four Year Training)
  - Fabrication Training (Six Year Training)
  - Welding Certifications
  - Advanced Class Amateur Radio License
- **Background**
  - Maintenance Field For 48 Years
  - Retired From Chevron After 32Years
    - ✓ Established A Steam System Program
    - ✓ Long Range Planner For Routine And Project Work
    - ✓ Planner For Outage Work
    - ✓ Major Contributor For Establishing A Planning Process For The Refinery.
    - ✓ Teacher for New Planners (Primavera And Planning)
    - ✓ Developed Software Programs and Utilities
- **Wal-Tech Valve, Inc.**
  - Began Working With Wal-Tech Valve In 2008
  - Developed Software And Processes
  - Helped Establish A Steam System Department
  - Assisted In Computer Systems Improvements

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Agenda

- *What Data Is Needed?*
- *Why Is The Data Useful?*
- *Managing Steam System Data*

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What Data Is Needed

- *What Data Is Typically Collected?*
  - *Steam Trap Data And Condition Of Trap*
  - *Some Steam Leak Data*
- *How Useful Is A Typical Survey?*
  - *Steam Traps Can Be Repaired Or Replaced*
  - *The Steam Leaks Identified Can Be Repaired*
  - *Possibly The Number Of Steam Traps is Known*
- *What Do I Really Need To Know?*
  - *How Many Steam traps are out of service?*
  - *Are there any drip traps out of service?*
  - *Are The Steam Traps Installed Properly?*
  - *Have System Low Points Been Identified?*
  - *Where is there insufficient or no insulation?*
  - *Are there any Critical Steam Traps?*
  - *Has Any Other Equipment Been Identified?*
    - *Pressure Powered Pumps*
    - *Liquid Drainers*
  - *Are There Other Problems With A Trap Station?*
  - *Have Issues That Are Not Associated With A Particular Steam Trap Been Identified?*
  - *Can I Perform Analysis On The Data?*

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Why Is The Data Useful

- *Water Hammers*
  - *Water-hammer occurs when a slug of water, pushed by steam pressure along a pipe instead of draining away at the low points, is suddenly stopped by impact on a valve or fitting such as a pipe bend or tee.*
- *Thermal Shock*
  - *Thermal shock occurs when steam is discharged into a body of cool condensate. A void is instantly created as the steam condenses. Liquid rushes into the void, colliding in the center, causing shock waves through the condensate, and the resulting waves collide with piping and equipment until the energy is depleted.*
- *Equipment Failures and Efficiency*
  - *Condensate In The System Causes Wet Steam That Damages Piping And Equipment, affects the efficiency and reliability of heat exchangers, and creates safety hazards.*

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Managing Steam System Data

- *Software*
  - *A Software Program Capable of Handling The Dynamics Of A Steam System Is Needed.*
  - *The Program Must Be Able To:*
    - *Record Multiple Surveys.*
    - *Steam Trap Status*
    - *Other Steam Trap Problems*
    - *Record Steam Leaks At The Trap Station*
    - *Collect Additional Steam Trap Data*
    - *Identify And Describe Additional Steam System Issues*
    - *Calculate Steam Lost*
    - *Analyze Multiple Surveys*
    - *Print Reports*

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Creating A Reliable Steam System

- *Obtain The Tools Needed:*
  - *Software Capable Of Handling Steam System Surveys*
  - *Testing Equipment: Ultrasonic Tester, Pyrometer*
  - *SRS: Technician Trained In Survey And Data Management*
- *Perform a Steam System Survey*
  - *Survey Steam Traps*
  - *Survey Pressure Powered Pumps*
  - *Survey Liquid Drainers*
  - *Survey Steam System For Low Points And Dead Legs*
  - *Survey Steam System For Missing And Damaged Insulation*
- *Create a Plan to correct the items found*
  - *Print Reports From The Software*
  - *Identify, Explain, And Organize The Repairs*
- *Implement the Plan*
  - *Appropriate Necessary Funds*
  - *Plan The Repairs*
  - *Assign A Crew To Perform The Work*

Programs for Small and Medium-Sized Manufacturers

Daniel Trombley Senior Analyst American Council for an Energy-Efficient Economy Washington, DC

ABSTRACT

The industrial sector represents a diverse grouping of companies that very significantly in their size and how they use energy. Industrial programs have tended to focus their efforts on customized incentives that capture large energy efficiency opportunities at each facility. While this approach works well for larger firms, the transaction costs of identifying and proposing projects for small and medium-sized manufacturers (SMM) is frequently prohibitive. As a result, programs have tended to focus on prescriptive rebates for equipment that do not address a significant portion of the energy use in these firms.

However, number of innovative approaches exist, including quasi-prescriptive rebates, funding in-house energy managers, working through supply chains, and working through trade groups and market allies to provide services through trusted networks. This paper will summarize recent research on energy efficiency programs targeting SMMs and provide recommendation for program design to maximize energy savings for small and medium manufactures.

INTRODUCTION

Energy efficiency programs, which are typically first tasked with finding the largest savings at the lowest cost, tend to tailor programs to large energy users in the business and industrial sectors. However, more programs are seeking savings from smaller manufacturers, either because that savings potential remains untapped or because they are directed to by the local utility commission.

Small and medium-sized manufactures (SMM) are important, because even though they consume less energy per site compared to large users, they play an outsized role in the U.S. economy. SMMs and other small businesses account for 99% of all manufacturing sites and employ 70% of the manufacturing workforce. Additionally, small manufacturers contribute significantly to technology innovation, international trade, and job creation (1).

DEFINING SMM

The term "small and medium-sized manufacturer" (SMM) is not clearly defined. Furthermore, studies looking at this market segment use a variety of terms, such as "small business," "small or medium-sized business," or "small manufacturer." This paper will use SMM to broadly cover these terms. Table 1 below shows a few different definitions.

Table 1. Small Business Definitions

Organization	**Term**	**Definition**
U.S. Small Business Administration (7)	small business (manufacturing)	• < 500 employees; *Note: includes all affiliates*
U.S. DOE Industrial Assessment Center Program (6)	small- and medium-sized manufacturer	• < 500 employees on site • < $100 million in sales • Between $100,000 and $2.5 million in energy costs • No in-house energy management staff *Note: applies to industrial site only*
Energy Trust of Oregon (4)	small industrial energy user	• < 500,000 kWh
ACEEE (5)	small and medium-sized industry	• < 500 employees • < 1 MW demand • No corporate energy management staff

There are two main ways to define these terms: energy consumption and employment. When discussing energy efficiency, the former is preferred, although the latter is more common in general (primarily because employment data is more easily accessible). In the U.S., the Small Business Administration's definition (which varies based on the product or service provided) is the most commonly cited. This paper covers any research focused on smaller industrial businesses.

LITERATURE REVIEW

A number of reports in the last few years have grappled with the question of how to address small businesses. Some are dedicated entirely to the topic, while other take a broader look at industrial program design but offer insight into offering for smaller industrial segments. This section gives on overview of their contents, focusing on challenges for SMM and the programs that serve them as well as lessons learned from successful programs.

Federal Support for Energy Efficiency in U.S. Industry (1)

This paper by Paul Bostrom of the Alliance to Save Energy discusses the importance of small and medium manufacturers (SMM) in the economy, provides an overview of programs at the federal level:

- Industrial Assessment Centers
- Manufacturing Extension Partnerships
- EPA Green Supplier's Network
- USDA Rural Development Program
- USDA Rural Energy for America Program
- USDA Business and Industry (B&I) Guaranteed Loan Program
- USDA Rural Business Enterprise Grant Program (RBEG)
- Small Business Administration
- High Growth Training Grants through the Department of Labor
- E3 (Energy, Environment, Economy) Partnership, and inter-agency program

The report also discusses several methods of reaching out to SMMs:

- Explore local utilities' offerings
- Utilize municipalities, state energy office and other state agencies
- Leverage existing relationships with SMM
- Include local investors
- Keep SMMs informed of regulatory and policy developments
- Promote technology transfer among SMMs
- Involve owners/executives directly in decision making where possible
- Enable information exchange among smms
- develop a comprehensive service offering

Trends in Industrial Energy Efficiency Programs (2)

Anna Chittum of the American Council for an Energy-Efficient Economy examined a number of energy efficiency programs targeting the industrial sector with the goal of identifying emerging trends in program design and offerings. The report also identified a number of programs and trends of interest to SMM.

Maintaining relationships with industrial customers, particularly SMM, is critical. Industrial programs must actively seek out their smaller industrial customers, because they are the customers generally least aware of their energy efficiency potential.

The report also notes that SMM "can offer important energy savings opportunities and can often be well-accommodated with simple prescriptive incentive programs that are relatively easy to administer. Smaller firms may require some level of further guidance on how to utilize those programs, but generally such programs can help facilitate the deployment of needed technology. Because these projects generally require less administrative overhead, it may be in a program's best interest to strengthen outreach to smaller firms that are prepared to take advantage of their less labor-intensive program offerings, a step that can directly follow an energy audit. Further, smaller companies have generally implemented fewer energy efficiency projects in the past, so more opportunities may be available."

Big Savings from Small and Midsized Business (3)

Kim Knox from ESource interviewed several energy efficiency program managers targeting SMM, and identified the following suggestions for reaching that market segment:

- Strong Ally Trade Networks make it easier to reach customers.
- Offering free assessments to identify low or no-cost measures helps programs get their foot in the door at SMM sites.
- Large financial incentives for direct install measures helps capital-constrained businesses while still requiring buy-in. Some utilities provide up to 60-90% of project cost.

- On-bill financing helps overcome first cost barriers by eliminating the upfront cost and spreading that cost over the life of the measure.

An Effective Approach to Reaching Small Industrial Savings (4)

Elaine Prause of the Energy Trust of Oregon helped design a program targeting smaller manufacturers and reported on the barriers SMM face:

- Too busy keeping the business in operations, the owner plays multiple roles and there's no dedicated energy manager.
- Lowest initial equipment investment is often the criteria for purchasing decisions, life cycle cost is not widely considered.
- Purchase decisions are usually made when equipment needs to be replaced and replaced in a hurry to avoid holding up production.
- There are limited off the shelf efficiency opportunities for industrial systems, few opportunities to think about energy use.
- No central industry association for communication and group assistance.

The Energy Trust program used a trusted vendor network to deliver the savings. Prause's report identified several key benefits of participation for vendors:

- Vendors can be the hero – Energy Trust doesn't need to take all the credit with participants, we just want sites to participate. Vendors can use the incentive from Energy
- Trust to make their customers happy.
- Increased sales of higher cost equipment by leveraging program funds
- The program has very quick turnaround time, often reviewing, approving, and returning applications within 2 working days – sometimes much quicker
- Vendors can add the Energy Trust logo to their promotional materials such as ads and trade show posters.
- Energy Trust doesn't get in the way between then vendor and the customer, they continue to own the relationship – it's not about us.

Finally, Prause lists several lessons learned from the program design process:

- Be willing to ask "who is my customer and what do they need?" This lesson may seem very basic in hindsight but it took some time to come to this full realization and design an effective process for the customer, vendor, and Energy Trust.
- Personal contact. Improving program process efficiency doesn't necessarily mean removing one on one contact with vendors and completely automating the delivery. That one on one contact is moving more projects through more quickly than ever anticipated.Keeping people involved in the processes who take responsibility for recognizing and guiding the outcome was a critical lesson learned.
- Practice continuous improvement. This operations technique is not just a practice that's beneficial to industry operations but applies to industrial efficiency programs too. Along the way we've made many additional improvements and have been keenly aware of the value in making those changes.
- Be flexible enough to know when and how to adjust the process and tools as you go

Energy Efficiency Programs for Small and Medium-Sized Industry (5)

Anna Shipley and others at the American Council for an Energy-Efficient Economy took an in-depth look at current program offerings for the SMM market. While the report was written in 2002, it still has a number of successful strategies and offerings:

- Plant assessments
- Develop network of EE service providers
- Leverage other market resources
- End-user education
- Financial analysis
- Purchasing & procurement
- Financing

The report also identified the limitations with some of these offerings, in particular the prescriptive rebate. To remedy some of the limitaitons, it calls for the development of "Quasi-prescriptive programs", and programs targeting new construction of manufacturing sites.

Frontiers of Energy Efficiency (8)

Dan York, along with team of researchers at the American Council for an Energy-Efficient Economy examined the "next generation" of energy efficiency programs. While its section of small business focused on very small businesses (not the manufacturing sector), it offers some unique advice on program marketing and outreach:

- Hiring auditors primarily based on sales ability, even above outstanding technical skills.

- Partnering with community-based organizations to offer job training, which offers the additional benefit of hiring a diverse workforce that is a match for community small businesses in language, culture, and ethnicity.
- Developing and maintaining an extensive network of qualified, local vendors and contractors. Trade allies play a vital role in managing community strategy, and they provide additional community intelligence to assist with business district targeting.
- Conducting door-to-door outreach, neighborhood by neighborhood, and getting in communication with businesses in advance of when energy service representatives visit, further builds awareness and trust.
- Providing educational seminars in multiple languages in conjunction with local non-profit organizations, including local business associations and faith-based groups, about energy efficiency and the programs offered.

CONCLUSIONS

A number of excellent resources on programs targeting small and medium-sized manufacturers exists, with an extension collection of program examples, barriers, lessons learns, and recommendations. However, the field of energy efficiency program design is not static, and as many of these reports are several years old it is important to continue examining the success of program offerings to SMM. Future work is require to more fully synthesize the available information, and combine it with the practical knowledge of those in the field, both program delivery and small manufactures themselves to identify the best programs for the SMM market.

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