Technology Drivers of Improved Energy Productivity in Manufacturing Process Enhancement Projects

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ABSTRACT

The heart of a manufacturing manager's job is to continuously seek out ways to lower unit operating costs through process enhancements while maintaining product quality. These process enhancements are intuitive and are largely influenced by labor/capital trade-offs. What is less intuitive and visible to the manufacturing manager are technology options for a given manufacturing application that reduce energy consumption per unit of output. In manufacturing plants where energy costs are a relatively large part of a company's value chain, selection of specialized technologies can have intrinsic energy productivity benefits that can significantly drive down unit costs.

The objective of this paper is to present key technology and process enhancements that have driven improved Energy Productivity (as measured by estimated Energy Usage per output produced) in manufacturing process applications. Energy Efficiency (EE) calculated project data from 2010-2012 drawn from Industrial Firms will be analyzed, focusing on EE projects for manufacturing process enhancements. The analysis will quantify and characterize the projects providing the greatest percentage of energy savings vs. baseline and correlate findings by industry sub segment, end-use, technology, and application. Benchmarking will also be used to normalize the findings. Additionally, a deeper dive will be performed on a representative sample of projects with similar characteristics to identify those technologies and end use elements which are most impactful in driving improved energy productivity. The findings from this study show that compressor and control measure energy efficiency projects comprised a large portion of the overall project set and created significant energy savings averaging 30-40% of project baseline energy consumption. The findings also indicate that industrial automation initiatives can intrinsically create foundational energy efficiency benefits. Manufacturing managers who automate their operations are on a path to reduce their energy costs per unit output.

Study Objectives and Methodology

The objective of the paper is to present key technology and process enhancements that have driven improved Energy Productivity (as measured by estimated energy usage per output produced) in manufacturing process applications. The California Public Utilities Commission (CPUC) has implemented policy guidance for investor owned utilities (IOU's) establishing that cost effective energy efficiency is the resource of first choice for meeting California's energy needs. Energy efficiency is the least cost, most reliable, and most environmentally-sensitive resource, and minimizes the contribution to climate change. (CPUC, 2005). To that end, Southern California Edison (SCE) has implemented a portfolio of energy efficiency programs for which ratepayer funded incentives are available, which are intended to promote adoption of energy efficiency projects and measures (SCE Program Database, 2010-2012). For this study, Energy Efficiency (EE) data from SCE's 2010-2012 Calculated Business Incentive Programs is analyzed, focusing on installed EE projects for industrial process enhancements.

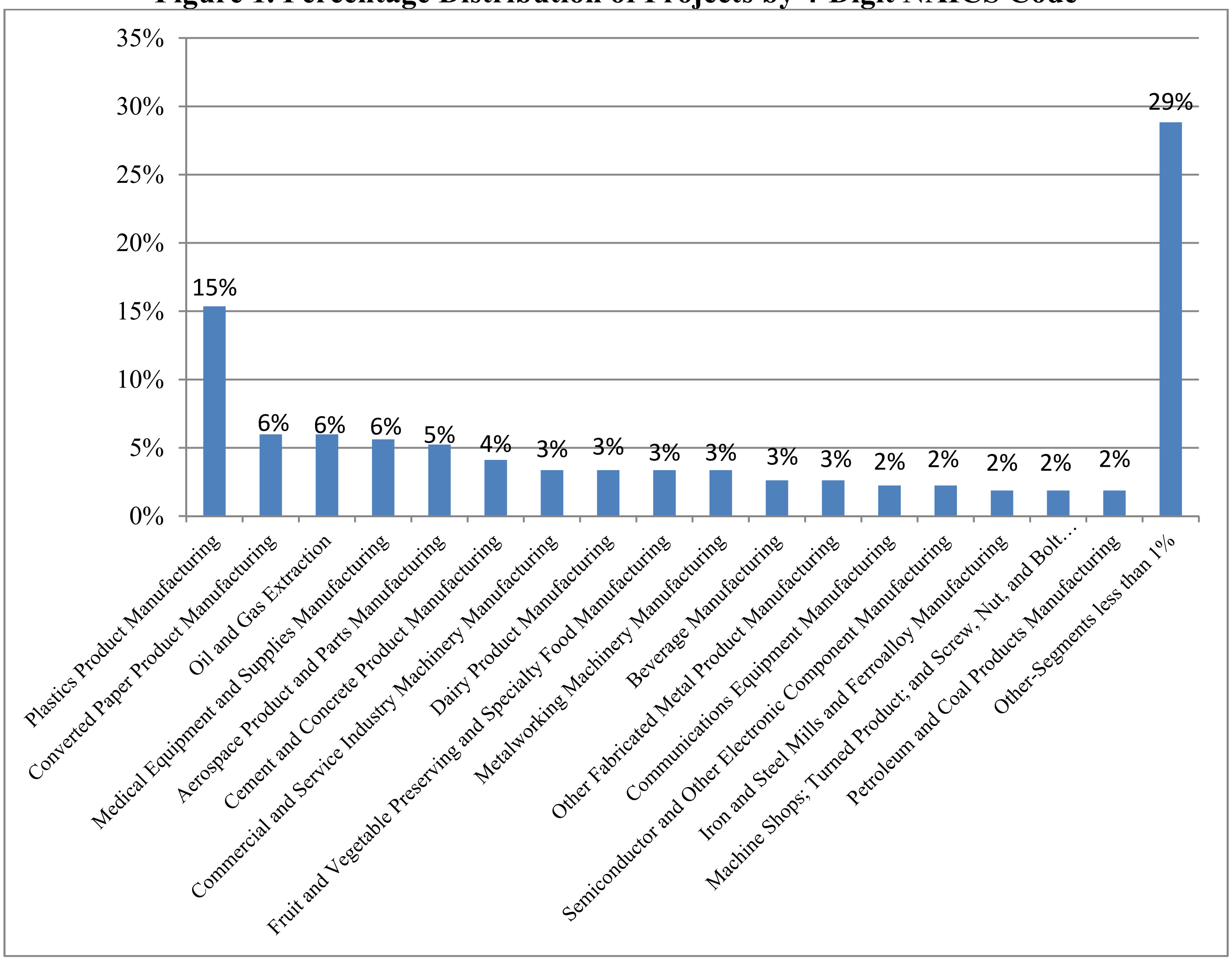
The study started with an initial project set of 600+ projects that had been installed by Industrial firms during 2010-2012 (SCE Program Database, 2010-2012). These projects include the following major technology end uses: 1) Lighting, 2) Heating, ventilation and air conditioning (HVAC), 3) Refrigeration, 4) Pumping, 5) Process and 6) Controls. The project set was distilled to the 250+ projects that were entirely or predominately Industrial Process related. This project set (the "sample group") was analyzed for the purposes of this study.

Analysis and Findings

Distribution of Projects

The distribution of the sample group across vertical industry segments is fairly dispersed with some concentration in Plastics Product Manufacturing, Paper Product Manufacturing, Oil and Gas Extraction, Medical Equipment and Supply Manufacturing, Aerospace Manufacturing, and Cement Product Manufacturing.

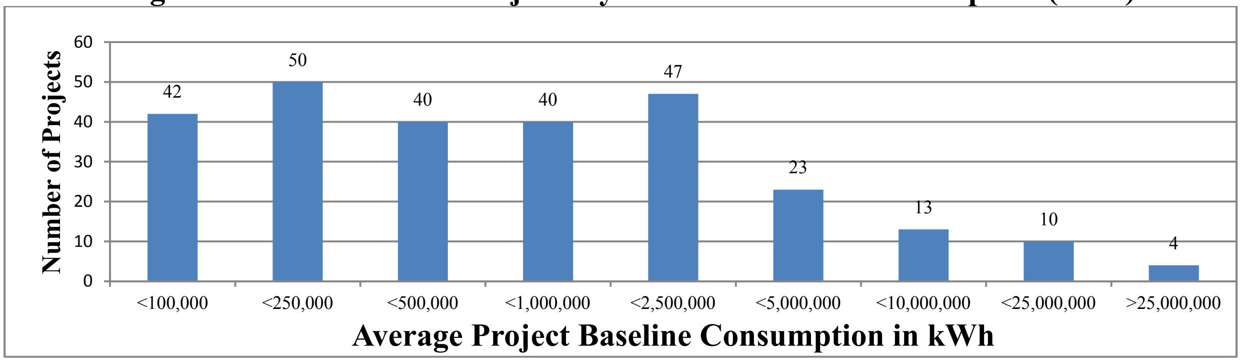
Figure 1. Percentage Distribution of Projects by 4-Digit NAICS Code



Source: SCE Energy Efficiency Project Program Operations Database 2010-2012

The sample group was analyzed based upon size distribution using baseline kWh consumption.

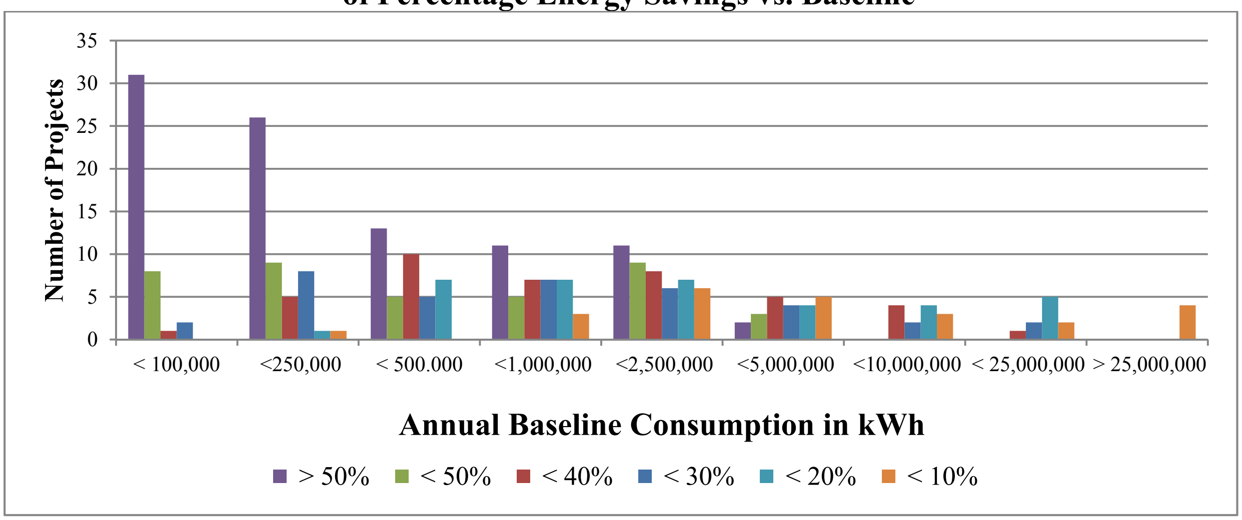
Figure 2. Distribution of Projects by Annual Baseline Consumption (kWh)



Source: SCE Energy Efficiency Project Program Operations Database

A deeper review revealed that as annual baseline consumption rises there tends to be a more even distribution of project energy savings (measured by percentage reduction vs. baseline) as seen in Figure 3 below.

Figure 3. Relationship between Annual Baseline Consumption and Distribution of Percentage Energy Savings vs. Baseline

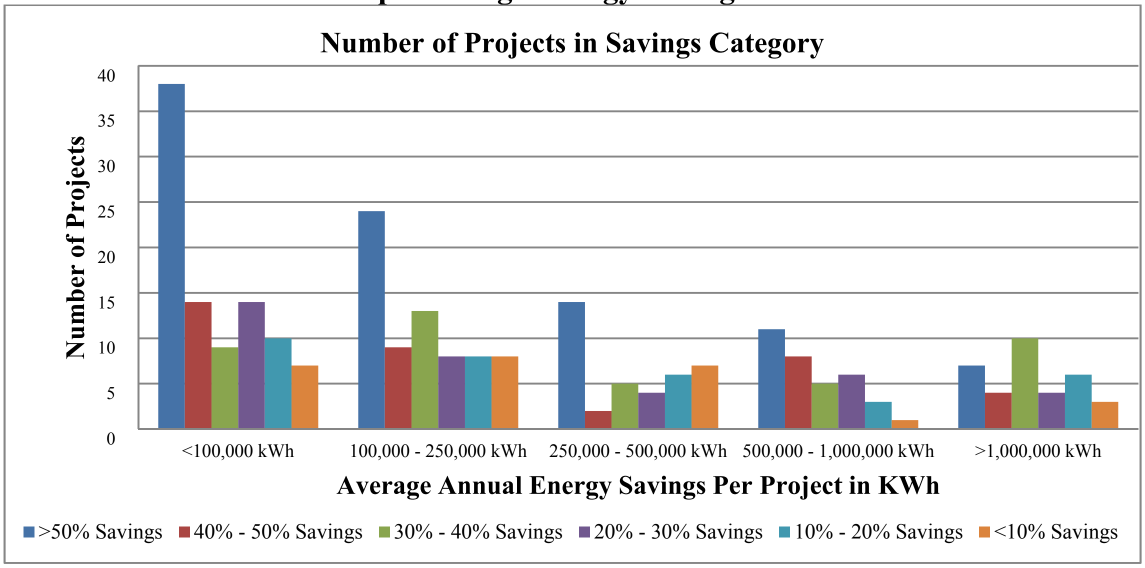


Source: SCE Energy Efficiency Project Program Operations Database

Stated another way, projects with high percentage energy savings are more prevalent when projects have lower initial baselines.

If project size is based upon absolute energy savings (rather than baseline energy consumption), there is a similar concentration of high percentage energy savings projects for projects with smaller absolute estimated energy savings. This is demonstrated in Figure 4.

Figure 4. Relationship between Annual Project Savings (kWh) and Distribution of percentage Energy Savings vs. Baseline



Source: SCE Energy Efficiency Project Program Operations Database

It is also worth noting that customers in lower demand bands (< 3000 kW) have a greater concentration of high impact projects (based upon percentage energy savings).

Technology and Application Characterization

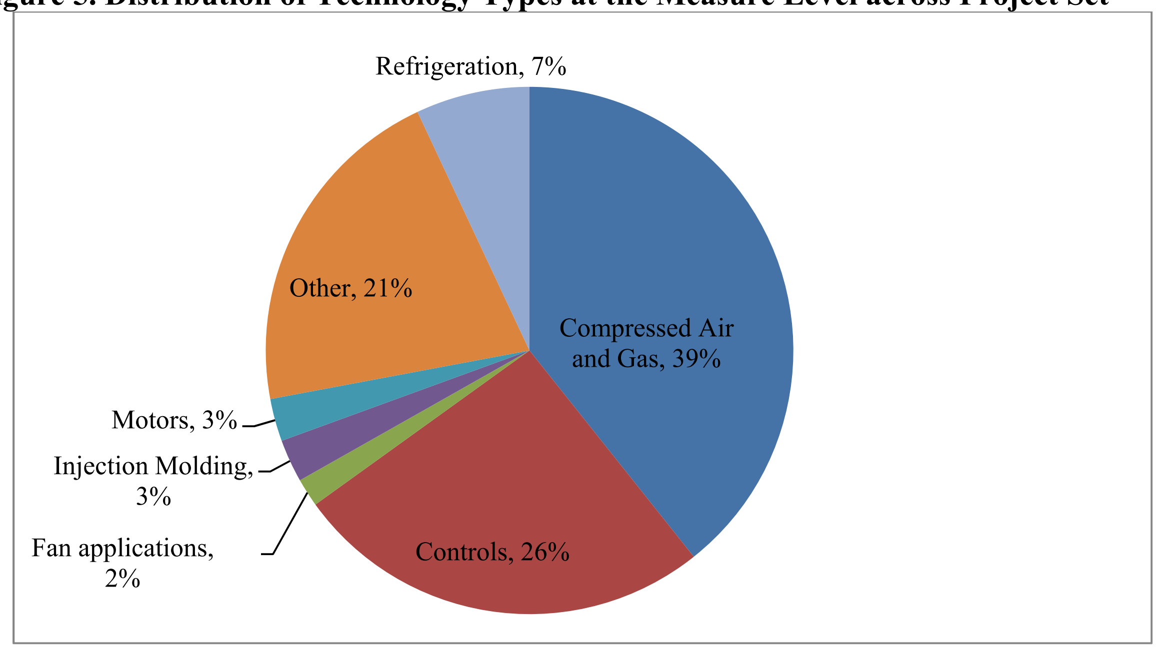
In an effort to identify those projects, technologies, and measures which best represented overarching trends in industrial technology energy efficiency project adoption, the survey group was further narrowed to those projects which had baseline consumption of at least 250,000 kWh per year. The resulting project sample size was reduced from 250+ projects to 175+ projects. Each of these 175+ projects comprises one or more energy efficiency measures. These energy efficiency measures were grouped into major technology categories based on the end use of the measures implemented on a broader system. The details of the systems are as following:

1. **Compressed air and gas**: A large percentage of energy efficiency projects submitted to SCE were related to a compressed air and/or gas system but not limited to compressors. This category includes measures related to compressor retrofits, compressor sequencing, compressor retro-commissioning, dryer upgrades/retrofits, compressed air leak remediation, and compressor system optimization including re-piping.
2. **Controls:** This category is the most diverse in terms of implementation but similar in the end use. With the advancement in technology and the economical availability of controls such as variable frequency drives (VFD's) and occupancy sensors, controls make up for more than a quarter of all energy efficiency projects analyzed in this research.

3. **Refrigeration**: It should be noted that this category is only for process refrigeration and not HVAC related. This category involved chiller optimization/upgrade and condensers optimization/upgrade.
4. **Injection molding**: Southern California is home to numerous molding companies. This section is specific to injection molding industrial process and includes optimization of the process including equipment upgrade.
5. **Motors:** This category is specifically for motor and pumps upgrade/retrofit involved in industrial processes.
6. **Fan applications**: Fan play is an essential role in many industrial processes but is usually part of a larger system. This category is for fan upgrades/retrofits in industrial processes.
7. **Others:** This category is a "catch all" bucket and includes onetime energy efficiency projects such as welding or oil/water separator technology to projects that were not defined in the data set used.

The following figure shows the technology distribution for these projects, based upon measure count.

Figure 5. Distribution of Technology Types at the Measure Level across Project Set



Source: SCE Energy Efficiency Project Program Operations Database

As can be seen, for this key industrial project sample set, Compressed Air and Gas, Controls, and Refrigeration comprise 72% of the overall technology type captured at the measure level.

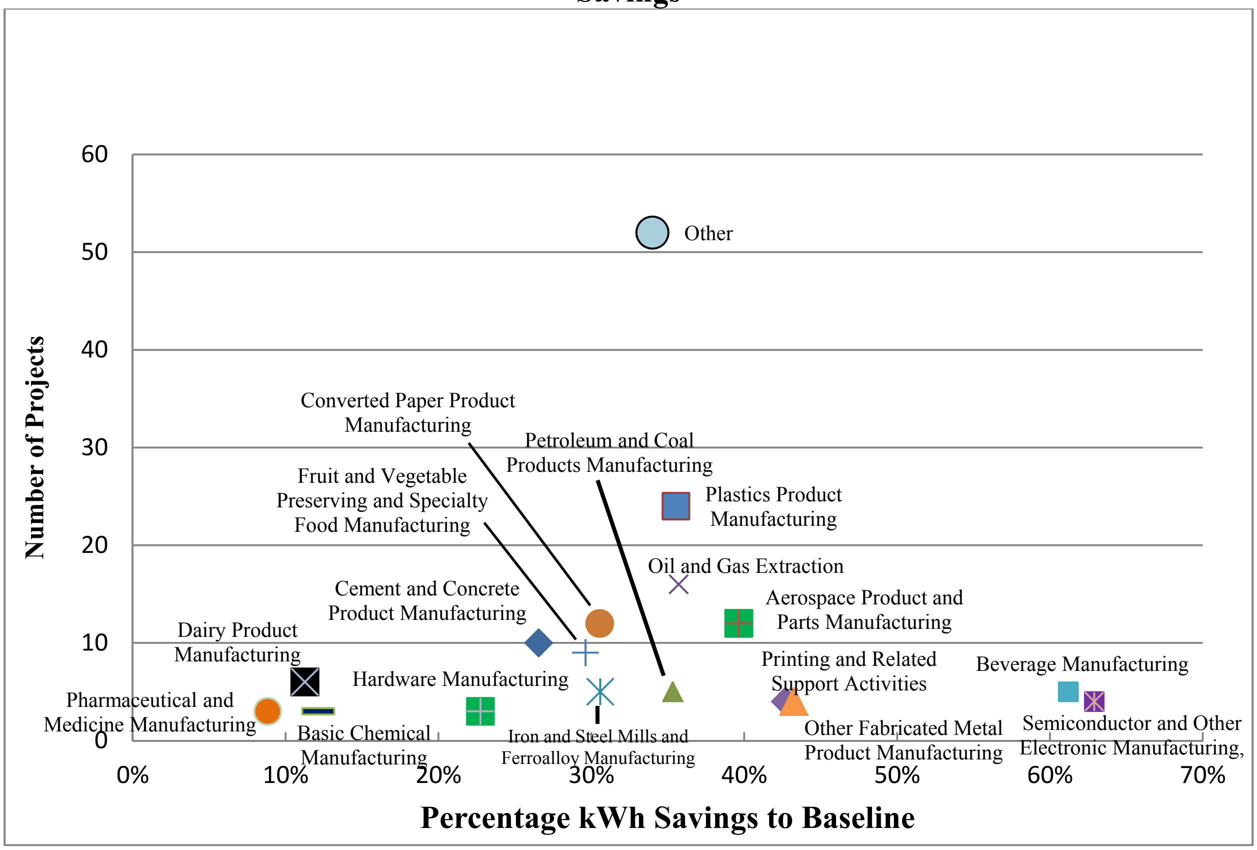
Following upon this measure level mapping of specific measures into broader technology categories, each of the projects in the sample set was categorized based upon its constituent measure categories. Most projects comprised only one major measure category; however, a number had two measure categories, and a very few projects had three measure categories.

Compressed Air and Gas Technologies are pervasive both in relative number and overall kWh savings contribution. They also have a significant average energy savings percentage to baseline of approximately 30%. Similarly, controls are a major driver in the project set with even greater average energy savings percentage to baseline of 34%, and a large number of projects. Not surprisingly, the third largest technology category is Compressed Air and Gas/Controls-----projects where the core compressor retrofits have been bundled with complementary controls technology. It is somewhat surprising that the average energy savings percentage to baseline is lower for this hybrid category than for each of the constituent categories. Finally, the Injection Molding technology category appears robust with 9 projects and an average energy savings to baseline of 61%.

Intersection of Market Segment Verticals and Technology Types

An analysis was prepared providing mapping of projects into major industry verticals at the four digit NAICS code level and is set forth in Figure 6.

Figure 6. Distribution of Major Industry Verticals, Number of Projects and Percent Energy Savings

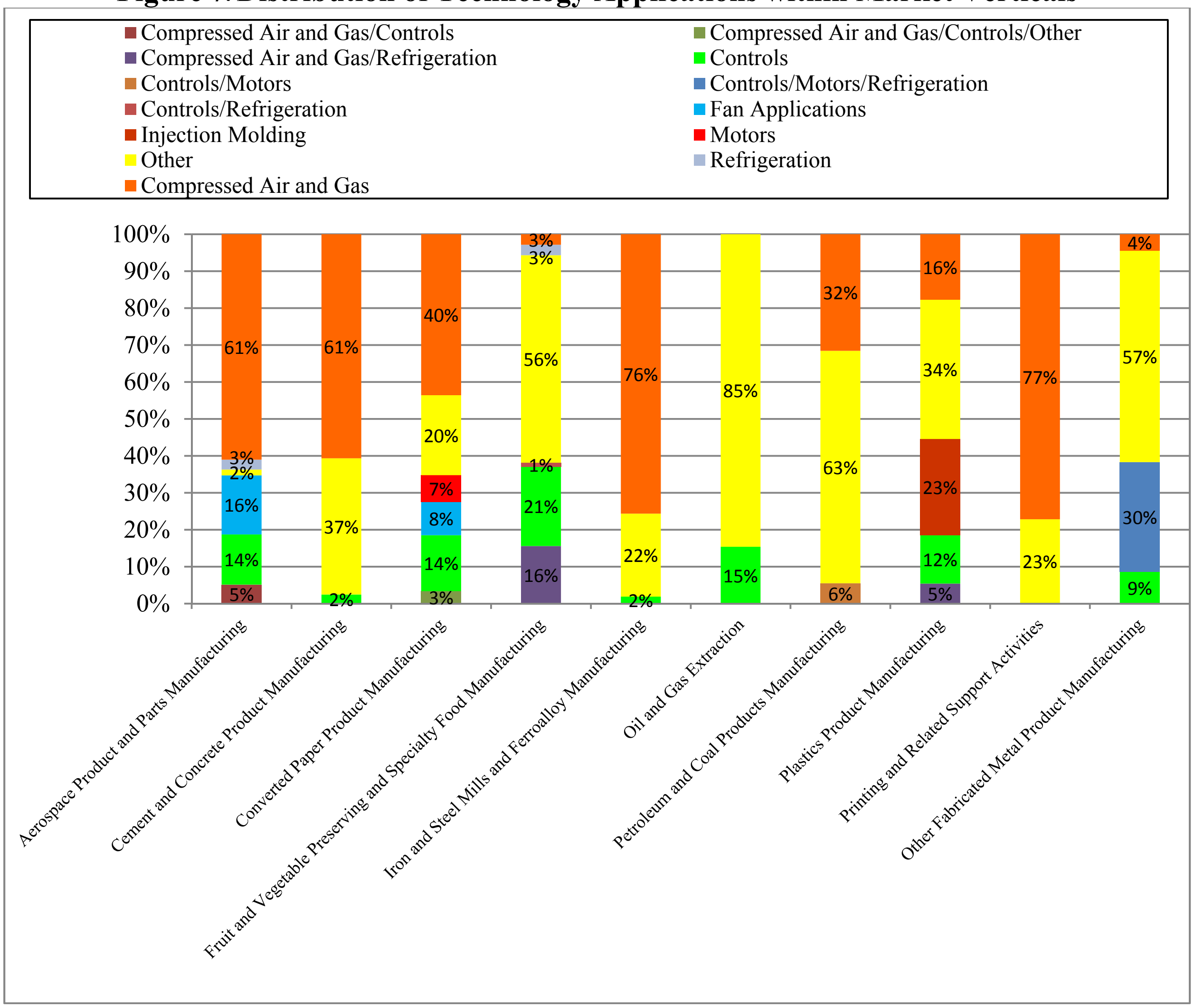


Source: SCE Energy Efficiency Project Program Operations Database

This major industry vertical mapping is notable along multiple parameters. First, there is an approximate bell curve distribution of average percentage energy savings to baseline with a rough mean between 25-45%.

The market segment analysis was narrowed to focus on ten key market segment verticals where energy savings were between 25-45%. The ten segments were 1) Cement and Concrete Product Manufacturing 2) Iron and Steel Mills, 3) Fruit and Vegetable Processing 4) Paper Product Manufacturing; 5) Petroleum and Coal Products Manufacturing 6) Oil and Gas Extraction; 7) Plastics Product Manufacturing 8) Aerospace Products Manufacturing 9) Other Fabricated Metal Manufacturing; and 10) Printing Activities. The constituent technology drivers for energy efficiency projects within each of these verticals are provided in Figure 7. For each of the ten key verticals, this figure provides the percentage contribution of the specific technology application (in kWh savings) to the overall kWh savings for a given vertical. Performing the analysis in this way normalizes the results across all of the key vertical segments, as shown below in Figure 7.

Figure 7. Distribution of Technology Applications within Market Verticals



Source: SCE Energy Efficiency Project Program Operations Database

This analysis shows that Compressed Air and Gas technologies are key drivers for 1) Aerospace, 2) Cement and Concrete Manufacturing, 3) Converted Paper Product Manufacturing 4) Iron and Steel Mills Manufacturing 5) Petroleum and Coal Products Manufacturing, and 6) Printing Activities . Control technologies, whether implemented on a stand-alone basis or in combination with other technologies, are also key drivers, although not to the same degree as Compressed Air and Gas. Control technologies are seen to be particularly important for 1) Aerospace 2) Converted Paper Manufacturing, 3) Fruit and Vegetable Manufacturing, 4) Oil and Gas Extraction, 5) Plastics Product Manufacturing, and 6) Other Fabricated Metals.

While these results are compelling, the analysis clearly shows that "other technologies" (often unique and customized to a particular industry) are also a critical driver for many of the key verticals including 1) Cement and Concrete Manufacturing, 2) Fruit and Vegetable Manufacturing 3) Oil and Gas Extraction, 4) Petroleum and Coal Products Manufacturing and 5) Plastics Product Manufacturing. This holds true even when the normalization of kWh is removed from the analysis. "Other technologies" is an important contributor to industrial market vertical energy efficiency outcomes----both on an absolute and relative basis relative to more specific technologies.

Comparison of Results to Emerging Technologies

The portfolio of projects studied is seemingly diverse, both in vertical market segments and in diversity of measures and technology platforms. This SCE sample survey of projects was compared against a schema developed by the U.S. Department of Energy Battelle National Laboratory (Chapas and Colwell 2007). In this study the authors identified four major technology platforms that presented the greatest opportunity for improved energy efficiency:

- **Industrial Reactions and Separations**: New technologies with improved energy intensity and process intensification capabilities
- **High-Temperature Processing**: Improvements for producing metals and non-metallic materials including deployment of lower-energy alternatives to conventional high-temperature processing technologies
- **Waste Heat Minimization and Recovery**: Technology advances will include the "Super Boiler" to reduce the overall energy demand and the contribution of steam generation to manufacturing; high-performance furnaces and broadly applicable waste-heat-recovery technologies that contribute to industrial sustainability, reduced water usage, and a lower carbon footprint while saving energy.
- **Sustainable Manufacturing**: Technologies that enable the manufacture of components with multiple market applications. New manufacturing options that reduce process steps or parts count (thereby reducing energy intensity through the manufacturing value chain) will be developed through the coupling of design options, materials combinations, and manufacturing technologies.

A direct mapping of each project in the SCE Sample Group into the Battelle schema is beyond the scope of this paper; however, what may be most notable is the apparent concentration of observed installed technologies in the sample group into the "Sustainable Manufacturing" platform. The Battelle study provides sub elements within each of the four technology platforms. For Sustainable Manufacturing one of the sub elements is "Integrated, Predictive Manufacturing and Plant Operations" which is described as "Designing control strategies using sensor and feedback systems to reduce down-time, waste, energy usage, and improve quality." (Chapas and Colwell 2007). Control measures identified in the sample group would seem to directly tie in to the Battelle Sustainable Manufacturing technology platform. It is less clear how Compressed Air and Gas measures map into the Battelle technology schema. This may only be determined through a future detailed review and analysis of individual project scope.

Conclusions and Recommendations

Analysis from this study shows that the key technology drivers influencing process related energy efficiency project adoption by industrial customers are 1) Compressed Air and Gas, 2) Controls, and 3) a combination of both. Deeper analysis led to the conclusion that compressors are used in a variety of industries with very diverse end uses, and thus a large number of energy efficiency projects are compressor related. Secondly, and a more impactful outcome of this study, is the realization of the importance of controls in energy efficiency. Technical advancement and price drop has made controls such as VFDs and occupancy sensors a low cost energy efficiency measure.

It is important to note how industry uses compressed air and gas technologies. Some of the key applications include:

- Pneumatics-the use of pressurized gases to do work (e.g. conveying work in process)
- Air-start systems
- Air tools
- Others

Control technologies provide an automated solution for better managing technologies that may run when they do not need to, or to have systems run at the optimum speed for the prevailing operating condition. Control technologies "smooth" consumption spikes, while not adding significant load themselves. Controls facilitate automated changes in equipment operating levels (and associated energy consumption) with minimal human intervention.

The heart of a manufacturing manager's job is to continuously seek out ways to lower unit operating costs through process enhancements while maintaining product quality. These process enhancements are intuitive and are largely influenced by labor/capital trade-offs. A manufacturing manager may not intuitively use energy efficiency as a tool in reducing per unit operating costs. What is very intuitive to a manufacturing manager is the instinct to automate manufacturing processes wherever possible. Automation can take multiple forms including:

- A direct trade-off from labor to equipment
- The implementation of "smarter" equipment (e.g. variable frequency drives) that provide a better match of needed operating levels to actual operating requirements (without incremental human intervention)
- Substitution-the implementation of a different technology type (e.g. compressed air applications) to perform a function that is energy intensive or requires excessive human intervention.

Thus, a manufacturing manager who implements automation initiatives and projects may well also create foundational energy efficiency benefits. Equipment controlled to operate at levels appropriate to the operating need will inherently consume less energy per unit output, all without compromising quality. Advanced compressor technologies oftentimes replace labor or produce more "work" with less input.

The results from this study suggest that compressed air and control technologies have been key technology drivers in driving energy efficiency within the sample group. These technologies are often captured within the broader umbrella of "industrial automation" initiatives. Thus, when a manufacturing manager implements an automation process enhancement initiative, we argue that they are likely to be simultaneously adopting energy efficiency measures and improving the energy productivity of their manufacturing operation.

Manual processes are prone to inconsistent performance and operational errors. This inconsistency can lead to inefficiency in operations leading to higher energy consumption. Automation follows a set of rules leading to more streamlined operation, increasing operating efficiency and leading to less variable and oftentimes lower energy consumption and peak demand. With changing market trends and renewed interest in energy efficiency across industries and sectors, it is recommended that industrial managers and regulatory bodies re-think the definition of energy efficiency measures. The rethinking should include the following notions:

1. Industries and companies need to develop a dynamic energy master plan that defines their energy goals including process optimization, operations optimization, energy consumption reduction, peak load management, carbon footprint management/reduction, and water management.
2. Controls lead to automation. Automation and energy efficiency go hand in hand. It is imperative that trainings be conducted for operating staff to show the importance of automation. A VFD is simply additional load if the system is not run properly or knowledgeably.
3. There needs to be greater incentives and emphasis on installation of communicating controls. Commercially available systems now have the capability to talk to the controls and collect data. This data can then be turned in to management reports. Some communicating control technologies have the ability to respond to dynamic external factors (e.g. weather) and adjust operating parameters accordingly.
4. System monitoring through the communicating systems provides valuable information about the system performance. After energy efficiency measures are implemented, a system can be monitored and trends created that can be used to easily find anomalies or degradation in system efficiency.

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