Reducing Energy Usage in a Manufacturing Facility through a Behavior Change Based Approach

By

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

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Abstract

Many companies have developed energy reduction programs for their manufacturing facilities to reduce their operational costs while also decreasing their greenhouse gas emissions. The majority of these manufacturing facilities have made progress in reducing their energy usage through technology changes, such as purchasing more efficient lighting or replacing old chillers, however, these improvements are often capital intensive. The goal of this thesis is to explore the use of low cost employee behavior changes to help a manufacturing facility reduce its energy usage.

The author conducted a six month case study at Raytheon’s Integrated Air Defense Center (IADC) in which a new approach for achieving energy related employee behavior changes was implemented. The framework is unique to the author but builds upon lean manufacturing principles, social psychology research, and energy management fundamentals. The approach first raises awareness and engages employees, second, helps employees develop energy saving improvements, and lastly, creates a mechanism to sustain improvements and behavior changes moving forward. The benefits of using such an approach are greater employee engagement (the percentage of employees who participated in a voluntary energy reduction program rose from 38% to 78%), more energy saving ideas being implemented (over 60 employee generated energy saving improvements were implemented on the manufacturing floor), and, ultimately, a reduction in wasted energy. Additionally, a real-time feedback system was designed and installed that provided manufacturing employees with information on their cell’s energy usage. This real-time feedback system was developed to help sustain improvements and further enable energy reductions through employee behavior changes. While specific tactics and tools of the applied approach may be unique to Raytheon’s IADC facility, the strategy and insights can be universally applied.

Thesis Supervisor: Sarah Slaughter, Senior Lecturer, MIT Sloan School of Management
Thesis Supervisor: Leon Glicksman, Professor of Building Technology and Mechanical Engineering
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1. Introduction

1.1 Project Motivation

1.1.1 Motivation to reduce energy usage in manufacturing facilities

Reducing Costs
Worldwide, the industrial sector accounts for nearly half of all energy consumed.¹ In the United States, the manufacturing sector is the largest energy consumer in the economy, using more energy than transportation, residential and commercial sectors.² Despite being such large energy consumers, most manufacturing companies allocate energy use, and its associated costs, into overhead or facility budgets, essentially making them hidden from direct production costs.³

However, in a global marketplace, controlling all costs, direct or indirect, is becoming a necessity for manufacturing facilities. For example, energy costs account for 3% to 56% of the total production costs for the ten most energy intensive manufacturing industries in the United States.⁴ Additionally, in a survey conducted by the Aberdeen Group, over 230 energy management executives were asked what was the primary reason for their companies attempting to better manage their energy demand. The top driver, cited by 80% of respondents, was the need to reduce their manufacturing costs.⁵

¹ (U.S. Energy Information Administration)
² (U.S. Energy Information Administration, 2010)
³ (EPA)
⁴ (Shah, Mehul; Littlefield, Matthew, 2010)
⁵ (Shah & Littlefield, 2009)
Controlling energy usage become even more paramount for manufacturing facilities in areas with high costs of energy. As Figure 3 demonstrates, energy costs, in this case the price per kilowatt-hour of electricity, can vary dramatically even within a country. For example, plants in New England and California will experience average electricity prices that are 50-100% higher than in the South or Midwest. Thus, it is not a surprise that manufacturing facilities, in particular facilities located in high energy cost areas, have increased their emphasis on using this commodity more efficiently.

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6 (U.S. Energy Information Administration, 2010)
7 (Shah & Littlefield, 2009)
Reducing Emissions

While energy reduction started as a cost reduction initiative, it is frequently becoming part of a larger corporate sustainability strategy. Ideally, a corporate sustainability strategy would span a company’s economic, environmental and social impacts, though in recent years there has been increased emphasis on an organization’s environmental impact, most notably, their greenhouse gas (GHG) emissions.

There are six major greenhouse gases being tracked by companies participating in GHG reduction programs: carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆). The largest GHG emission from most manufacturing companies is carbon dioxide resulting from the combustion of fossil fuels. When determining their GHG footprint, companies must account for their direct emissions, such as burning natural gas in a boiler, and their indirect emissions, such as electricity usage.

It is important to note that corporations are not reducing their emissions simply because of altruism, rather, most companies have a more sustainable motivation, capitalism. Specifically, companies that have emission reduction plans believe there are strategic business reasons for doing so. Table 1 highlights some of the more widely cited reasons why companies are voluntarily reducing their greenhouse gas emissions in a transparent way.

---

8 (U.S. Energy Information Administration)  
9 (Shah & Littlefield, 2009)  
10 (EPA)  
11 (EPA, 2010)
Customers are demanding it. Walmart has developed a sustainability supplier assessment which scores suppliers based on their sustainability efforts. The first four questions of this fifteen question assessment relate to the suppliers GHG emission reduction efforts.12

According to the EPA, documented early action by businesses can contribute to future reduction targets.13

Leadership in GHG and energy reduction is often correlated with effective management. According to a study by the Aberdeen Group, companies that have Best-in-Class energy management programs, on average, outperform their corporate operating margin targets by 14%, while Laggard companies miss their profitability targets by 9%.14

Four out of five recent college graduates would prefer to work for a company that is a leader in environmental sustainability.15

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<td>Four out of five recent college graduates would prefer to work for a company that is a leader in environmental sustainability.15</td>
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Table 1: Strategic reasons why companies are reducing their greenhouse gas (GHG) emissions

1.1.2 Motivation to focus on behavior change

"Those of us who call ourselves energy analysts have made a mistake...we have analyzed energy. We should have analyzed human behavior."

– Lee Schipper, Energy Economist

"You can install all the energy meters in the world, they won’t do anything if the people aren’t engaged."

– Raytheon Electrical Engineer

12 (Walmart, 2009)
13 (EPA)
14 (Shah, Mehul; Littlefield, Matthew, 2010)
15 (Experience.com, 2008)
The two quotes above capture the motivation to focus on energy reduction through employee engagement and behavior changes. While energy management and reduction programs are not a new concept, they have traditionally focused on technology changes such as investing in more efficient chillers or switching to more efficient lighting.

Unfortunately, similar to a plant manager trying to increase the productivity of a manufacturing plant, simply purchasing a new machine that is able to make more widgets per hour (or more widgets per kilowatt-hour) is only part of the solution. Instead, the plant manager often needs to also change the culture in the facility, empowering employees to solve problems and take ownership of their work and the plant’s success. This need for engaging employees to increase the productivity and profitability of a manufacturing plant has been documented many times in lean transformation stories.

The requirement for engaging employees is equally as relevant when trying to increase the energy productivity of a manufacturing plant. While purchasing new energy efficient technology is certainly part of the solution, it alone is not sufficient. Instead, an energy reduction program should be augmented by a comprehensive employee engagement and behavior change program.

Despite the importance of employee engagement in energy reduction programs, the amount of literature on the subject is limited and the methods for achieving the desired changes are underdeveloped.\textsuperscript{16} Table 2 shows a comparison of the current approaches used for technology changes compared to the approaches used for behavior changes.

\textsuperscript{16} (Finlinson, 2005)
A key reason for the lack of sophistication in most behavior change energy reduction programs is the lack of resources available, especially when compared to energy reduction methods through technology changes. For example, if a plant manager wanted to reduce the energy usage of their facility through a technology change, they could assign an engineer to investigate purchasing a more efficient HVAC system. This engineer could then attain the necessary information to help them properly execute this task from a variety of sources; sales literature from companies trying to sell HVAC systems, trade organizations like the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), engineering textbooks to calculate energy saving opportunities, etc. However, if the plant manager asked this engineer to reduce the plant’s energy usage through behavior changes, the amount of resources available is significantly limited. For example, there are not sales representative trying to sell (and in the process educate) the engineer an employee behavior change energy reduction program. Additionally, there are not mature trade organizations dedicated to employee energy conservation programs. There is not even formal academic literature, let alone textbooks or formulas, which the engineer can use to calculate the potential energy savings due to employee behavior changes.
In addition to having less sophisticated approaches and resources available, behavior change programs have another feature that make them difficult to execute, namely, the high degree of organizational complexity involved. Returning back to our HVAC system example, the engineer could execute the majority of this HVAC improvement task working solely with people in the manufacturing plant’s facilities department. However, if the engineer wanted to execute a behavior change energy reduction program, they would have to work with employees in all departments in the plant, most notably, the manufacturing employees.

Thus, because of the low level of sophistication of many current energy behavior change programs, the lack of resources available for companies, and the organizational complexities involved with implementing an employee behavior change program, there is a clear need to develop a systematic approach that companies can use to reduce their energy usage in a manufacturing facility through employee engagement and behavior changes.

1.2 Problem Statement

Many companies have developed energy reduction programs for their manufacturing facilities to help reduce operational costs while also reducing their greenhouse gas emissions. Raytheon’s Integrated Air Defense Center (IADC) manufacturing facility has made significant progress in energy and greenhouse gas reductions in recent years. However, the majority of this success has been due to technology changes, which are often capital intensive. The goal of this thesis is to explore leveraging employee engagement and using low cost behavior changes to help a manufacturing facility reduce their energy usage. Specifically, the author conducted a six month case study in which a new approach for achieving employee behavior changes was implemented. The framework is unique to the author but builds upon common lean principles, social psychology research, and of course, energy management fundamentals. While it was not feasible to monitor the exact amount of energy that was reduced due to employee behavior changes, a combination of macro indicators (plant wide energy usage, production quantities, employee headcount, etc.) as well as micro indicators (the number of energy ideas implemented, the percentage of employees who voluntarily became “Energy Citizens”, etc) will be used to quantify the success of this new approach. While specific tactics and tools of the approach may be unique to the situation at Raytheon’s IADC facility, the strategy and insights can be universally applied.
1.3 Hypothesis

When trying to reduce energy usage in a manufacturing facility, rather than focusing solely on technology changes, such as buying more efficient chillers or more efficient lighting, companies need to also focus on employee behavior changes. Building upon lean principles from the Toyota Production System, a behavior change approach must utilize the knowledge and problem solving skills of employees on the manufacturing floor, closest to where the energy is being used. The approach should first raise awareness and engage employees, second, help them develop energy saving improvements, and lastly, create mechanisms to sustain their improvements and behavior changes moving forward. The benefits of using such an approach are greater employee engagement, more energy saving ideas being implemented, and, ultimately, a reduction in wasted energy.

1.4 Thesis Overview

- **Chapter 1** – States the hypothesis, the motivation for answering it, and the specific problem statement for the facility the hypothesis will be tested in.
- **Chapter 2** – Provides a contextual overview of key theories and information needed to better understand the hypothesis and its implementation. Notably, it discusses energy management fundamentals, lean principles and general information of the facility the hypothesis is tested in.
- **Chapter 3** – Outlines the conceptual framework for the hypothesis and discusses how an employee behavior change energy reduction program should be implemented. Each stage of the implementation discusses the theoretical approach, a case study in which the ideas and tools are actually implemented and finally the key insights learned from the case study.
- **Chapter 4** – Reviews the hypothesis and determines if the results validate or disprove it. Also discusses recommendations for other facilities attempting to reduce their energy usage through a behavior change based program. Finally, potential follow on research is proposed.
2. Background

2.1 Energy in Manufacturing Facilities

2.1.1 Sources & End Uses
As highlighted in the Introduction chapter, there are many reasons for companies to increase their emphasis on implementing energy management programs, specifically in their manufacturing facilities. However, before examining the goals and approaches of industrial energy management programs, one must have a basic understanding of how energy is generated and used in a manufacturing facility.

Figure 4 shows the sources of energy for the industrial and manufacturing sector in the United States. It is important to note, this breakdown of energy sources does not represent the breakdown of energy usage of a "typical" manufacturing plant, rather, it is a breakdown of the total energy used by all industrial and manufacturing plants across the United States. The diversity of energy sources used by different facilities makes understanding a manufacturing plant’s energy sources a prerequisite before implementing an energy management program.

![Figure 4: Breakdown of Energy Sources Used in U.S. Industry & Manufacturing](image)

Once the energy sources are identified, an important next step is to understand the end uses of energy in a facility. Figure 5 displays many of the typical end uses of energy in a manufacturing facility. Similar to the sources of energy, the breakdown of energy end usage displayed is an aggregate representation across the entire sector. The actual percentage breakdown of energy end use varies drastically between

\[17\% \text{ Coal} \quad 7\% \text{ Coke & Breeze} \quad 4\% \text{ Fuel Oil} \quad 2\% \text{ LPG (propane)} \quad 17\% \text{ Electricity}\]

\[36\% \text{ Natural Gas} \quad 33\% \text{ Other Sources}\]

\[\text{Figure 4: Breakdown of Energy Sources Used in U.S. Industry & Manufacturing}^{17}\]

\(17\) (U.S. Energy Information Administration, 2006)
facilities. Determining the amount of energy each operation or set of equipment draws is often difficult because it requires the installation of power meters throughout the facility, which can be both time consuming and costly. Regardless, having this end use information is critical in identifying energy inefficient areas and cost saving opportunities.

![Figure 5: Breakdown of U.S. Industrial Sector Energy Direct-End Use](image)

### 2.1.2 Costs
Reducing operational costs is the top reason why the majority of manufacturing facilities are interested in improving their energy management program. Thus, understanding how energy is billed is an essential component to an energy reduction program. While the majority of energy providers charge a manufacturing facility primarily on the amount of a specific energy source that facility uses (i.e. a natural gas provider charges for the quantity of natural gas a facility uses), electricity billing is often more complicated. Unlike residential electric utility bills in which the majority of the bill is a result of how much electricity the customer actually uses (also known as a consumption charge), industrial customers like manufacturing facilities have to pay a consumption and a demand charge. The consumption charge is analogous to a residential consumption charge, it is based on how much electricity the facility used

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18 (EPA)
19 (Shah, Mehul; Littlefield, Matthew, 2010)
20 (The Manufacturing Institute, 2000)
21 (Shah & Littlefield, 2009)
over a given time period (typically one month). A demand charge is determined based on the peak electrical demand of the facility during each month. Figure 6 demonstrates how the electrical demand of a facility varies over time and what the peak demand for this facility is during this time period.

![Diagram](image.png)

*Figure 6: Electricity demand at a Raytheon facility during the month of August*

To better understand the difference between electrical consumption charges and demand charges it is useful to review the basic units of electricity. A watt is the standard unit of power, though, in manufacturing facilities power is often referred to in kilowatts (kW). Power represents the instantaneous use of energy, often referred to as electrical demand. The electrical demand of a facility, as shown in Figure 6, is constantly changing. A good metaphor for power is the speedometer in an automobile; it is constantly changing depending on how hard the driver is pressing on the gas pedal.

The other unit needed to understand an industrial electric bill is the kilowatt-hour. A kilowatt-hour (kWh) is a unit of energy. Energy is simply a measurement of the amount of power used over a given time. For example, one kilowatt-hour is the amount of energy used to power ten, 100W light bulbs for one hour. A good metaphor for energy is the odometer in an automobile; it is constantly increasing as the automobile drives.
Relating these units back to the electric utility bill of a manufacturing facility, the number of kilowatt-hours used by a facility over a month timeframe determines the facility’s consumption charge while the peak demand is the highest kilowatt draw the facility had on the utility (the peak demand value is typically averaged over 15 minutes, thus, not entirely instantaneous). Table 3 provides an example of how this breakdown in electrical costs can look for a manufacturing facility.
The reason that utilities break out their bill into consumption and peak demand is that peak demand determines the utility's generation capacity. For example, even though a utility may only realize a system wide peak in its demand once or twice a year (traditionally during the summer) it must have the infrastructure and generation capacity needed to meet these peaks. Thus, having this peak demand charge is a way for utilities to recoup the cost of building and supporting this extra generation capacity.\footnote{(Eggick, 2007)}

The ratio of demand versus consumption charges varies dramatically by region. In the Raytheon facility in Andover, MA in which the case studies for this thesis were conducted, demand billing is less than 20% of the total electric bill, while at another Raytheon facility in Tuscan, Arizona the demand charge is nearly 50% of the total electric bill. Thus, if a key driver of an energy management program is to reduce the facility’s energy cost, not only should the program look to reduce overall energy usage, but it should also explore opportunities to reduce its peak demand.

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\footnote{(EPA)} \footnote{(Eggick, 2007)}
2.1.3 Energy Management Programs

Corporations are more focused on better managing their energy resources now compared to any other time in recent decades\(^{24}\), thus, it is not a surprise that energy management programs have increased in quantity and sophistication in the manufacturing sector. While each company needs to develop an energy management program that is unique to their corporate goals and culture, there are common traits across traditional energy management programs.

One common characteristic is a heighten focus on technology changes and improvements to increase energy efficiency rather than a comprehensive program that also includes employee engagement. In a study done by The Manufacturing Institute and the National Association of Manufacturers, in which more than 400 US manufacturers were surveyed about their energy management programs, over 50% of the respondents had made technology changes such as improvements to their HVAC equipment, processing equipment and motors in the plant. However, only 10% of companies said they had an employee energy efficiency information campaign\(^{25}\), let alone an actual employee engagement program for energy reduction.

While the primary goal of this thesis is to demonstrate the energy saving opportunities available to corporations that include employee engagement, especially on the manufacturing floor, as part of their comprehensive energy management program, it is important not ignore the necessity of technology changes to increase energy efficiency. Table 2 lists some common technology changes and improvements various companies have achieved. These technology changes can have impressive financial returns; however, they often require an initial outlay of capital. This causes many capital intensive technology changes to have difficulties in getting implemented because these energy improvements compete for the same capital that could be used for more urgent production or facility upgrades. Conversely, employee engagement energy reduction programs are often low cost and can ride the coattails of existing programs in manufacturing facility, such as a lean or operational excellence programs.\(^{26}\) Additionally, without the engagement of the employees who will be operating this new (or upgraded) equipment, the employees could continue to operate these more energy efficient pieces of equipment in inefficient ways, because of lack of knowledge, concern, or incentive.

\(^{24}\) (Bennet & Whiting, 2005)
\(^{25}\) (The Manufacturing Institute, 2000)
\(^{26}\) (EPA)
Another recent trend in energy management programs is the investment in automated energy data collection systems. These energy data systems continuously collect energy usage data from within a plant, providing better visibility and understanding of how a facility is using, and perhaps wasting, energy. Companies are finding that this continuous monitoring of energy usage has increased their effectiveness in identifying energy saving activities compared to traditional energy audits that simply provide snapshots of energy usage at discrete times.\(^{27}\) Thus, it is not surprising that in a study by the Aberdeen Group, companies with best-in-class energy management programs are more than three times as likely to have automated energy data collection systems installed in their facilities than companies who are considered Laggards in terms of energy management. The study also found that these same best-in-class companies are nearly twice as likely to try to optimize their production operations while simultaneously trying to increase their energy performance.\(^{28}\) This highlights another important feature that automated energy data collection systems provide to best-in-class companies, namely, that energy management is not only about data collection, but more importantly, it’s about attempting to provide “the right data, to the right decision maker, at the right time, and in the right context”.\(^{29}\) Manual energy usage collection systems (typically consisting of facility or utility employees manually reading electric meters) do not have the capability to meet these important criteria, hence, the rise of automated energy data collection systems.

While it is important to be aware of new trends and improvements in the field of energy management, they alone are not the essential element that makes a company’s energy management program successful. Implementing a successful energy management program is not very different than implementing any other large program within an organization. It must abide by proven management principles, a sample of which can be seen in Table 4. Also, while there are many different variations of energy management programs, a widely adopted set of guidelines is the Energy Star model shown in Figure 8. Again, following an exact prescription on how to implement an energy management program should not be the goal, instead, a company should focus on the fundamental principles needed for success and aligning within their company’s operating culture.\(^{30}\)

\(^{27}\) (Shah, Mehul; Littlefield, Matthew, 2010)  
\(^{28}\) (Shah, Mehul; Littlefield, Matthew, 2010)  
\(^{29}\) (Shah, Mehul; Littlefield, Matthew, 2010)  
\(^{30}\) (Bennet & Whiting, 2005)
Traditional Management Principles needed in Energy Management Programs

- Leadership at the very top of the company with a clear commitment to results
- Clearly stated goals and measurable objectives at appropriate levels
- Clear accountability for results, whether with single or multiple executives
- Sufficient resources to enable achievement of the objective and goals
- Periodic review and updating of goals, objectives and resource commitments
- Recognition of progress and reward for achievements

Table 4: Key execution principles needed to achieve significant results

<table>
<thead>
<tr>
<th>Make commitment</th>
<th>Assess Performance and Set Goals</th>
<th>Create Action Plan</th>
<th>Recognize Achievements</th>
<th>Implement Action Plan</th>
<th>Evaluate Progress</th>
</tr>
</thead>
</table>

Figure 8: ENERGY STAR's Guidelines for Energy Management

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31 (Bennet & Whiting, 2005)
32 (ENERGY STAR)
2.2 The Toyota Production System & Lean

2.2.1 Toyota Production System & Lean Basics
The Toyota Production System (TPS) was developed by Kicchiro Toyoda, Taiichi Ohno and others at Toyota as a way to keep their company competitive after World War II. By the 1980s other companies began to recognize the competitive advantage TPS gave Toyota and thus, numerous studies were initiated to understand what TPS was and how other firms could implement it in their facilities. In 1990, James Womack, Dan Jones and Daniel Roos published the book *The Machine That Changed the World* as the conclusion of a $5 million, five-year study in which they studied Toyota and other auto manufacturers. In this book, they coined the term “lean production” which described the principles of the Toyota Production System, though, now commonly referred to simply as “lean”.

At its core, lean, and thus the Toyota Production System, is about identifying and eliminating waste in production processes. Waste, also called “muda” (the Japanese term for waste), is defined as any activity that consumes resources but creates no value for the end customer. There are eight forms of waste commonly found in production processes: overproduction, defects/correction, inventory, transportation, waiting, motion, over processing, and underutilized talents. There are many tools and approaches Toyota and other companies use to identify these non-value added activities and reduce/eliminate them, however, these tools alone are not what increases the efficiency and profitability of a manufacturing plant.

Moreover, even though there have literally been hundreds of books and papers attempting to codify the principles of lean and the Toyota Production System, many companies still mistake the tools and practices they read about and see on plant visits with the system itself. In the landmark paper, “Decoding the DNA of the Toyota Production System”, Dr. Steven Spears and his colleagues identified the four rules that govern the Toyota Production System and that the most critical feature of TPS is its creation of a “community of scientists”. Specifically, the system is designed to empower employees to

33 (Lean Enterprise Institute)
34 (Kisby, 2009)
35 (Womack & Jones, 2003)
36 (Womack & Jones, 2003)
37 (Kisby, 2009)
38 (Lean Enterprise Institute)
39 (Spear & Bowen, 1999)
engage in a form of experimentation, with its roots in the scientific method, as the way to eliminate non-value activity in manufacturing processes.\footnote{Spear & Bowen, 1999}

The four rules Spears outlined, as seen in Table 5, provide the framework necessary to create an organization that is continuously learning and continuously improving. The first three rules show how Toyota sets up their operations in a way that allows for better identification of problems (i.e. deviations from their standard design). The fourth rule outlines how Toyota makes improvements once a problem has been identified.

<table>
<thead>
<tr>
<th>Rule 1 – Standard Work</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Key Insights</strong></td>
<td></td>
</tr>
<tr>
<td>- All work is highly defined</td>
<td></td>
</tr>
<tr>
<td>- Work instructions detail each employee’s actions and expected outcomes</td>
<td></td>
</tr>
<tr>
<td><strong>Why so effective?</strong></td>
<td></td>
</tr>
<tr>
<td>- Enables workers to detect deviations (problems) immediately when an expected outcome is not met</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rule 2 – Standard Information Flow</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Key Insights</strong></td>
<td></td>
</tr>
<tr>
<td>- Connection between employees is specified and unambiguous</td>
<td></td>
</tr>
<tr>
<td>- Each employee knows when, and from whom, information is provided to them</td>
<td></td>
</tr>
<tr>
<td><strong>Why so effective?</strong></td>
<td></td>
</tr>
<tr>
<td>- Enables workers to detect deviations immediately when information does not flow along the specified path</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rule 3 – Standard Product Flow</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Key Insights</strong></td>
<td></td>
</tr>
<tr>
<td>- Production lines set up so product flows along a defined path</td>
<td></td>
</tr>
<tr>
<td>- Product does not flow to the next available employee or machine but to a specific employee or machine</td>
<td></td>
</tr>
<tr>
<td><strong>Why so effective?</strong></td>
<td></td>
</tr>
<tr>
<td>- Enables workers to detect deviations immediately when product does not flow along the specified path</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rule 4 – Standard Improvement Process</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Key Insights</strong></td>
<td></td>
</tr>
<tr>
<td>- Improvements must be made closest to where the deviation occurred</td>
<td></td>
</tr>
<tr>
<td>- Frontline employees make improvements to their own jobs using the scientific method. Supervisors provide assistance as teachers.</td>
<td></td>
</tr>
<tr>
<td><strong>Why so effective?</strong></td>
<td></td>
</tr>
<tr>
<td>- Creates a &quot;community of scientists&quot; continually looking for improvements to eliminate non-value activities (i.e. wastes) caused by deviations</td>
<td></td>
</tr>
</tbody>
</table>

Table 5: The four rules of the Toyota Production System\footnote{Spear & Bowen, 1999}
This thesis builds heavily on the fourth rule as a way to engage frontline workers to become a "community of scientists" searching for improvements to eliminate energy waste. Toyota's experimentation method, outlined in Table 6, provides a great framework for continuously identifying problems and developing improvements. However, the first two steps of the scientific process in Table 6, hypothesis and sign of a problem (which both align very closely with rules 1-3) work well when identifying traditional forms of manufacturing waste, such as time, motion, defect, etc. Unfortunately, these rules often do not work as well when attempting to eliminate energy waste. Since energy, and its associated cost, is often buried in overhead budgets, it is rare that an energy hypothesis had ever been defined. Furthermore, there is not a clear way for a frontline employee to identify a sign of an energy related problem. Thus, without this signal, or pull, ever prompting the response of a frontline employee, energy improvements are rarely made. In the case study in Chapter 3, we attempt to create the impetus, or pull, to get employees to initiate the response phase of the Toyota Production System and implement energy saving improvements for their specific areas.

<table>
<thead>
<tr>
<th>Action</th>
<th>Hypothesis</th>
<th>Sign of a Problem</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Definition of standard work/process flow</td>
<td>Identification of deviation from standard work/process flow by frontline employee</td>
<td>Frontline employees and supervisors go to place deviation occurred, creates new hypothesis for standard work/process, quickly runs experiment to validate/disprove hypothesis</td>
</tr>
<tr>
<td></td>
<td>Traditional Manufacturing Example</td>
<td>Installing 4 bolts in 4 holes should take 35 seconds</td>
<td>2nd shift employee installs 4 bolts in 45 seconds</td>
</tr>
<tr>
<td>Energy Manufacturing Example</td>
<td>Standard amount of energy used to perform a task is not defined</td>
<td>Employee is unable to identify when they are using too much energy</td>
<td>No response, and thus improvement action, is initiated</td>
</tr>
</tbody>
</table>

*Table 6: Toyota’s Experimentation Method*

41 (Spear & Bowen, 1999)  
42 (Spear & Bowen, 1999)
2.2.2 Lean and Energy
While eliminating traditional forms of manufacturing waste often leads to indirect energy savings, as shown in Table 7, in recent years there has been a new trend to explicitly use the approach and tools of successful lean programs to help identify and eliminate energy waste. As outlined in the Introduction chapter, two important drivers for this new trend are manufacturing firms attempting to decrease their operational costs while simultaneously trying to increase their environmental sustainability. These drivers have made more lean implementers and energy managers investigate and explore the natural integration of these two fields. There has also been an increase in academic literature on the subject; however, it is still nascent.

<table>
<thead>
<tr>
<th>Traditional Manufacturing Waste</th>
<th>Indirect Effect on Energy Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overproduction</td>
<td>• More energy consumed in operating equipment to make unnecessary products</td>
</tr>
<tr>
<td>Inventory</td>
<td>• More energy used to heat, cool, and light inventory storage and warehousing space</td>
</tr>
<tr>
<td>Transportation and Motion</td>
<td>• More energy used for transporting and moving products unnecessarily</td>
</tr>
<tr>
<td>Defects</td>
<td>• Energy consumed in making defective products (and potentially reworking them)</td>
</tr>
<tr>
<td>Over processing</td>
<td>• More energy used in operating equipment because of unnecessary processing</td>
</tr>
<tr>
<td>Waiting</td>
<td>• Wasted energy from heating, cooling, and lighting during production downtime</td>
</tr>
</tbody>
</table>

Table 7: Examples of how eliminating traditional manufacturing wastes can indirectly reduce energy waste

One of the most comprehensive reports on the natural integration of energy reduction and lean programs was published by the Environmental Protection Agency (EPA) in 2007. The EPA partnered with
leading companies and organizations in fields of lean implementation and energy management to develop a report entitled "The Lean and Energy Toolkit". This toolkit was created to provide lean implementers strategies and techniques of using traditional lean tools to reduce energy usage while also introducing readers to the range of energy management resources available through the federal government.44

In addition to the toolkit, the EPA has partnered with the Manufacturing Extension Partnership (MEP) program to set up pilot programs in the Northeast to demonstrate how manufacturing companies can use lean methodologies to reduce energy costs. In these pilot programs, which were scheduled to begin in 2009, the MEP and EPA are working directly with manufacturing facilities to help them use lean principles to reduce their energy usage. Both government agencies are hoping these pilots will provide further evidence of how lean programs can be used to help make manufacturing facilities in the United States more energy efficient, and thus, more competitive in a global marketplace.45

2.3 Raytheon Company

2.3.1 Corporate Business Overview
Raytheon is a technology provider specializing in defense, aerospace and homeland security solutions to governments throughout the world. Headquartered in Waltham, Massachusetts, Raytheon has approximately 73,000 employees and net sales of $23.3 billion in 2008. Raytheon’s primary customer is the United States government, particularly the Department of Defense. In 2008, 87%, or $20.2 billion, of its revenue was from sales to the US government. There are six main business units within Raytheon; Integrated Defense Systems (IDS), Intelligence & Information Systems (IIS), Missile Systems (MS), Network Centric Systems (NCS), Space & Airborne Systems (SAS), and Technical Services (TS).

The Integrated Defense Systems (IDS) division of Raytheon is headquartered in Tewksbury, Massachusetts and has annual revenues of $5.1 billion (22% of Raytheon’s total revenue). IDS employs 13,500 workers spread across 11 sites globally, which combined, have a facility footprint of 5.45 million square feet. IDS’s primary product lines are Seapower Capability Systems, National & Theater Security Programs, Patriot Programs, Civil Security & Response Programs and Global Business Operations. In recent years there has been a resurgence of the Patriot Programs and IDS is expecting to grow

44 (EPA)
45 (Sciortino, Watson, & Presnar, 2009)
significantly and rapidly, mostly due to international sales. The Integrated Air Defense Center manufacturers many of the key components for the Patriot Program and is the site used for the case study in Chapter 3.

2.3.2 Corporate Energy Overview

Raytheon is a leader in energy management and environmental sustainability. As can be seen in Figure 9, they have achieved 30% reduction in energy consumption per billion dollars of revenue over the last six years. This statistic, along with some of their innovative energy efficiency approaches, has earned the company multiple awards from ENERGY STAR, most notably, Partner of the Year honors in 2007 and Sustained Excellence honors in 2008 and 2009. Additionally, Raytheon is a charter member of the EPA’s Climate Leaders program, a voluntary industry/government initiative that requires participating companies to set long-term greenhouse gas emission goals. Raytheon set a goal to reduce their emissions by 33% from 2002 to 2009. As can be seen in Figure 10, they achieved this goal a year early, reducing their emissions by 38% by 2008.

![Figure 9: Raytheon's energy usage over time (billions of BTUs/$B of revenue)](image)

![Figure 10: Raytheon's greenhouse gas emissions over time (thousands of metric tons/$B of revenue)](image)

The impressive energy and emission reductions Raytheon was able to achieve were coordinated by the Enterprise Energy Team (EET). The EET is composed of facility employees and managers from each of

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46 (ENERGY STAR)
47 (Raytheon Company, 2008)
48 (Raytheon Company, 2008)
Raytheon’s six divisions. The EET reports directly to the Facilities Leadership Council (FLC). The FLC is a group of facility directors from each of Raytheon’s divisions. The EET is lead by Steve Fugarazzo, the Facilities Engineering Manager within IDS. Through biweekly teleconference meetings and multiple sub groups, the EET develops and implements programs designed to help the corporation reduce its energy usage, reduce its energy related operational costs and decrease their greenhouse gas emissions. The EET also helps to develop the energy reduction and greenhouse gas emission goals for the corporation and for each Raytheon division. These divisional goals are ultimately rolled down to the facility level.

Aside from helping to provide strategic direction for the company on energy issues, each EET member is responsible for helping their specific division meet their energy goals. Each facility within a division has a liaison from the EET that works with the lead Energy Champion at that facility to implement energy saving programs. While each facility has one lead Energy Champion which coordinates the facility’s energy saving programs, it also has department level Energy Champions that coordinate energy saving initiatives at the department level. Finally, each departmental level Energy Champion works with the motivated Energy Citizens within their area to encourage energy conscious behavior.

This organizational structure has provided a system that as enabled the EET to influence Raytheon’s energy strategy at both a corporate and individual facility level, however, it is not without flaws. Most
notably, with the EET consisting solely of facilities employees, it is often viewed as a facilities initiative rather than a business and operations initiative. Also, the majority of people involved, especially the Energy Champions and Energy Citizens, work on these programs on a volunteer basis. Thus, accountability is not as strong as if it were part of their formal job responsibilities.

Nonetheless, the EET represents an innovative and effective system that has attained impressive results. Not surprisingly, best-in-class energy management companies are more than two-thirds as likely to establish a formal energy management programs, similar to the one employed by Raytheon, when compared to laggard companies.⁴⁹

2.3.3 Integrated Air Defense Center Overview

Facility Overview
The Integrated Air Defense Center (IADC) is located in Andover, Massachusetts and is IDS’s largest manufacturing facility. The IADC has a footprint of 1.2 million square feet (22% of IDS’s total footprint) and has more than 4,400 employees. While the facility’s primary function is manufacturing, it also has traditional office space, two dining centers and a data center onsite. The largest program supported by the facility is the Patriot Air & Missile Defense System, however, the facility also manufacturers and integrates products for various land and sea based systems. The size and complexity of the products manufactured at the facility span the production of circuit cards to the final assembly of large radars used on naval ships.

Lean Overview
In 2001, the IADC increased its emphasis on operational excellence and began a lean transformation. After working with outside consultants, the IADC developed their own internal lean office, called the Operational Excellence Resource Center (OERC). The OERC works directly with manufacturing departments and cells in the IADC to implement principles of the Toyota Production System. Aside from using traditional lean tools such as kaizen events and value stream mapping, the OERC attempted to foster the “community of scientists” described in Spear’s fourth rule by developing a program called Total Employee Engagement (TEE). The goal of TEE is to engage all manufacturing employees to develop small improvements to their jobs every day. This philosophy is represented in a mantra that is commonly cited in the facility, “a million one dollar ideas are better than one million dollar idea”.

⁴⁹ (Shah & Littlefield, 2009)
Despite the IADC being a heavily unionized facility, TEE has been incredibly successful. For example, from January to September of 2009, employees implemented over 600 improvements throughout the facility.

Another equally, if not more important, facet of the IADC's lean program is the Virtual Business System (VBS). Founded in 2004 by Raytheon employee John Day, VBS uses real-time data to enable lean principles. The philosophy of VBS has its roots in a quote from Lord Kelvin, “If you cannot measure it, you cannot improve it”. Furthermore, VBS uses real-time data to influence employee behavior in two ways; first, to provide real-time, actionable data employees can make decisions based on, second, to help foster a culture in which all employees try to continuously improve their jobs.

VBS has many functions, but one of its principal advantages is its ability to aggregate data from multiple legacy systems found within the IADC into a single, easy to understand dashboard. These VBS dashboards provide real-time, objective production information in a format and context that enables real-time decision making by all employees in the facility; both managers and frontline employees. A primary motivation for this real-time visibility and decision making is to identify problems as they occur, not “after the damage is already done”. Additionally, many VBS dashboards have drilldown capability, allowing users to simply click on data or charts within the dashboards to inquire even further about the details or the source data. Finally, this data and information is continuously compiled by the VBS database, therefore no non-value added time is wasted by employees updating reports or charts.

50 (Antoniou, 2008)
51 (Day, 2008)
Figure 12: VBS combines data from disparate databases into dashboards that provide actionable information for employees. Once a dashboard is created it automatically and continuously compiles the data.52

A second key feature of VBS is that it is a systematic way to bias the action by employees at all levels of the organization.53 Specifically, actionable data is continuously delivered to the employees who can improve performance. If these employees do not improve performance the results are not hidden in Excel spreadsheets, instead, results are displayed for everyone to see. There are almost 80 flat screen monitors throughout the IADC; in hallways, offices, the dining center, and of course, on the factory floor. These monitors are continually cycling critical information of the local manufacturing cells or of the facility as a whole. In addition, there are over 3,832 installations of VBS on the personal computers of manufacturing employees (represented employees, cell leaders and senior managers) which provide instant reporting ability, and thus, accountability. In the words of John Day, “you cannot hide from the

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52 (Day, 2008)
53 (Day, 2008)
data, it comes after you”. Not only does this accountability improve results, but equally as important, it influences employee behaviors by promoting continuous improvement.

**Energy Overview**

The IADC’s primary source of energy is electricity, representing 90% of its total energy usage. The remaining 10% is essentially all natural gas. The IADC had an annual electricity consumption of approximately 57,574 MWhs in 2009, which is the equivalent amount of electrical energy used by 5,126 average American homes. The IADC’s peak power during this was 11,410 kW, occurring in mid August. Since the IADC is such a large energy user, it negotiates its rates directly with its electricity provider. Its approximate annual electricity bill is $9 million.

Electricity is delivered to the IADC with a voltage of 15 kV at two points and then distributed through its own internal electricity grid to ten substations spread out in the facility. These substations do not align with departments or manufacturing value streams, rather, the substations align with geographic areas of the plant. While it is preferred to have substations align with organizational departments, especially from a reporting and accountability standpoint, it is often not realistic because equipment and departments relocate over time. From these substations, the electricity is stepped down to various voltages (typically 480V, 220V and 120V) and then delivered to equipment on the manufacturing floor or wall outlets in office areas.

Figure 13 shows the percentage breakdown of energy used by each substation over a typical week. Note, the equipment used in substations varies dramatically, so substations with larger average loads may not be inefficient compared to their peers, rather, they just have equipment that consume much more energy. Typical energy users on the manufacturing floor are ovens, processing equipment, test equipment, air compressors, HVAC, lighting and individual work benches.
The IADC has over 200 Schneider Electric meters (often referred to as sub meters) installed in the facility. These sub meters continuously record power, energy and other electrical data at various locations in the facility. All this data is automatically uploaded to a SQL database operated by Schneider Electric. This data is then used by Schneider Electric’s ION EEM web interface software in which authorized Raytheon employees can remotely access the data to make historical charts of power and energy usage using any combination of sub meters. All this data can be exported directly to Microsoft Excel.

The primary use of this data is by the IADC’s facility-level Energy Champion who sends weekly reports on the facility’s energy usage to other department-level Energy Champions (only the facility-level Energy Champion has access to the ION EEM database at the IADC). In the IADC, each substation had an assigned department-level Energy Champion. These Energy Champions and some motivated Energy Citizens meet monthly to review the energy data from previous months as well as to discuss any other energy related issues or ideas.

The IADC Energy Champions and Energy Citizens have worked to raise awareness and decrease energy usage over the past few years with success. Some of their activities include annual Energy Day events, conducting energy audits afterhours to see what equipment was mistakenly left on and by starting a campaign to label which machines should be turned off every night (engineering maintenance employees do not want certain pieces of equipment turned off in fear of losing critical production parameters).
While all of these actions are commendable, they are achieved through the work of a small contingent (less than ten) of passionate and committed employees volunteering their time. In order for the IADC to achieve its goal of 0.0% increase in the absolute energy usage in 2009 compared to 2008 (even through production was increasing dramatically during 2009), the actions of this concentrated group needed to be expanded to all employees in the facility.

**Unique Features of IADC Influencing Hypothesis Implementation**

Like all manufacturing facilities, the IADC has unique features that make the implementation of a new program more difficult, but also have legacy factors that can be leveraged. One of the most important features of the IADC is its heavily unionized workforce. Nearly all of the facility’s 2,000 manufacturing employees are represented, or unionized, employees. In general, Raytheon has a satisfactory relationship with its unions\(^\text{54}\); however, a union environment does present an additional layer of complexity for a variety of reasons. Most notably, union employees are not required to participate in any of the IADC’s lean programs nor are they required to use VBS, it is strictly voluntarily (though highly encouraged).

Also, during the implementation of this thesis, the IADC was experiencing large increases in their business. Not only did this require additional output from existing manufacturing cells but also caused an increase in the amount of employees and shifts in certain departments. During 2009, the revenue from the IADC increased by 5% and the number of employees increased by 16%.

A final unique challenge to the IADC was its security restrictions. Being a defense contractor, there are certain areas within the plant that are restricted to specific employees. This prevents complete collaboration between cells and hinders the ability of energy experts, even within Raytheon, to easily work with certain areas of the plant.

Despite these challenging features, there were existing factors within the IADC that were able to be leveraged. Perhaps the most important legacy factor is the facility’s robust lean program. Employees, managers and senior leaders were already aware of the power of continuous improvement and employee engagement, thus, we could simply integrate with an existing program when implementing our hypothesis rather than trying to concurrently develop a lean culture. Additionally, the existing infrastructure of VBS provided an ideal medium to provide real-time feedback on energy related

\(^{54}\) (Raytheon Company, 2008)
metrics, most notably energy usage, because the programming capability and the supporting hardware were already in place. Finally, Raytheon’s strong commitment to energy and sustainability by its most senior leaders provided the necessary spotlight to get a new, innovative energy reduction program off the ground.
3. Testing of Hypothesis

3.1 Conceptual Framework

A conceptual framework was developed to translate the theoretical goal of reducing energy usage through employee behavior change and engagement into a pragmatic methodology. The framework combines lessons from three distinct areas of research; lean manufacturing, energy management and social psychology, into an actionable plan which can be implemented in a manufacturing environment.

The approach includes three stages:

- **Engage**: During the engagement stage, companies should be attempting to get employees to care about reducing their energy usage. While many programs like this exist, they often involve companies creating energy awareness campaigns that consist of posters, emails and other forms of corporate promotion. Instead, the approach should leverage social norms and peer pressure to increase energy awareness and engagement amongst employees.

- **Improve**: During this stage companies should be working with employees on the manufacturing floor to develop energy saving improvements for their specific areas. This helps transition energy management programs from having a small subset of employees trying to reduce the energy usage of a giant facility to getting all employees, especially the employees who are actually using the energy, searching for energy saving opportunities. This is analogous to...
creating the “community of scientists” that is the cornerstone of the Toyota Production System. To achieve this, the manufacturing facility must integrate energy reduction into their existing lean program.

**Sustain:** Finally, a mechanism must be put in place that sustains the employee energy improvements and behavior changes over time. Unfortunately, energy waste is a hidden waste. Unlike inventory or defective parts, kilowatt-hours do not visibly pile up next to a manufacturing cell. Thus, in order to aid employees in the continual identification and elimination of energy waste, energy waste must become visible, preferably in a real-time, actionable format that allows employees to identify where energy is being wasted. Not only will this engender further employee improvements to reduce and eliminate energy waste but should also motivate employees to change their behaviors to become even more energy efficient.

During the subsequent sections we describe the implementation of each of these stages through case studies at Raytheon’s Integrated Air Defense Center (IADC). Results demonstrating the effectiveness of this framework are shown for each distinct stage as well as for the entire implementation. While the exact tools used at the IADC may not be transferable to all manufacturing facilities, the set of behaviors and insights the framework provides can be universally applied.

### 3.2 Engagement Stage

#### 3.2.1 General Approach

Following the principles of the Toyota Production System, workers who are closest to where the actual work is being conducted should be involved in developing improvements for their work areas. However, before an employee can effective in identifying waste and opportunities for improvement the employee needs to have a basic understanding, and hopefully motivation, on why they should be looking for a particular form of waste. This is the main goal of the engagement stage, to not only inform but to motivate employees to be engaged in helping to reduce wasted energy.

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55 (Spear & Bowen, 1999)
It is important to note, that education alone is not enough of an impetus for people to change their behaviors. Specifically, sending out energy newsletters and posters educating and encouraging employees to be more energy efficient is not an effective way to engage a workforce. Instead managers need to create a work environment that motivates employees to adopt energy saving behaviors because reducing energy usage is the established culture, or norm, in the facility. Creating such an engaged workforce can result in tangible and intangible benefits to the factory. However, creating this type of culture is often difficult and requires interfacing with employees at the highest and lowest levels of the organizational chart.

A prerequisite for any behavior change based energy reduction program is senior level buy-in. However, this need for executive level commitment is not unique to energy behavior change programs, rather, it is needed for nearly any program in which you are trying to change the behaviors of a large group of employees. For example, two analogous behavior change programs to energy reduction programs are quality and safety programs. Both require employees to change the way they traditionally do their work in order to see benefits that may not directly, at least in the short-term, create any benefit for the individual employee. Predictably, quality and safety programs that do not have senior level commitment continually underperform. In contrast, best-in-class energy management companies are more than two-thirds as likely as laggard energy management companies to have energy management as one of their senior leader’s top three focus areas.

However, while top level backing in an energy reduction program is a prerequisite it alone is not sufficient to significantly increase engagement and foster the needed employee motivation to help with energy reduction efforts. Instead employees, just like people outside of work, are more heavily influenced by their peers than “top down edicts.” Thus, a peer-to-peer driven engagement campaign, one in which peers influence each other to become more engaged on energy saving issues, is needed.

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56 (Doug McKenzie-Mohr, 2008)  
57 (Shah & Littlefield, 2009)  
58 (Bennet & Whiting, 2005)  
59 (Eggick, 2007)  
60 (Eggick, 2007)  
61 (Shah & Littlefield, 2009)  
62 (Eggick, 2007)
There are two elements that make a peer-to-peer campaign successful. First, peer-to-peer campaigns rely heavily on personal interactions. Social psychology research reveals that people are most likely to modify their behaviors due to direct appeals from others.63

For example, during the 1930s the U.S. government developed an information campaign to inform farmers how to prevent the loss of topsoil in their fields, a significant problem at the time. Brochures were distributed to farmers that discussed the severity of the problem and specific actions farmers could take to reduce their soil erosion. Unfortunately the brochures and the government’s efforts were not successful and few farmers changed their behaviors to conform to the suggested actions. Shortly afterwards, a new approach was attempted that involved providing a small number of farmers direct assistance in adopting soil erosion prevention practices. The logic was that if the erosion prevention practices were modeled by some farmers, that neighboring farmers would be more open to also abiding by these practices. This approach turned out to be a success and these new erosion prevention practices spread quickly. Researchers observed that when neighboring farmers saw the changes that their peers were making, these neighbors would informally discuss these changes with the early adopting farmers. Once the neighboring farmers saw the results, they quickly adopted similar practices.64 The learning from this study is two-fold; first, education and information alone is not enough to change people’s behaviors (at least not in terms of mass adoption), second, that peer-to-peer interactions are more effective in creating the desired behavior change than traditional top down messages.

The second key element of a peer-to-peer campaign is the development of social norms. Social norms are rules developed and used by a group of people that stipulate how the people within a particular group should act.65 While the rules are often implicit they create the behavioral expectations amongst a group of people, whether it be a set of students in a high school, fans at a sporting event, or in our case, employees in a manufacturing facility. Even though social norms tend to be tacitly enforced, there are many social experiments that demonstrate people tend to conform to these implicit, yet established social rules.

One such experiment was done at the University of California Santa Cruz. During this experiment researchers were interested in determining how establishing a social norm could change people’s

63 (Doug McKenzie-Mohr, 2008)
64 (Doug McKenzie-Mohr, 2008)
65 (SociologyGuide.com)
behaviors in regards to water conservation. In one of the university’s athletic complexes, the researchers placed signs in the male shower room that encouraged students to turn off the shower while they lathered up with soap. This sign had little effect in changing people’s behavior, on average, only 6% of unaware participants complied with the sign. However, when an actor was placed in the shower area and the actor followed the signs’ instructions, the amount of students that turned off their water while lathering up rose to 49%. When two actors were placed in the shower area to model the sign’s instructions, the students who complied with the water conservation appeal increased to 67%. Thus, the sign alone was not effective in engendering significant behavior changes. However, when the sign was combined with an established social norm the amount of people who conformed to the desired behavior change increased substantially.  

![Conserve Water!](image)

**Figure 14: Sample sign used in social norm experiment to reduce water usage by students**

While the context may be slightly different in a manufacturing facility the core principles used in these two experiments are still relevant. First, top down declarations are not always the best way to initially change people’s behavior, instead, people often respond more openly to personal contact and appeals from their peers. Then, as an increasing number of people within a group begin to model a specific set of behaviors, a social norm is established. Once the social norm is established, i.e. these behaviors are deemed appropriate by the group, nonconformance because increasingly unlikely and more people comply with the desired behavior change (creating a positive feedback loop). Thus, these core principles

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*66 (Doug McKenzie-Mohr, 2008)*
can be leveraged to create a set of energy saving behaviors that become the social norm within a manufacturing facility. We attempt to create such a social norm in the following case study at Raytheon’s IADC manufacturing facility.

3.2.2 Case Study

Goal
In the following case study a peer-to-peer energy employee engagement campaign was implemented. The campaign was designed to utilize the best practices outlined in the general approach section to increase the amount of employee engagement in Raytheon’s energy program. The most important of these principles were:

- Having senior level buy-in of the program
- Realizing that education and information alone are not enough to change behaviors
- Using personal contact and peer pressure to get initial adoption
- Creating a social norm allows for more widespread adoption

While the general goal of the engagement stage is to increase the number of employees engaged in energy saving activities, the specific goal for Raytheon’s IADC facility was to increase the amount of Energy Citizens in the manufacturing area.

The Energy Citizen program is a novel program developed within Raytheon to help raise awareness about energy conservation amongst employees. For an employee to become an Energy Citizen they have to complete an Energy Quiz that asks if they perform simple energy saving activities at work and at home. The quiz is designed so that nearly everyone passes and an employee only needs to answer “yes” on seven out of fourteen questions to be deemed an Energy Citizen. The Energy Quiz changes annually and employees need to complete the quiz every year to get an Energy Citizen pin in which many employees wear on their security lanyards. A paper copy of the quiz can be seen in the Appendix, though most people take the quiz online.

Each year the Enterprise Energy Team (EET) sets goals for the amount of Energy Citizens they aim to reach. They use this metric to help determine how well they are engaging Raytheon employees in their energy conservation program. The Integrated Defense System’s Energy Citizen goal for 2009 was to have 40% of their employees be Energy Citizens. The IADC, IDS’s largest manufacturing plant, had 38% of their
manufacturing employees already signed up as Energy Citizens when we started our case study in the beginning of July.

A common criticism of the Energy Citizen program is that it simply involves employees taking a two minute quiz and is not a true measurement of the workforce’s awareness and engagement in Raytheon’s energy program. While the author agrees that the amount of Energy Citizens is not a perfect measurement, monitoring the number of employees who become an Energy Citizen at least gives some proxy of what percentage of employees are taking time out of their day to participate in Raytheon’s voluntary energy reduction program, even if it is only two minutes. Additionally, psychological research suggests that these negative accusations against the Energy Citizen program may be unwarranted and that even engaging employees for just two minutes is an important first step towards leading to more significant employee engagement in Raytheon’s energy reduction program.

Specifically, the Energy Citizen program aligns with an approach called the “Foot-in-the-door” compliance technique. The “Foot-in-the-door” technique involves asking a person to comply with a small initial request and then asking them to comply with a more costly second request. Multiple psychological studies have shown that the likelihood of the person complying with this second more costly request is much greater if the person is first asked to comply with the small request than if they were just initially asked to comply with the more expensive second request. Thus, this “Foot-in-the-door” phenomena suggests that if we ask manufacturing employees to comply with a small energy reduction request, such as take a two minute Energy Citizen Quiz, the likelihood that they would later comply with a more expensive energy reduction request, such as identifying energy saving improvements for their area, is much higher than if we just initially asked them to comply with this more expensive energy reduction request.

Specific Approach

During this case study, we attempted to increase the amount of Energy Citizens in the IADC using two methods. The first method was a traditional energy awareness campaign and the second method was a peer-to-peer campaign. Before and after each method we recorded the number of Energy Citizens, which allowed us determine which approach was more successful.

67 (Gueguen, 2002)
68 (Gueguen, 2002)
For the traditional energy awareness campaign we used conventional tools to increase the number of employees who satisfactorily completed the Energy Citizen Quiz. Some conventional techniques we used were promotional items such as emails and posters. We also attended daily “toolbox” meetings in which we spoke directly with manufacturing cells at the start of their shift highlighting why we need to reduce the IADC’s energy usage and how they can help by becoming an Energy Citizen. A passionate member of the EET even dressed up as Uncle Sam before the Fourth of July holiday, passing out paper copies of the Energy Citizen Quiz trying to get employees to take the quiz during their lunch break.

For the peer-to-peer campaign we took a much different approach. Instead of directly promoting and encouraging employees to become an Energy Citizen, we built tools that would help current Energy Citizens reach out to their peers in the facility, personally asking them to become an Energy Citizen. Building upon the ideas outlined in the general approach section, we believed if the employees who were already passionate about Raytheon’s energy reduction program personally reached out to their peers it would spur greater initial adoption. Then, as an increasing number of employees took the quiz, it would make becoming an Energy Citizen a social norm in the facility.

To help foster the peer-to-peer interaction, manufacturing employees that were passionate about the Energy Citizen Program needed visibility on who was and who was not an Energy Citizen. Therefore, we created the Virtual Business System (VBS) dashboard shown in Figure 16 that creates a list of who is and who is not an Energy Citizen. The dashboard works by an employee selecting which department they are interested in from a dropdown menu (circle 1). This action triggers two events: first, the dial directly below the dropdown menu displays the percentage of employees in that department that are Energy Citizens (circle 2). Next it populates a list of all the different manufacturing cells that are within this department (also circle 2).
To help foster the desired social norm, and to add a little competition amongst the cells within a department, we add functionality to the dashboard so that cells were highlighted different colors depending on how many employees in their cell were Energy Citizens. If a cell is highlighted in green that meant it had the highest percentage of Energy Citizens in their department. If a cell was highlighted in red it signified that the cell was below the 40% goal for the amount of Energy Citizens in the IADC plant. If the cell was not highlighted in red or green it meant the cell did not have the highest percentage of Energy Citizens however it was above the minimum goal for the plant. While this simple visual indicator of green or red may not seem that sophisticated it proved, to our surprise, to be rather effective in initiating change. In fact, within a few days after we launched this dashboard one of the manufacturing managers came running into the VBS office saying, “my cell is red, I’m one of the only cells in my department that are red, how do I get out of the red?” Within 24 hours this manager’s cell, and the other red cells within that department, were no longer red.

69 (Raytheon Employee 1., 2009)
The final, and most important, piece of functionality for this dashboard was when an employee clicked on a cell’s name in the list box (circle 3), the VBS dashboard then populated a list of which employees within that cell were Energy Citizens and which employees were not (circle 4). These tables were not meant to get any employees in trouble, in fact, due to the union agreement with employees Raytheon could not force employees to participate in programs like the Energy Citizen Quiz. These initiatives had to be strictly voluntary. Instead, the purpose of creating these tables was to give the passionate Energy Citizen employees visibility on whom to approach and ask to become an Energy Citizen.

We observed this phenomenon, in which employees in the Energy Citizen list petitioned the employees in the Non-Energy Citizen list to become Energy Citizens in many different departments. However, the most impressive example of this was a represented employee, Deb Nickles, who worked in the Circuit Card Assembly (CCA) department of the IADC. CCA is the largest department in the IADC and Deb was determined to get her department, and for that matter all the IADC, to 100% Energy Citizens. Once the VBS dashboard in Figure 16 was released, Deb worked with a group of other passionate individuals to convert the Non-Energy Citizens. By figuring out who had personal connections with people on the Non-Energy Citizen list (also affectionately known as the “naughty list”) the group would approach these employees about becoming an Energy Citizen. Deb would often show up an hour or two early for work to help sign employees up. In the end, we attributed nearly 100 new Energy Citizens directly to Deb’s voluntary efforts.

Aside from showing who is and who is not an Energy Citizen at the cell level we felt it was important to show how many employees within the entire manufacturing facility were Energy Citizens. Our reasoning was that this plant wide visibility would further reinforce the desired social norm, specifically, that becoming an Energy Citizen was the accepted behavior by manufacturing employees at the IADC. The graph that showed the amount of Energy Citizens in the IADC can be seen in Figure 17 (circle 1).
Figure 17: Team Works dashboard that allowed employees to see how many of their coworkers had become Energy Citizens. This dashboard was used to help create a social norm in the facility.

While the Who is and Who is Not an Energy Citizen Dashboard displayed in Figure 16 was its own separate dashboard (i.e. employees would have to take the initiative to go to the launch pad and open it themselves), we decided to put the plant wide graph shown in Figure 17 within an existing dashboard. More specifically, we placed this graph in the Team Works dashboard, the most frequently and widely used VBS dashboard by manufacturing employees in the plant. We hoped by placing this dashboard in a high traffic location it would be more likely that an employee would look at it.

Additionally, on the right side of the graph there is a thermometer graphic (circle 2) that shows what percentage of their cell is an Energy Citizen. Finally, to make it easy for an employee to conform to this social norm, we added a button on the top right of the dashboard next to each employee’s login ID (circle 3) that said “Become an Energy Citizen” if the employee viewing the dashboard was not yet an Energy Citizen. If this employee clicked on the button it automatically brings them to the online version
of Energy Quiz so they can quickly take the test and become an Energy Citizen. If the employee was already an Energy Citizen, then the button just read “Energy Citizen” next to the employees login ID.

**Results**

We decided the best way to perform this experiment would be to implement these two methods, the traditional engagement campaign and the peer-to-peer engagement campaign consecutively rather than at the same time. If we implemented both methods at the same time it would be difficult to attribute the increase in the amount of Energy Citizens from one method versus the other. It is also worth noting that the method implemented second should, theoretically, have a more challenging task because the employees that require less convincing would have been converted to Energy Citizens already. Thus, we decided to conduct the traditional energy engagement campaign from June through August and then conduct the Peer-to-Peer method from September through November. The results of these two methods can be seen in Figure 18.

![Figure 18](image-url)

*Figure 18: The effectiveness of increasing the amount of Energy Citizens using a traditional engagement campaign versus a peer-to-peer campaign that utilized social norms.*
During its three month implementation, the traditional energy engagement campaign increased the amount of manufacturing employees who were Energy Citizens from 38% to 42%, an overall increase of 4%. The Peer-to-Peer method increased the number of Energy Citizens from 42% to 78%, an overall increase of 36%. Thus, it is quite clear that the Peer-to-Peer method was more effective in increasing the amount of Energy Citizens.

### 3.2.3 Key Takeaways

Motivating employees to become engaged in energy saving activities can seem to be a nebulous and unscientific task. However, following a few simple guidelines can drastically improve a program’s likelihood for success.

As with any change management program in an organization, having senior level buy-in is a prerequisite. This is not only true for engaging employees to become more energy efficient but also true for more traditional manufacturing initiatives such as quality, safety, even lean. The next logical step after getting senior level buy-in is raising awareness and engaging employees in the energy reduction initiative. As demonstrated in the case study at the IADC, traditional awareness and engagement techniques are not sufficient to create significant behavior changes.

Aligning with psychology research on behavior change, it was the Peer-to-Peer approach that produced significant increases in the number of employees engaged in IADC’s Energy Citizen Program. A key attribute of this peer level approach is that it relies heavily on personal contact between peers to help create awareness and engagement amongst employees. As the number of employees who are engaged (in the IADC’s case, the number of Energy Citizens) started to reach a critical mass, a social norm was created in which becoming an Energy Citizen became the accepted behavior. Once the social norm was in place minimal effort is needed by management, instead the ownership and effort is distributed throughout the facility, most importantly, to frontline workers who influence their peers.

While the case study centered on increasing the amount of Energy Citizens, which really just meant we increased the amount of employees who took and passed a short Energy Citizen Quiz, it represents an important first step in engaging manufacturing employees in energy reduction efforts. This initial engagement will be leveraged in the improvement stage, in which we attempt to get employees to develop energy saving improvements in their areas. While it is not necessary to have all employees engaged or become Energy Citizens before moving to the improvement stage, the awareness and social
norms that were developed in the Engagement stage provide an important foundation which can be built upon and expanded in the next stage of our new approach.

### 3.3 Improvement Stage

#### 3.3.1 General Approach

At its core, the improvement stage is about trying to get employees on the manufacturing floor to identify and implement energy saving improvements for their specific areas. Obviously this is not a new idea; it is a core philosophy of the Toyota Production System. However, many facilities have been unable to fully utilize their employees' knowledge and problem solving potential to eliminate wasted energy. While the reasons for this underperformance may vary slightly from facility to facility there are two important features that the majority of energy management programs do not include when they try to elicit energy saving improvements from their employees. First, they do not make reducing energy usage a social norm (i.e. the engage stage was not executed properly). Second, they did not integrate energy reduction with their existing operations improvement program. While there are many variations of operations improvement programs none have the intrinsic characteristics needed to help a manufacturing facility get their employees involved in identifying and implementing energy saving improvements like a robust lean program.

One reason why lean is ideal for an energy reduction program is that lean programs are already seen as critical to the success of an organization by senior managers. This significantly lowers the organizational hurdle of gaining management buy-in for a “new” energy reduction initiative. In essence, the energy reduction program can “ride the coattails of lean activity”.

Another key feature of lean that makes it a great vehicle to launch an energy program is its emphasis on identifying and eliminating waste. As discussed in the Background chapter, waste is defined as anything that does not directly add value to the product. Generally, there are eight forms of waste, and while these forms of waste focus on more traditional manufacturing wastes such as defective parts, waiting, motion, the lean mental model translates well for energy reduction. Any energy that is not directly adding value to a product is a form of waste, and it must be identified and eliminated.

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70 (Spear & Bowen, 1999)
71 (EPA)
Once, energy is declared an unwanted waste, employees can use the proven lean approaches and tools they are already familiar with, such as standard work, visual indicators, mistake proofing, and others to attack and eliminate energy waste. In addition, many lean programs have an emphasis on small, non-capital intensive solutions for eliminating waste on the plant floor. This dovetails well with a behavior based approach to energy reduction. For example, the IADC’s lean program stresses the philosophy that “one million one dollar ideas are better than the one million dollar idea.” Put in energy reduction terms, the IADC would rather save energy by implementing a million small energy improvements rather than buying a new one million dollar energy efficient chiller.

Finally, as mentioned earlier, the Toyota Production System’s principle of including frontline employees in developing and implementing improvements is an attribute of lean that is necessary for any behavioral based energy reduction program. Table 8 summarized why integrating energy reduction with an existing lean program should be the general approach for any manufacturing facility in the improvement stage. In the following case study we will implement this approach at Raytheon’s IADC manufacturing facility.

<table>
<thead>
<tr>
<th>Reason</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Lean is already seen as critical to the success of a plant by most plant managers, thus, initial buy-in should be easier than trying to create a “new” energy improvement separate from lean</td>
<td></td>
</tr>
<tr>
<td>2. Lean’s emphasis on identifying and eliminating waste translates well for energy; any energy that is not directly adding value to a product should be identified and eliminated</td>
<td></td>
</tr>
<tr>
<td>3. Once energy waste is identified, employees can use proven lean tools to eliminate the energy waste</td>
<td></td>
</tr>
<tr>
<td>4. Inclusion of frontline employees is essential as they are traditionally the ones operating the equipment on the manufacturing floor that is consuming the energy</td>
<td></td>
</tr>
</tbody>
</table>

*Table 8: Reasons why energy reduction programs should be integrated in an existing lean program to properly execute the Improvement stage*
3.3.2 Case Study

**Goal**

Over a three month time period, September through November, we attempted to significantly increase the number of employee generated energy saving improvements that were implemented at Raytheon’s IADC facility. Fortunately, the IADC already had a vibrant and robust lean program in place before this case study began. For example, from January through August, IADC manufacturing employees generated and implemented over 600 improvements to their areas. However, nearly all of these improvements focused on more traditional forms of manufacturing waste, such as defects, motion, waiting, or inventory and only two of these improvements were explicitly energy improvements.

**Specific Approach**

Creating a pull for improvements

A common mistake for inexperienced lean programs is to simply implement common lean tools, such as mistake proofing or visual indicators, without creating a system that creates a “pull” for improvements. Rather than focusing on the lean tools, seasoned lean programs instead emphasize continuous improvement; encouraging their employees to develop improvements to their jobs every day. Lean tools are simply aids to be used as needed. While ideally such a system would take the form of a social norm, i.e. developing improvements would be an implicit activity that employees perform continuously, due to the multiple demands and requests that are put on manufacturing employees the IADC uses a more explicit system that helps focus employees on developing improvements.

The system the IADC uses to create a continuous pull of improvements from the manufacturing floor is called the “Lean Challenge”. The Lean Challenge occurs four times a year, (typically aligning with the four seasons), and each manufacturing cell is their own team. Every three weeks each cell, or team, has to come up with at least one improvement for their area. The improvement can help eliminate any of the eight forms of waste, though often times the Operational Excellence Resource Center (OERC), the department that facilitates the Lean Challenge, creates themes for each round of the games. For example, a round of games could have the theme of reducing motion, thus, encouraging every manufacturing cell in the facility to try and implement improvements that help their cell eliminate unneeded motion.

72 Originally each cell had to come up with an improvement for the Lean Challenge every two weeks, however, this was becoming overly burdensome on the teams so the OERC lengthen the time between games to three weeks.
At the end of this three week cycle each team creates a kaizen plaque as shown in Figure 19. This kaizen plaque simply states what the problem was, what was the team’s solution and what was the result of the solution (i.e. how much time, material, money, etc., was saved due to their improvement).

Originally, this plaque only gave manufacturing cells credit for traditional manufacturing results (i.e. time savings, floor space reduction, etc), however, after discussion with the OERC, energy improvements were added to the plaque.

Another key feature of the Lean Challenge is that each manufacturing cell does not just fill out the Kaizen plaque and submit it to the OERC. Instead, each team meets at the facility’s dining center at designated times (cells are staggered over the three week cycle to prevent the entire plant from shutting down) and the teams present their plaques to each other. Not only does this instill pride in their improvements (the teams get extra points if they have a union employee present), but it also helps foster idea sharing between teams.

Typically, three manufacturing teams are booked for 30 minute time slots and spend fifteen minutes presenting to each other on their improvements. During the remaining fifteen minutes the teams play...
some sort of game, ranging from beanbag toss to Wii Bowling. One of the reasons for playing the game afterwards is help get represented employees to participate in the Lean Challenge (it is completely voluntary for the employees to come to the presentations, they also give anyone who comes a $1 token to use at the dining center) but a secondary reason is to facility camaraderie amongst team members. Even employees who originally thought playing these games were a waste of time admitted they saw value in the games after they participated in the Fall 2009 Lean Challenge.  

Each cell’s Kaizen plaque gets reviewed and scored. Figure 20 shows the scoring sheet used for the plaques. Again, originally cells did not get any points for any energy reduction related activity (i.e. for the number of Energy Citizens in their cell or the number of energy saving improvements they implemented), however, for the Fall 2009 Lean Challenge, the OERC included energy reduction related metrics.

![Figure 20: Kaizen plaque scoring sheet for the fall 2009 Lean Challenge, which, for the first time, gave teams points for energy related activities](image)

74. (Raytheon Employee 2., 2009)
While traditional manufacturing metrics like floor space reduction or time savings get awarded points for the amount of floor space or time the specific improvement saves, it was decided that this would not be the appropriate scoring method for energy improvements. We thought asking employees to quantify their energy savings in kWhs or dollars saved would either force them to make large assumptions, thus discrediting the data, or would create an additional hurdle for implementing an energy improvement, i.e. it’s much easier to calculate floor space savings than energy savings, thus discouraging employees from focusing on energy improvements. Therefore, we decided to give every energy saving improvement an equal point value, whether it had the potential of saving $10 or $10,000 per year. Additionally, we thought this would further promote the “million one dollar ideas” philosophy already embedded in the facility.

The score from the Kaizen plaque gets combined with the team’s score from the game they played at after the presentation, giving each manufacturing cell a score for every three week cycle. For the Fall Lean Challenge we conducted four cycles, or rounds, of these improvements (i.e. each cell had to make and present four kaizen plaques). All 72 manufacturing cells participated (these cells were spread across three shifts) and then a smaller subset of these teams continued playing in the playoffs. Ultimately, a manufacturing cell from each shift is deemed the winner of each season of Lean Challenge and large trophies are passed out at festive plant wide celebrations.

*Figure 21: IADC employees presenting and playing at a Lean Challenge event*
While this may seem like a complicated and time consuming process to create a “pull” of employee generated improvements, it is important to note that this facility has reduced their bottom line costs by 20% every year from 2005-2008. Senior leaders at the IADC claim the primary catalyst allowing the facility to achieve this remarkable feat is that their frontline employees are actively involved and empowered in developing improvements. The Lean Challenge is one of the facility’s primary mechanisms for achieving employee engagement in developing these manufacturing improvements.

Energy Brainstorming Sessions
Once the pull for manufacturing improvements was created, cells were encouraged to use the same lean tools they had been using for years to identify and eliminate energy waste. A sample of these tools can be seen in Table 9. However, in the early weeks of the Lean Challenge, aside from conducting energy audits, cells were experiencing difficulty applying traditional lean tools to reduce energy waste. Thus, we began offering energy brainstorming sessions for cells. Fortunately, we did not have to make this brainstorming sessions mandatory, the Lean Challenge gave manufacturing cells the need (or pull) to

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75 (Day, 2008)
come up with energy saving improvements, thus, the cells were incentivized to participate in energy brainstorming sessions.

<table>
<thead>
<tr>
<th>Common Lean Tool</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Indicators</td>
<td>Displays the performance of a process so that the status can be understood in a glance by all employees</td>
</tr>
<tr>
<td>Standard Work</td>
<td>Precise work instructions specifying the sequence of steps needed to complete a task</td>
</tr>
<tr>
<td>Right-sized equipment</td>
<td>The tool/equipment used is not over or undersized</td>
</tr>
<tr>
<td>Mistake-proofing</td>
<td>A device or procedure that prevents a defect from occurring</td>
</tr>
<tr>
<td>Audits</td>
<td>An evaluation of a process/cell to ensure it is complying with a determined set of criteria</td>
</tr>
<tr>
<td>Total Preventative</td>
<td>A series of methods and actions that are routinely completed to ensure that every piece of equipment in a production process is always ready to perform</td>
</tr>
</tbody>
</table>

Table 9: Common Lean tools used at the IADC.76

When a cell leader or employee requested a brainstorming session, we would assemble a team of 2-3 cross-functional employees to visit the cell. When possible our cross-functional team included an energy expert from facilities, a lean expert from the OERC and a cell leader or employee from a different cell, though, not all these roles were represented at each brainstorming session. Typically the cell leader would introduce our cross-functional team to their cell, in which we would give a high level overview of our tasks and how we intend to help, always stressing that we did not have any of the answers and were simply there to ask questions and facilitate discussion. Next we followed the value stream of the product through the cell; essentially walking the path the product would follow through the cell, from entry to exit. At each value added step of the production process, we would stop and discuss how energy is being used at that step with the employees who actual do the work.

In addition, while we followed the product’s value stream, we would reference a question list we generated beforehand. This question list had simple, thought provoking questions we could ask employees to help them identify where energy could be wasted or used in non-value ways. We also

76 (Womack & Jones, 2003)
brainstormed possible solutions to help reduce wasted energy, always including the employees in the process and never just listing of a bunch of actions they should take.

At the end of the brainstorming session the cross-functional group would compile all the notes and employee ideas (giving credit to the employee(s) who came up with specific ideas) and then email this list to the cell leader. The cell leader would then attack this list of ideas in their desired priority. We encouraged cell leaders to approach and include the employees listed with each idea when trying to implement the solution.

Finally, we would include an energy saving Excel spreadsheet with the email to the cell leader. This spreadsheet allowed the cell leader or represented employee to estimate the impact of their improvements, both in terms of kWhs, dollars and greenhouse gas emissions. A portable power meter was also made available for employees to measure the power usage of devices in their area, though, it was only able to be used with low voltage (110V) equipment.

<table>
<thead>
<tr>
<th>Energy Waste Calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power Usage of device (W)</strong></td>
</tr>
<tr>
<td><strong>Power Usage of device (kW)</strong></td>
</tr>
<tr>
<td><strong>Amount of time device is wasting power each day (hours)</strong></td>
</tr>
<tr>
<td><strong>Amount of energy wasted each day (kWh)</strong></td>
</tr>
<tr>
<td><strong>Number of work days per year</strong></td>
</tr>
<tr>
<td><strong>Amount of energy wasted annually (kWh)</strong></td>
</tr>
<tr>
<td><strong>Cost of 1 kWh of energy ($)</strong></td>
</tr>
<tr>
<td><strong>Amount of money wasted annually ($)</strong></td>
</tr>
<tr>
<td><strong>Amount of CO2e / kWh in Mass (CO2e tons)</strong></td>
</tr>
<tr>
<td><strong>Amount of emissions wasted annually (CO2e tons)</strong></td>
</tr>
<tr>
<td><strong>Amount of pounds in 1 tonne (lbs)</strong></td>
</tr>
<tr>
<td><strong>Amount of emissions waste annually (CO2e pounds)</strong></td>
</tr>
<tr>
<td><strong>Avg amount of CO2e emitted by a car annually (CO2e tons)</strong></td>
</tr>
<tr>
<td><strong>Amount of emissions wasted annually (car equivalents)</strong></td>
</tr>
</tbody>
</table>

Figure 23: Excel spreadsheet that calculated impact of energy saving improvements employees were generating. Employees simply inputted information in the yellow cells and the spreadsheet outputted information in the red cells. The grey cells were fixed conversion values.

Our cross-functional brainstorming team conducted approximately ten of these sessions with different cells. Most of the sessions generated great ideas, however, there were certainly some sessions that
were more difficult than others. Some of the difficulties were related to the equipment used by the cell. For example, a cell claimed that all their testing equipment could not be turned off at night because if it was they would have to spend the entire next day recalibrating it. The cross-functional team did not have any data to refute such specific claims, thus, ideas generated in some cells were less substantial than for others.

Difficulties also arose due to personnel issues. As stated previously, union employees are not required to participate in process improvement activities (though most do). Consequently, there were a few instances when employees bluntly stated their desire not to participate in energy brainstorming sessions. We bring this up not to disparage any IADC employees or managers, but rather to demonstrate that employee pushback and disinterest is natural with most new initiatives. Whenever, a difficult employee was encountered, we simply moved on to the next employee who often was more than willing to help.

If nothing else, these brainstorming sessions provided another reason to have an energy reduction discussion with employees. The more employees hear about and participate in such discussions, the more it becomes a social norm and part of the facility’s DNA.

Sharing Ideas
A final tool created to help employees develop energy saving improvements was a medium that allowed employees to share ideas across cells and departments. The Lean Challenge already fosters some sharing of ideas; however, it was done on a very micro scale (i.e. each cell only got to see two other improvements every three weeks). Thus, we felt it necessary to create a medium that would foster more idea sharing. This sharing of ideas is also encouraged with the scoring of the Kaizen plaques, if a team uses an idea from another cell, they get extra points (see Figure 20).

In order to more widely share the best and most interesting energy saving improvements with all employees we developed the Energy Exchange. Following the theme of building on existing infrastructure, we took the Energy Kaizen plaques that different cells had submitted and put them onto the communication tab of the Team Works VBS dashboard. As discussed in the Engagement section, the Team Works dashboard is the most widely used dashboard by representative employees, thus, we felt this was a great medium to promote the sharing of ideas. By simply clicking on the communication tab and selecting energy, all employees could cycle through a presentation of all the best and most interesting energy saving improvements that other cells had implemented. In addition to fostering
sharing, it created recognition for cells and employees that developed these solutions. We also displayed these kaizen plaques on TV monitors throughout the facility.

![Image of Energy Exchange dashboard]

**Figure 24:** The **Energy Exchange** in the Team Works dashboard provided a medium for employees to share and learn about energy saving improvements other cells had made.

**Results**

From September through November, over 60 employee generated energy saving improvements were implemented at the IADC. The number of energy improvements implemented is actually even higher, the 63 energy improvements being cited in Figure 25 represents only energy saving improvements that were documented through the Lean Challenge’s Kaizen plaques. In a separate tally done by the OERC, the number of energy improvements was 119. However, this number is not being used as the official result because, unlike the kaizen plaques, each improvement was not documented and thus could not be verified. Nonetheless, 63 employee generated energy improvements is a substantial increase from the 2 improvements from the first six months of 2009.
Figure 25: The number of employee generated energy saving improvements implemented at the IADC through the Lean Challenge

Three of the energy saving improvements that were generated and implemented by Raytheon manufacturing employees are outlined below. In the appendix are example improvements that cells made using each of the common lean tools discussed in Table 9. These examples are included to demonstrate how traditional lean tools were used to create practical energy saving improvements. However, it is important to reiterate, simply replicating the specific tools or improvements discussed will not lead to sustained energy reduction. Such an approach will lead to short-lived gains as employees will not feel ownership in the ideas nor will they learn the process of identifying and eliminating energy waste in the future. Instead, managers should first raise awareness on the importance of energy saving activities and then formally integrate energy reduction into the plant’s lean or operational improvement program. “Pushing” behavior change ideas onto the employees will not work, rather, managers need to create a “pull” for improvements from the manufacturing floor.
Visual Control Example

As defined in Table 9, visual controls involve the use of indicators that quickly communicate the status of a system or process to everyone involved. One cell in the IADC astutely realized the potential of using visual controls to help prevent ovens from being left powered on, when they should be turned off. As shown in the before image in Figure 26, for an employee to know if an oven was on when it should be off, they would have to walk to the front of the oven, turn to its side and read a display screen that was 1”x2”. This display screen did not even say on or off, instead, it displayed 212 or 87. The employee would have to know that 212 represented the oven’s “on” condition (i.e. 212°F) and that 87 represented the oven’s “off” condition.

![Before and After Images](image.png)

*Figure 26: Energy reduction improvement uses visual indicators*

Using previously learned insights from visual controls, this cell affixed green and red magnetic flags onto the oven. When the oven was on the employee using the oven put the green flag up in the air. When the oven was off the employee put the red flag in the air. Now, when any employee in the cell was leaving at the end of a shift they could quickly scan the area and if they saw a green flag up but knew there were not any parts being processed overnight they could quickly walk over to the oven, turn it off, put the green flag down and the red flag up.

This simple improvement helped prevent ovens in this cell from unnecessarily being left on all night. While this visual control will only help the IADC save approximately $10 per night per oven in energy efficiency.

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(Womack & Jones, 2003)
costs, it is a great example of the application of “a million one dollar ideas”. Also, considering the IADC facility has over 100 ovens, this idea could easily be shared and replicated throughout the facility.

Mistake-Proofing Example

Often referred to as poka-yoke, mistake-proofing involves setting up a process or piece of equipment in such a way that prevents defects from occurring. During a cell meeting a representative from the OERC was recognizing an employee in the cell who identified that the air pressure in the tools they were using was too high and this employee helped identify a regulator to better control the amount of compressed air used (this improvement is written up further in the appendix). The OERC representative was highlighting that this was a great improvement because not only help reduce the noise in the area, but also helped save energy by placing less of a demand on the facility’s air compressors.

After the meeting a different employee in the cell, an employee who typically did not participate in any of the lean improvement activities, raised his hand and said he did not realize that compressed air savings counted as energy savings. This employee works during second shift, when the manufacturing floor is much quieter, and he can hear compressed air leak from the air nozzles above his head.

Even though these air nozzles have couplings that are suppose to prevent air leaks, the air was still escaping, placing a non-value added demand on the facility’s air compressors, 24 hours a day, 365 days a year. About 6 inches before these couples each air nozzle has a manual shut off valve and the employee suggested that if we turn off the manual shut off valve it should prevent any air from getting to the couplings, thus preventing the unnecessary air leaks. We tried employee’s hypothesis, and it worked.

Therefore, this easy, no cost solution was implemented for all the unused air nozzles in the department, saving an estimate $38 per air nozzle annually. There were over twenty nozzles in this employee’s department alone and even more in the entire facility. Aside from illustrating how mistake-proofing can be applied to help reduce energy waste, this example also helped demonstrated how small ideas can spread and build upon each other in a manufacturing facility. This is what continuous improvement is all about.

Right Sized Equipment Example

While the goal of the case study at the IADC was to demonstrate that frontline employees, when properly engaged, can be effective in developing energy saving improvements, the focus on energy improvements quickly bleed into other environmental areas, which we highly encouraged. For example, one cell realized they could use the lean principle of right sized equipment (i.e. using the right size
equipment/tool for the right task) to help eliminate the amount of adhesive they had to discard at the end of every shift. The employees in this cell used 10cc syringes of adhesive for a window installation they conducted. A maximum of 3cc of adhesive was needed during any one shift but the adhesive, once opened, only had a shelf life of seven hours. Thus, 7cc or more of this adhesive was discarded at the end of almost every shift. The cell worked with the adhesive manufacturer to supply smaller quantities of this adhesive. The supplier complied with the request and now the cell will prevent discarding 7,800cc's of this adhesive while simultaneously saving the IADC $11,279 annually. Not only is this a great example of how simple, low cost improvements can help eliminate environmental wastes other than energy, but also highlights the potential to collaborate with suppliers to make small changes that can significant impacts.

3.3.3 Key Takeaways
Traditional energy reduction programs consist of energy experts, mostly in facilities departments, attempting to identify energy saving opportunities for nearly the entire facility. While this model works well for technology based energy reduction programs, it does not work well in behavior based programs.

Instead, if an energy reduction program hopes to engage manufacturing employees in creating energy saving improvements and foster energy saving behaviors from their employees, the program must create a “pull” for energy saving ideas. Integrating energy reduction with a plant’s existing lean program is a necessary first step in creating this pull for ideas. As the IADC case study illustrated, using novel approaches like the Lean Challenge is an effective way to create the necessary pull that unleashes the energy saving potential of frontline employees.

Once this pull for energy saving ideas is created, employees can apply the proven lean tools they have used on traditional forms of manufacturing waste to identify and eliminate energy waste. Though, through the implementation of the case study, it became apparent that initially many cells had difficulty using familiar lean tools to reduce a new form of waste. Thus, providing assistance through energy brainstorming events or creating a medium for the employees to share energy ideas is an essential feature of an energy reduction program in the Improvement stage.

Also worth noting is the difficulty of quantifying the actual amount of energy saved due to improvements and behavior changes. Thus, especially in the onset of an energy reduction program, it is more important to push for participation and celebrate all energy saving ideas, regardless of how much
money the idea will save the company in the short term. These smaller improvements will build momentum, spread throughout the facility and in aggregate and over time, will continuously improve the facility's operations. After the initial launch and the program matures, more effort should be placed on quantifying the impacts of specific improvements. Not only will this help employees prioritize their actions but through the process of quantifying improvements additional insights may be discovered. However, a central tenet in a behavior change program is that one should not discount the impact of many small improvements, in fact, sometimes a million one dollar ideas are more effective than one million dollar idea.

Finally, while this thesis is partial to the integration of energy reduction with a lean program, integrating with lean is not the only avenue to get frontline employees to implement energy saving ideas, especially if the facility does not already have a lean program in place. Instead, the company should attempt to use whatever process improvement infrastructure is already in place in the target facility.

However, as the case study demonstrated, integrating energy reduction with a lean program might be the most effective existing infrastructure to build upon. Not only do lean programs already have senior leader buy-in, but they provide an excellent mental model for the necessity and the process of eliminating energy waste.

3.4 Sustainment Stage

3.4.1 General Approach
The Sustainment stage of this energy reduction methodology involves developing a system to maintain the energy saving improvements that were achieved in the Engagement and Improvement stages. In order to maintain these changes, increased visibility must be provided to manufacturing employees and managers on the amount of energy being used, or in many cases wasted, in real-time. Providing this real-time feedback will help overcome one of the most significant challenges of energy reduction programs, specifically, that energy waste is a hidden waste. Unlike traditional forms of manufacturing wastes, like inventory and defective parts, an employee cannot see kilowatt-hours pile up next to a manufacturing cell. Thus, providing employees visibility to energy usage the same way they already have visibility to traditional manufacturing wastes will not only help with preventing the facility from falling back into old energy inefficient habits, but, will also make it easier for employees to identify additional
areas energy is being wasted, thus, increasing the likelihood of developing more energy saving improvements.

In addition to sustaining past energy saving improvements while also helping to create new improvements, providing real-time feedback on energy usage can create further energy efficient behavior changes amongst employees. There have been multiple experiments that have shown if residents are given real-time feedback on their household energy usage they will reduce their energy usage by 5-15%, simply through behavior changes. Similar experiments have been conducted on family housing units at military bases, in which residents do not pay for their electricity usage, and these residents also achieved similar results, experiencing over a 10% reduction in their electricity consumption.

While there have been multiple of these studies conducted in residential environments, we were unable to find any experiments done in a manufacturing environment. The closest industrial example found was a Baxter International facility in Spain that recorded their daily energy usage and used statistical process control (SPC) charts to identify when the facility’s energy usage rose above 15% of their average usage. When the facility went above this energy threshold, a kaizen event was conducted to identify its root cause. While this appears to be an effective way to manage peak loads, it is not nearly of the same granularity that residents received in the real-time feedback experiments (entire facility vs. individual home), and the reporting frequency was much longer (every day vs. every fifteen minutes). This lack of granularity in both the area being measured and the frequency of feedback do not engender the significant energy related behavior changes that created the impressive results in the residential experiments.

Therefore, in order to more closely replicate the experiments conducted in residential settings, this real-time feedback system should enable immediate energy reducing activity (i.e. should provide frequent energy information in which an employee can act on immediately, not the next day). During the Sustainment case study we created a system for the IADC to be the first facility to replicate the granularity of the experiments conducted in residential environments. Specifically, we designed and built a system that gives a manufacturing cell real-time feedback on their energy usage.

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78 (Darby, 2006)
79 (Eggick, 2007)
80 (EPA)
81 (Eggick, 2007)
3.4.2 Case Study

**Goal**
This case study was conducted to determine if providing visibility on a cell’s energy usage would help sustain the energy saving improvements that resulted from previous improvements while also making it easier for employees to identify and implement new energy saving improvements. A second objective of the experiment was to determine if providing real-time feedback on a manufacturing cell’s energy usage would cause a similar reduction in energy usage as was experienced in residential settings, specifically, a 5-15% reduction.

After speaking with multiple power meter providers and performing a literature review, it was determined that there are not any existing systems or any facilities that provided manufacturing employees with real-time feedback on their energy usage. Thus, a team from Raytheon’s Virtual Business System (VBS) had to design and build the software system in-house to provide this level of real-time feedback. In parallel we also installed and troubleshooted all the off-the-shelf hardware used to provide this real-time feedback.

At the time of this thesis writing, the necessary hardware is installed, the software built and the pilot ready to be conducted. However, due to time constraints, it was not possible to properly conduct the pilot and measure its effectiveness. Fortunately, a follow on internship by Leo Espindle, Leaders for Global Operations Fellow Class of 2011, will conduct this pilot during the spring of 2010. Therefore, instead of having quantifiable findings for the Sustain stage, during this case study we will discuss the tools used to build the system, from both a hardware and software perspective. In the results section we explore examples of the system’s functionality and the expected usefulness to manufacturing employees.

**Specific Approach**
In order to minimize expenses in the cost of meters as well as the internal installation costs, it was decided to build a real-time feedback system for only one manufacturing cell. After reviewing manufacturing cells throughout the IADC, a cell in the Magnetics Oil Room (Mags) was selected for the pilot. This cell was selected because it was relatively easy to meter (only three additional meters would need to be purchased and installed), the cell is a fairly large energy user (average load was estimated to
be 45 kW, the equivalent of the energy usage of approximately 25 homes), and the employees were interested in participating.

This Mags cell consisted of an array of seven ovens. Each oven, as shown in Figure 27, was approximate six feet tall, four feet wide and eight feet deep. The ovens had three distinct electrical power draws; heating elements, vacuum pumps, and auxiliary electronics. The heating elements only consumed power when an employee in the cell set them to a certain temperature. The vacuum pumps and auxiliary electronics were left running continuously. The mechanics assigned to this cell claimed that the pumps should not be turned off because the pumps have problems starting after shutdowns. Thus, the only power draw the employees operating these ovens currently have control over is whether the heating element is being used.

*Figure 27: One of the seven ovens in the Mags manufacturing cell*
Nonetheless, these ovens consume 14 kW when the heating element is engaged and 3 kW when just the vacuum pumps and auxiliaries are on. On average, two or three ovens are used during any one shift, though, there are certainly times when all seven or none of the ovens are being used to heat product. The processing instructions for the parts that are processed in these ovens vary substantially. Some parts just need to be placed in the oven for a set amount of time (this process is called a “bake”), while other parts needed to be placed in a tank of oil within the oven and cannot come out until a certain minimum vacuum pressure is achieved and a specific time threshold is surpassed (this is called a “vacuum bake”). Therefore, helping to reduce the amount of energy wasted due to over-processing (i.e. leaving the part in the oven longer than its minimum requirement) is not always as straightforward as just setting a timer for each product (though, it is worth noting that all seven ovens had mechanical timers added to them in the early 2000s, however, none of the employees use these timers, a great example of a technology solution implementation that never got employee engagement). Currently there are two represented employees that are assigned to these ovens and a third represented employee that occasionally uses these ovens for different test procedures.
In order to allow for the quick integration with the existing metering and energy management system used at the IADC, Enercept power meters from Schneider Electric were selected to be used in our case study. Essentially all the power meters currently installed at the IADC, as well as the energy management software package used, are Schneider Electric products. Thus, just about any Schneider Electric power meter would have integrated into the existing IADC system, however, the Enercept meter provided the data we needed (real energy and power) at the lowest hardware cost. Additionally, the Enercept meters have the lowest install cost. Their split core design, shown in Figure 29 and Figure 30, allow electricians to wrap the meter around the three phases of current without having to do any rewiring.

![Image of Schneider Electric Enercept Meter](Figure 29: Schneider Electric Enercept Meter used to record power used by Mags ovens)

![Image of Enercept meter installed in an electrical panel](Figure 30: Enercept meter installed in an electrical panel)

Essentially, an Enercept meter is a sophisticated current transformer (CT) that measures the magnetic field around the three phases of current. It uses the strength of the magnetic field to calculate the current being used. The Enercept meter also taps into the voltage of the oven. The meter then multiplies the current and voltage and a designated power factor to calculate the power an oven is using at any given time. Another convenient feature of the Enercept is that the actual meter and the communication device are located in the split-core CT casing. Unlike most power meters, in which the meter is actually separate from the CT, this prevents the need to mount the meter within an already crowded electrical cabinet, making an Enercept a good choice for retrofit applications.
Figure 31: A current transformer such as an Enercept Meter measures the magnetic flux around an active wire to determine the amount of current being used.\textsuperscript{82}

Figure 32 demonstrates how only three Enercept meters needed to be added to measure the power usage of all seven ovens. As can be seen, these seven ovens use a mix of 575V, 480V and 208V fed from a variety of sources. Fortunately, power being used by 575V equipment in this substation was already being measured by an existing meter, thus, it was determined that we could utilize the data from this meter for our real-time feedback system (there were a few other pieces of equipment in the Magnetics area that also ran on 575V power, however, the majority of these pieces of equipment were used infrequently so it would not significantly affect our pilot). Also auspiciously, the 208V that fed Ovens F, E, D, C, and B were all fed from the same electrical panel (Panel 245) and this panel did not feed any other equipment in the area. Therefore, rather than having to meter each oven separately, we could just meter Panel 245 and combine it with the power data from the 575V meter, providing the power usage of the first five ovens.

\textsuperscript{82} (NK Technologies)
Finally, for Ovens A and G, we had to install meters directly onto the ovens. Aside from installing the three Enercept meters, we had to run a communication line from the meters to a communication gateway so the data could be sent to the Schneider electric’s energy database (the database is called Power Logic). Overall, each Enercept meter took one electrician between 60-90 minutes to install, while running the communication line took two electricians over an entire day (one of the reasons the communication line took so long was it had to be run along the ceiling lights in order to maintain a safe and clean work environment in the Mags area).

From a systems level, the real-time feedback system works as follows. As seen in Figure 33, the employees in Mags have control of when the ovens, specifically the heating elements, are turned on and off. The Enercept meters record the oven’s power usage and send the data to a communication gateway (Schneider Electric’s EGX200). This communication Gateway essentially acts as a static IP address and gets pinged for data at a certain time interval (our system is set for every 15 minutes but can be set for a near instantaneous data recovery if desired). This power data gets stored in the SMS SQL database, which is a SQL database owned and operated by Schneider Electric. This database stores the electrical
data and when a user logs onto the ION EEM web portal (also owned and operated by Schneider Electric) the user can access the data and generate a variety of charts and tables using the data stored in the SMS SQL database.

Unfortunately, there are two inherent problems with the current state of the system. First, the manufacturing employees who actually determine when the ovens are on or off, do not have access to the internet to view this web portal. Second, and more importantly, while the ION EEM software makes excellent charts and tables to be looked at by a facilities manager, they are not easily understood or actionable for a manufacturing employee. Therefore, even if a manufacturing employee did have access to this web portal, it would do very little to change their behavior.

Therefore, with the help of a John Day, the founder of VBS, we created our own IADC SQL database to store our facility's energy data. Then we made easy to read and actionable dashboards that can be put directly in front of manufacturing employees. To do this, we used the existing VBS platform and interface that employees are already comfortable using. Also, by using the VBS in-house system we can...
integrate data from other production software systems within the IADC and combine it with energy usage data. For example, we now had the capability of displaying energy usage and production quantities into a single dashboard for employees. Essentially we closed the loop of the system, giving real-time energy usage data to the frontline employees who actually use the energy.

**Results**

As discussed in the background section, there are already 200 meters in place through the IADC that have been recording energy data for over the past two years. Therefore, while we were installing the hardware for the Mags' pilot we were also able to build a proof-of-concept software prototype using existing meters. Rather than building our proof-of-concept for the entire facility's energy usage, we decided to go a layer of granularity deeper to the substation level. As described in the background section, there are 10 substations located throughout the facility. Unfortunately these substations do not align with specific departments or cells, instead, they just represent different geographic areas of the plant. Nonetheless, it was decided that substations would make a good proof-of-concept because the complexity was equivalent to what would be needed to be built for the Mags pilot (having to add and subtract data from multiple meters every 15 minutes) while also providing employees with a new level of visibility and granularity to their energy usage.

This proof-of-concept was built using the common structure of a VBS dashboard. First data gets deposited and stored into the IADC SQL database. The actual dashboard is built in a National Instruments program called LabView. These dashboards are composed of essentially two parts, the user interface and the block diagram. The block diagram is where the actual programming code is developed and calculations are performed while the user interface is simply an interface in which the user inputs information and views data the Labview program outputs.

The substation proof-of-concept dashboard can be seen in Figure 34. The user simply selects which substation (or zone) they are interested in from the dropdown menu and then a plot appears in the graph area. The solid blue line is the median power usage of the selected substation from 2008. This median power usage line was developed by taking all the power data from 2008, separating workdays (weekdays) from non-workdays (weekends and holidays) and then determining the median power measure for each hour of the day (i.e. 1 AM, 2 AM, etc). The two offset light blue dotted lines are the 25th and 75th percentile power measurements using the same 2008 power dataset for this substation. Finally, the dark purple line is the actual power usage of this substation plotted in real-time, every 15 minutes.
We chose this format for displaying the data for multiple reasons. First, there is evidence that displaying data in relative terms rather than absolute terms is more effective in motivating and creating change.\(^{83}\) In addition, since manufacturing employees are often busy with multiple tasks, this dashboard format allows them to almost instantly know if their area is using more energy than normal (i.e. is the purple line above the blue line). Furthermore, the 25\(^{th}\) and 75\(^{th}\) percentile lines give the employee some perspective, at least in terms of magnitude, on how much extra energy they are using (or hopefully saving) at any given time. Finally, this format replicates a common manufacturing technique for identifying defects, namely, statistical process control (SPCs) charts.

\(^{83}\)(Eggick, 2007)
However, after discussions with employees at the IADC, it was decided that additional functionality needed to be added to this proof-of-concept. On the right of the graph there is the “Today’s Scorecard” table. This table displays how much energy this substation has saved or overused thus far today compared to a normal production day in 2008. The first row is simply the deviation of kilowatt-hours that this substation has used. The next row displays the amount of extra money saved/spent on energy so far during this day compared to a normal production day in 2008. The following two rows show the carbon dioxide equivalents this extra energy emitted, both in pounds and car equivalents. If the data is highlighted in red, this means the substation has used more energy today than an average production day in 2008. If it’s green, then the substation is saving energy today. Therefore, the substation being displayed in Figure 34 has used 141 kilowatt-hours of electricity more today than a median day in 2008. This equates to an extra $18 spent on energy and an extra 180 pounds of CO2e, or the equivalent of having an extra six cars on the road today. These calculations are performed instantly by LabView.

At the bottom right of the dashboard is the “Monthly Scorecard” which helps to highlight trends in the substations energy usage. The units of the x axis are days and the units of the y axis are the deviations of dollars save/spent on energy versus the 2008 median. Each column represents one day’s energy deviation. If it is negative and green, that means that substation saved money that day. If it is positive and red, that means they spent more energy than they did on a typical day in 2008. In addition to the column graph, we also included a quick data point that displays how much money this substation has saved/spent on energy over the last month.

A few more additional details regarding this dashboard, first, when opening up this dashboard and selecting a substation to view, it automatically defaults to showing the energy usage of that substation for the current day. However, by clicking the icon that lists the current date, a calendar will appear and allowing the selection of any date since the dashboard was created. Second, based on the date selected, the Labview Program automatically knows if the date is a weekday or a weekend, and will pull up the appropriate 2008 medium plot to compare the energy usage against (so a user will never be comparing the substation’s weekend energy usage to a weekday median energy plot). As one would surmise, the power profiles of the substations are quite different on weekdays and weekends.

This proof-of-concept dashboard provided an excellent demonstration showing the capability to build real-time feedback dashboards at the IADC while also incorporating new functionality and granularity to energy data. However, these dashboards could not be directly replicated for the manufacturing cell pilot in Mags because, unlike the substation meters that have been recording power data for years, the
power meters in Mags only started recording energy data in November. Thus, we did not have sufficient historical data to make the energy SPC chart like we did for the substations. Also, power profile in the Mags cell is not as smooth as in a substation. The energy usage in Mags can change dramatically because of a single event, such as an oven turning on, while the substation’s power demand is the result of many discrete events occurring across many different cells, thus, more and less averaging out in the long run, creating a relatively smooth curve through the day. Therefore, a next generation dashboard needed to be produced.

This next generation dashboard to be used by the Mags pilot can be seen in Figure 35. After discussing with employees and potential users of this dashboard we tried to retain the features that were seen as most useful while also increasing functionality that helps employees reduce wasted energy. The largest item on the screen continues to be the real-time power plot. However, we shrunk the size of this plot to include space for a data table that shows what parts are being processed by which ovens.

![Figure 35: Proposed next generation real-time energy feedback dashboard for Mags cell.](image)
This data table replicates a dry erase board that employees in the Mag’s cell currently fill out. The main advantage of having employees fill out this digital table rather than the table on the dry erase board they currently fill out (the digital table and dry erase board are asking for essentially the same data) is that capturing this data and displaying directly beneath the energy usage plot, will allow employees to better correlate energy usage with product throughput. For example, if the power usage is high but there is only one oven actually processing parts, they will know something is wrong. A common error that could be avoided is heating elements that are mistakenly left on, but are not processing any parts. This can also help identify when ovens might need maintenance to help them run more efficiently.

Replicating this white board in a digital format has other advantages as well. For example, the current dry erase board system does not generate any formal documentation; the information is simply erased after the part is taken out. Also, the dry erase board is hidden off to the side of the ovens where no one walks; our dashboard will be prominently displayed for everyone to see. Finally, when employees enter a time for “Expected Time Out” on the digital dashboard, we can use VBS to send them alerts to let them know when this expected time is approaching.

Perhaps the most significant improvement for this Mags pilot dashboard was the inclusion of the Value Added versus Non-Valued Added Energy bar chart (top right of the dashboard). Based on discussions with employees, especially represented employees and cell leaders, labeling energy as value-added and non-value added resonates is an effective method to highlight wasted energy. One reason it especially resonates with manufacturing employees is because it uses a common lean framework that employees are used to, namely, separating work into value added and non-valued steps. Once something is identified as non-value added, employees can use their lean tools to reduce or eliminate it.

Unfortunately the Enercept power meters cannot distinguish if the power is being used for a value added activity and what power is being used for a non-value added activity. Therefore, we had to do some estimation and simple calculations to determine this breakdown.

The first bar chart represents all the energy used by the Mags’ ovens during the present day (calculated by multiplying the average power reading over a fifteen minute span by .25 hours). Next to calculate value added energy, specifically energy that is being used to produce sellable product, we simply take the average power demand for a part in an oven (approximately 14 kW) and multiple it by the amount of time the part was in an oven (for example, 10 hours). The time element of this calculation is driven by the employees’ inputting of the “Time In” and “Time Out” in the digital data table just discussed.
Specifically, when an employee places the part in the oven, it starts the clock; when they take the part out, the clock stops. Finally, non-value added energy, energy that is not being used to produce saleable product, is simply the total energy being used by all ovens minus the value added energy used across all the ovens.

While this is an indirect (relying on users to input data regarding when ovens are in use/not in use) and the average power usage of 14 kW is an estimate (actual power amount varies during a bake operation) it still provides useful and actionable data. Long-term, simple sensors can be placed on the oven that automatically record when an oven is on or off, making this a much more direct system. Additionally, as data is collected, a standard amount of energy used per part can be developed to better track how long parts are left in ovens or if an oven needs maintenance (for example if there is a leak in the door seal, etc).

Nonetheless, what the chart lacks in precision it makes up in clarity and usability. The amount of non-value added energy may not be exact but it highlights energy waste in a way all IADC employees can relate to, more specifically, they know having a large amount of non-value added anything (energy, time, motion), means there is room for improvement. Once employees see the large amount of non-value added energy, it will create a great opportunity (or pull) to talk with them about how to reduce this waste.

Finally, the daily and monthly scorecards were kept on the dashboard, however, modified slightly. Since we don’t have a deviation from a goal to calculate against (because of lack of historical data) we can calculate our daily/monthly scorecards in one of two ways; have this scorecard calculate the absolute electricity costs, CO2 emissions, etc. of their cell each day, or, have this scorecard calculate the non-value added electricity costs, CO2 emissions, etc of their cell each day.

The author believes the second option, using the non-value energy measurements is the better choice because there is psychological research that shows people are more likely to change their behavior when a resource is framed as being “wasted” than if that same resource is framed as being “saved” or if the absolute amount of a resource being used is shown.\textsuperscript{84} This bias must be even truer for any manager that has been exposed to Lean training. However, final details and modifications to this dashboard will be made by the Leo Espindle and John Day as they will be leading the real-time feedback effort in the

\textsuperscript{84} (Doug McKenzie-Mohr, 2008)
Mags’ cell. While the dashboard design displayed in Figure 35 provides a great foundation to begin the real-time feedback pilot, it is likely there will be further iterations as the pilot progresses.

3.4.3 Key Takeaways
Again, due to time constraints, this real-time feedback system and dashboard were not able to be piloted in the Mags area, however, the pilot is planned to begin in the spring of 2010. Nonetheless, there were many key takeaways from designing, building, installing and prototyping a real-time feedback system for a manufacturing environment.

Anecdotally and through discussions with employees, there appears to be value in providing employees with visibility to energy data. If the energy data can be presented in a common production or lean framework its message resonates even more with employees compared to simple charts showing absolute measurements. The substation proof-of-concept SPC chart provided useful relative measurements and comparisons for employees, however, requires large amounts of historical data to create. The Value Added versus Non-Value Added Energy bar chart also resonated with employees, though, some additional system design work needs to be completed to make value added energy measurement more of a direct measurement, rather than an indirect measurement relying on employee compliance. Despite these slight drawbacks, employees and manufacturing managers all expressed benefits in these systems, both in their ability to change employees behavior and to help the identify new energy saving improvements.

Unfortunately the hardware available for providing real-time feedback in a manufacturing facility, especially at the cell level, leaves much to be desired. Ideally, all manufacturing equipment sold in the future will have power meters built into them, continuously recording data that can be transmitted to a central energy management system, though this seems unlikely in the short term. Therefore, using meters to retrofit onto equipment and different applications will most likely be the solution used for companies attempting to get better granularity and visibility on how energy is being used on the plant floor. While the Enercept had some product features that made it useful for cell level real-time feedback, it was not ideal. Notably, the installation labor needed for wiring the communication line between each meter and the communication gateway was the most significant hardware related expense, thus, there seems to be a significant opportunity for wireless meters. Also, as the case in the Mags cell, when equipment is being fed from multiple panels and voltages it increases the hardware cost because multiple meters are needed to properly meter one piece of equipment.
After building and installing this prototype real-time feedback system, it is apparent that real-time feedback is still in its infancy in the manufacturing environment. Nonetheless, the pilot experiment in the Mags cell should provide useful insights, both on its effectiveness as well as possible design improvements. As real-time metering gains popularity in residential environments with companies like Google, Microsoft, Apple, Intel and General Electric all beginning to play in the home energy meter space, hopefully some of this technology can be modified to be used in manufacturing environments.\(^{85}\)

\(^{85}\) (La Monica, 2010)
3.5 Effectiveness of Conceptual Framework

3.5.1 Strengths
A key strength of the employee engagement energy reduction approach used at the IADC is that it is built heavily upon existing infrastructures. Perhaps the most important existing infrastructure we utilized was the IADC’s lean and continuous improvement program. By integrating with their lean program our energy reduction efforts quickly gained initial buy-in from senior leaders. Additionally, utilizing the lean problem solving skills of frontline manufacturing employees to help identify and implement improvements to reduce energy waste was much more effective than relying on a handful of facilities employees trying to implement improvements across the building’s entire manufacturing floor. Moreover, this inclusion of manufacturing employees in the idea generation process helps them have ownership in the energy saving improvements while also empowering them to develop more energy saving improvements in the future.

Aside from helping employees develop energy saving improvements, during the case study at Raytheon we attempted to utilize existing infrastructures to increase employee engagement by partnering with the Energy Citizen program. Finally, the use of the Virtual Business System to create a system that provides employees with real-time feedback helped overcome technical hurdles (such as needing IT to develop or learn an entirely new software system) and organizational obstacles (such as getting employees to use a new software system). While some of these existing infrastructures are specific to Raytheon, many companies have analogous programs which can be utilized to achieve energy reductions. Not only does using existing infrastructure help reduce cost and ramp up time, but, perhaps equally as important, it helps decrease the organizational complexity of trying to get an entire factory to get involved in an entirely new initiative or program. Often it is easier to simply expand an existing program than to create an entirely new one.

A second key strength of this new approach is that it creates a “pull” system for energy saving improvements and engagement. Rather than trying to force employees to be Energy Citizens it provided the visibility so that like-minded employees can partner together and create social norms around being an Energy Citizen, essentially using peer-pressure rather than relying on top-down pressure or altruism. Additionally, pull for ideas from the Lean Challenge helped focus an entire facility on creating new energy saving improvements. Due to this pull, the IADC implemented more employee generated energy saving ideas than ever before.
A final key strength of this new approach is the visibility it creates. Of course the real-time feedback system provides new visibility and granularity to energy usage on the plant floor, but the Engage-Improve-Sustain approach used in the case study also enabled visibility in other areas. For example, the visibility created by the Who Is and Who Is Not dashboard allowed for mass diffusion of the Energy Citizen program. Also, by placing energy saving kaizen plaques on the Energy Exchange provided new visibility on the different improvements cells were implementing; making idea sharing easier while also providing recognition and competition between cells. The more visibility on which employees and cells are engaging, improving and sustaining in energy saving activities, the better. As Lord Kelvin said “If you cannot measure it, you cannot improve it.”

3.5.2 Challenges
Perhaps the most difficult challenge of a behavior change based energy reduction program is that quantifying savings is not straightforward. The complexity of how energy is used in manufacturing plants forces employees to make assumptions (which are often difficult to validate) when determining how much energy is saved by any one improvement. Thus, attempting to quantify the savings from a behavior change program across an entire facility is near impossible. While installing additional metering can help provide some estimation of the savings, it is not always cost effective to do so. Fortunately, the IADC had already subscribed to the philosophy that a million one dollar ideas are better than one million dollar idea. The IADC knows from experience that quantifying small improvements made on the manufacturing floor is hard, but over time these improvements add up and can be seen in a plant’s income statement. The best proof of this philosophy is that the IADC reduced their bottom line costs by 20% every year for four years straight. Unfortunately, not all facilities will have leadership that buy into this model of continuous improvement thus implementing a behavior change approach can be difficult. Nonetheless, all energy saving improvements should be celebrated in the initial launch of a behavior change based energy reduction program; however, as the program matures more effort should be placed on quantifying the amount of energy each specific improvement yields.

Additionally, external factors, such as production quantities and product mix, make implementing this behavior change framework difficult when trying to reduce absolute energy usage. Unlike a residential environment in which a person can control what devices they use, a production employee often cannot. For example, a manufacturing cell may be doing a great job reducing their energy use Monday through

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86 (Day, 2008)  
87 (Day, 2008)
Thursday, however, if their cell needs to make a large order of very energy intensive product on Friday, this can make their energy usage for the week look high, thus negating all their energy efficiency efforts from the week.

3.5.3 Summary
Reexamining this new approach in Figure 36 demonstrates that it was effective in meeting its goals of helping the IADC reduce their energy usage through employee engagement and behavior changes. Through the use of social norms and peer-pressure, the percentage of Energy Citizens rose from 38% to 78%. Even though becoming an Energy Citizen is a small commitment, it represents an important first step in increasing awareness and engagement in the facility’s energy reduction program.

<table>
<thead>
<tr>
<th>Goal</th>
<th>Approach</th>
<th>Effect</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Get employees to</td>
<td>Create a peer-to-peer driven awareness campaign</td>
<td>Made being an Energy Citizen a social norm</td>
<td>&gt;75% of manufacturing employees became Energy Citizens</td>
</tr>
<tr>
<td>care about reducing their energy usage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Get employees to</td>
<td>Integrate energy reduction with lean program</td>
<td>Created a “pull” for energy saving improvements</td>
<td>&gt;60 energy saving improvements implemented</td>
</tr>
<tr>
<td>develop energy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>saving improvements</td>
<td>Create a peer-to-peer driven awareness campaign</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrate energy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>reduction with lean program</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sustain employee</td>
<td>Make energy waste a visible cost that can be</td>
<td>Transformed energy from a hidden waste to a visual waste</td>
<td>System designed and installed, ready to pilot during Spring 2010</td>
</tr>
<tr>
<td>improvements &amp;</td>
<td>measured</td>
<td></td>
<td></td>
</tr>
<tr>
<td>behavior changes</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 36: Review of behavior change based energy reduction approach used at the IADC*

Once the engagement foundation was built, the energy reduction program was integrated into the facility’s lean program. By leveraging the “pull” for ideas created by the Lean Challenge and encouraging employees to use well understood lean tools, the number of employee generated energy saving improvements increased from two during the first six months of the year to over 60 in a three month timeframe.
Finally, to sustain these improvements and behavior changes moving forward, a first of its kind real-time energy feedback system was built using the IADC’s Virtual Business System and using off-the-shelf Schneider Electric power meters. While this system did not get to be piloted due to time constraints, the system was built and installed, providing many key insights along the way. Through anecdotal examples and discussions with employees, this real-time feedback system appears to provide employees with a sufficient amount of data to sustain and foster energy saving behavior. The pilot of the IADC system in the spring of 2010 should provide useful insights to quantify the system’s effectiveness in sustaining past energy saving improvements while also helping to identify new improvements.

In addition to the individual results this new framework helped create, the IADC facility achieved impressive energy reduction metrics across the entire facility. Compared to 2008, in 2009 the facility increased their revenue from production by 5%, increased their headcount by 16%, however, kept their energy usage essentially flat (0.2% increase). While this year over year reduction certainly cannot be solely attributed to the framework we implemented, it did help the facility trend in the right direction.

As stated in the start of this case study chapter, even though the specific tools and approaches employed during the implementation of this new Engage-Improve-Sustain framework may not be transferable to all manufacturing facilities, the set of behaviors this framework creates and the key takeaways the case study identified are. Specifically, the need to integrate energy reduction programs with the existing infrastructure and initiatives that already work well in a manufacturing facility. The integration with a plant’s lean program appears to dovetail perfectly with a behavior change based approach to energy reduction. The thought process and set of behaviors a lean program promotes, such as identifying and eliminating waste at the lowest level of the organization, closest to where the work is being done, aligns well with attempts to reduce wasted energy through a behavior change based program. Most notably, the constant “pull” for continuous improvement and the inclusion of manufacturing employees in developing these improvements are essential elements that every energy reduction program will benefit from.
4. Conclusions

4.1 Hypothesis Review

In the Introduction chapter a theory was presented that stated manufacturing facilities should build upon established lean principles from the Toyota Production System and include a behavior change based approach, in addition to a technology change approach, as part of a comprehensive energy management program. Specifically, such a program should include three distinct steps that first, raise awareness and engage employees in the new energy reduction initiative, second, help manufacturing employees develop energy saving improvements for their specific areas, and lastly, create a system that ensure these improvements and behavior changes are sustained over time. Additionally, it was hypothesized that applying this new approach would lead to greater employee engagement, more energy saving improvements, and, ultimately, a reduction in wasted energy.

This new approach was implemented during a six month case study at Raytheon’s Integrated Air Defense Center (IADC) manufacturing facility in Andover, MA. The theoretical goals and specific actions taken while implementing this new approach at the IADC are summarized in Figure 36.

During the Engage phase the metric for increasing employee engagement was the percentage of manufacturing employees that became Energy Citizens. Through a peer-to-peer campaign, being an Energy Citizen became a social norm in the facility and the percentage of Energy Citizens increased from 42% to 78%.

The success of the second step of the hypothesis, the Improve phase, was quantified by the number of energy saving ideas that employees implemented. During a three month period employees implemented over 60 energy reduction improvements for their manufacturing areas compared to two employee generated energy saving improvements over the first six months of 2009. By creating a pull for these energy saving ideas and helping employees understand how they could use traditional lean tools to eliminate energy waste the number of energy saving ideas increased dramatically.

Finally, the last step of the newly proposed approach, the Sustain phase, discussed the need for a system that maintained accountability for these recently implemented energy saving improvements and behavior changes. Thus, a real-time feedback system was designed and installed that had capabilities of providing visibility of energy usage to employees on the manufacturing floor. Due to time constraints, a pilot was not performed during the six month implementation but from a conceptual level it is apparent
that providing such feedback on energy usage should only increasingly enable further energy saving improvements and behavior changes.

In addition, the IADC was able to meet its internal goal of using the same amount of energy in 2009 as it did in 2008. Specifically, the facility has a .02% increase in absolute energy usage despite a 5% increase in revenue and a 16% increase in employee headcount. While this impressive energy goal cannot be solely linked to the efforts and achievements of this new employee engagement approach, the author can without hesitation validate the hypothesis that employee engagement should be a part of an energy management program in a manufacturing facility and that, if implemented using the Engage-Improve-Sustain methodology, it will lead to increased employee engagement, increased number of energy improvements implemented and a reduction in energy waste.

4.2 Recommendations

Attempting to lead change in a manufacturing facility is hard, especially when it involves changing employee behavior. Since every facility and every company is different there is not a single formula for leading change in organizations, however, using proven frameworks can be a useful guide. Specifically, when attempting to lead a behavior change based energy reduction program in a manufacturing facility (or any work environment) there are some general principles that have proven useful.

A prerequisite of an energy reduction program is attaining senior leader buy-in. Endorsement from a senior leader gives the program credibility and this leader’s organizational influence can be used to overcome potential obstacles in the future. Often it is easiest to gain this high level support if the energy program aligns with a facility’s lean or process improvement program. Not only will following this approach help with securing senior leader support, but it will also allow for easier inclusion of manufacturing employees later in the process because most employees should already be familiar with such process improvement programs. Finally, attempts should be made to have a senior leader make a public energy related goal for the facility (such as reducing energy usage by 10% or implementing 100 energy saving improvements). Facility level goals help motivate and focus employee efforts around nascent programs.

Once senior leaders have made their support known for the energy reduction program, a team should be formed to help develop and implement a plan. This team should not consist exclusively of facilities or
EHS employees; rather, it should be an interdisciplinary team with employees representing different functions, groups, and locations within the workplace. Raytheon’s use of local Energy Champions is an effective model for creating structure to a new program. This newly formed team should develop strategies to help the facility reduce their energy usage using both behavior change and technology change based methods. For the behavior change based approach, the team should use the Engage-Improve-Sustain framework discussed in detail in this thesis.

In the Engage phase the goal is to raise awareness of the new energy reduction program. Raising awareness and engaging employees in energy saving activities can be a nebulous and, at least initially, frustrating task. However, as demonstrated in the case study at the IADC, traditional awareness and engagement techniques (such as creating posters and sending emails) are not effective ways to engage employees in a behavior change based reduction program. Instead the team should attempt to institute a Peer-to-Peer approach that relies heavily on personal contact between employees to help create awareness and engagement. Additionally, instead of simply trying to educate employees on the need for energy reduction, attempts should be made to get employees to make a small commitment regarding the program (for example, Raytheon had their employees take a short quiz on energy savings and once they passed they became an Energy Citizen).

Once a foundation is built in the Engage phase, in the Improve phase the leaders of this new energy program must attempt to work with manufacturing employees to help them identify and implement energy saving improvements on the manufacturing floor, where the energy is actually used. The most effective method to get manufacturing employees motivated to make such improvements is to integration the energy reduction program with facility’s lean and continuous improvement (or process improvement) program. Using this existing infrastructure is essential to a robust factory-wide rollout because the energy reduction program does not become just another initiative; rather, it is simply an extension of existing program. Furthermore, by integrating with an existing lean program employees already understand the main concepts (i.e. eliminate all non-value added work) and there is usually processes in place regarding identifying and implementing improvements that can be leveraged.

During the Improve phase, in addition to integrating with an existing lean program the leaders of the energy reduction program should attempt to create some form of “pull” for energy related improvements. Typically just asking employees is not sufficient. An example of a pull system for improvements could be found at Raytheon in their Lean Challenge, every three weeks each manufacturing cell had to come up with at least one improvement for their area. Once this pull for ideas
occurs, employees should be encouraged to apply their proven lean tools and skills to identify and eliminate energy waste. It is important to recognize that many employees will initially struggle in developing energy saving improvements past some of the more obvious actions such as turning off a computer monitor at night. Therefore, employees on the energy reduction team should help facilitate brainstorming sessions with different manufacturing cells or groups to help their fellow employees identify this relatively hidden waste.

Also, it is worth noting that quantifying the impact of energy saving impacts is difficult on a manufacturing floor because of the different types of equipment and voltages used. While installing power meters to record energy savings would be ideal, it is not necessary in the early stages of a new program. Instead, the team should celebrate every energy saving improvement, whether it will save one dollar or a million dollars, as a key component of this Improve phase is to make implementing energy saving improvements a social norm in the facility. To create this social norm requires lots of ideas being implemented and visible. As the energy program matures, more emphasis and priority can be placed in quantifying the impact of various improvements.

The final phase of this behavior change framework is the Sustain phase, in which the energy reduction team should be developing a system to give employees real-time feedback on their energy usage. The goal of this real-time feedback is to make wasted energy a visible waste, just like scrap parts or large amounts of inventory. While both the Engage and Improve phase can be completed within a calendar year, implementing and managing a real-time feedback energy system for the Sustain phase often takes more time.

This additional time is needed to purchase and install the metering hardware as well as develop the real-time feedback user interface. The user interface should display energy usage data in a manner that is easy to understand (an employee should know if they are using too much energy by looking at the display for just a few seconds) and be located in a high visibility place. Finally, the data should be presented so it motivates action. For example, at Raytheon’s IADC we found it most impactful to employees when energy usage was framed as value added versus non-value added. From their lean training employees knew they should eliminate all their non-value added energy usage.

Throughout the entire Engage-Improve-Sustain process a facility’s energy reduction team should continue to evaluate their progress and track key performance metrics such as the number of employees engaged in their reduction program, the number of energy saving improvements
implemented and of course the plant (and hopefully also at substation level) energy usage. The leaders of this energy program should also make it a priority to recognize individuals, both within and outside of their core team, who are exceeding expectations to help the program succeed and the facility reduce their energy usage. Finally, periodically the team should evaluate their goals and their plan to ensure there is alignment.

4.3 Potential Follow on Research

While this Engage-Improve-Sustain approach to reducing energy waste was successful at the IADC, there is certainly potential research that needs to be done to further hone and validate our findings. In the Engage phase, the social norms that were developed within the IADC should be attempted to be replicated in additional manufacturing facilities, as well as in more traditional office environments. In the Improve phase, the concept of continuous improvement must remain the central theme of this phase as it creates the foundation for this new approach. However, attempts should be made to build upon smaller, one dollar ideas, and integrate energy saving activity into more advanced lean tools and methodologies. Specifically, conducting energy kaizen events or including energy in value stream mapping exercises seems like an obvious next step, as long as frontline employees are actively involved.

The implementation of the real-time feedback pilot system is a necessary next step to validate that making energy a visible cost will ultimately sustain improvements and employee behavior changes over the long run. In addition, now that a proof-of-concept system is in place in the Mags cell, similar experiments should be replicated at the IADC and other facilities. Experiments on the manufacturing floor and in non-manufacturing environments, such as labs or offices, should be explored. Again, over the past few years there have been studies showing that giving people real-time feedback on their household energy usage will reduce their energy usage by 5-15%. These follow on experiments will be the first attempts to replicate these experiments in a manufacturing environment. If they yield a similar reduction in usage, not only will it create an entirely new way for manufacturing companies to reduce their energy costs, but, will also create a new market for manufacturing specific meters and feedback systems.

Finally, the author hopes other manufacturing facilities will attempt to use this entire Engage-Improve-Sustain approach in their facilities. Some energy management programs may omit different aspects of this approach, for example, trying to integrate energy reduction in their lean program without spending an adequate amount of time making energy reduction a social norm within their workforce. While this
may yield positive results for a facility, the author feels these results are not as sustainable as the comprehensive approach detailed in this thesis. Based on the results from the IADC case study, the whole is greater than the sum of the parts and the more facilities that implement, build upon and hone this approach, the more effective it will become.
5. Bibliography


6. Appendix I – 2009 Energy Citizen Quiz

Name:______________________ Clock #:______________________

WORK QUESTIONS

1. To save resources, I have used Sametime or Teleconferencing to conduct meetings instead of traveling.  
   Tip: Using Sametime or Teleconferencing not only saves energy, but travel costs as well.
   YES ___  NO ___  N/A ___

2. I have set a good example for others by turning off unnecessary plug loads.  
   Tip: Plug loads are any devices that plug into or are wired into a building’s electrical system and can be controlled by employees. Examples are machine tools, test equipment, test chambers, ovens, and office equipment such as PC’s, fax machines, computers, printers and copiers.
   YES ___  NO ___

3. I car pool, van pool, walk, bicycle, take public transportation, telecommute or live less than 20 miles from work.  
   Tip: Car pooling, van pooling, walking, bicycling or taking public transportation to work saves on fuel costs and helps reduce air pollution and consumption of non-renewable energy sources.
   YES ___  NO ___

4. I took the 2008 Energy Citizen Quiz? (select N/A if you are a new hire in 2009)
   YES ___  NO ___  N/A ___

5. I use a network printer or multi-function device instead of a desktop printer?  
   Tip: Using a network printer or multi-function device instead of a desktop printer is a more energy/cost-efficient solution than using a desktop printer. Idle laser printer type devices continue to use electricity even when they are in “Energy Savings” or “Sleep” mode.
   YES ___  NO ___  N/A ___

6. I am an “Energy Champion” in my work area.  
   Tip: It is good to volunteer as an “Energy Champion” at your office location. Energy Champions embrace the energy conservation culture and work with their peers and energy teams to conserve energy at work. To become an Energy Champion you may contact an Enterprise Energy Team Member in your Business Unit.
   YES ___  NO ___
HOME QUESTIONS

1. I use reusable bags when I go shopping? *Tip: Reusable shopping bags made of materials that don’t harm the environment are a better option than paper or plastic.*
   
   YES ___  NO ___

2. I turn off televisions, stereos, DVD’s, VCR’s, computers, etc. when not in use. *Tip: Turning off unnecessary appliances or equipment helps reduce energy and cost. Equipment not in use is a complete waste of energy and result in costly utility bills.*
   
   YES ___  NO ___

3. My home has a programmable thermostat and/or I set back my temperatures when at work and/or at night. *Tip: You can set back temperatures in your home while at work and/or at night with a programmable thermostat. You can also save up to $100 per year by purchasing a programmable thermostat. Plus you may qualify for a utility company rebate.*
   
   YES ___  NO ___

4. I fully load my dishwasher and washing machine before using.
   - Consider air-drying clothes on clothes lines or drying racks. Air-drying is recommended by clothing manufacturers for some fabrics.
   
   YES ___  NO ___

5. I teach my family and/or friends that saving energy is the right thing to do. *Tip: Set good examples for others by turning off any “plug load” not in use. Encourage others to conserve energy.*
   
   YES ___  NO ___

6. I use natural light and turn off the lights whenever possible. *Tip: Turn off unnecessary overhead lighting and use task or desktop lamps instead. Replace all incandescent light bulbs with compact fluorescent lights (CFLs) to save up to 75% on energy costs.*
   
   YES ___  NO ___

7. I drive a hybrid, electric, or fuel efficient vehicle with an average EPA Fuel Economy rating of greater than 25 mpg (or 11 km/L). *Tip: Vehicles that meet the EPA’s Fuel Economy rating of greater than 25mpg can save you anywhere from $200 - $1500 in fuel cost.*
   
   YES ___  NO ___  N/A ___

8. I have completed the 2009 Change the World, Start with ENERGY STAR® Pledge?
   *Popup: The Change the World campaign is a national challenge to encourage Americans to change the world. Take your pledge today.*


   YES ___  NO ___
7. Appendix II – Examples of Lean Tools

In the Improvement section of Chapter 3, three energy saving improvements that were implemented by Raytheon manufacturing employees were described. Below are additional examples of energy saving improvements that employees identified and implemented using each of the common lean tools discussed Table 9 as well as a contrasting technology change improvement. These additional examples are included to further demonstrate how traditional lean tools can be used in a behavior change based energy reduction program. However, it is important to reiterate that simply replicating the specific improvements outlined below will not lead to sustained energy reduction in a manufacturing facility. Instead, such an approach will lead to short-lived gains as employees will not feel ownership in the ideas nor will they learn the process of identifying and eliminating energy waste in the future. Instead, managers should first raise awareness on the importance of energy saving activities and then formally integrate energy reduction into the plant’s lean or operational improvement program. Raytheon’s IADC facility used its Lean Challenge to create a pull for these improvements, therefore, all the examples below are framed in the Kaizen Plaque format that employees used to present and share their improvements. Note, many of the before and after images were removed due to security and propriety concerns. The name of each cell, value stream and employees were also removed.

**Visual Indicator**

![Visual Indicator Example Kaizen Plaque](image-url)

**Problem Description:**
Operators were unsure if they should power down the equipment in their cell in fear that if they did the equipment would not start up properly the next day/shift.

**Solution Details:**
Walked around cell with maintenance and inging engineers and labeled machines. The three different labels let employees easily understand if the equipment should:
- Always powered down at the end of the shift
- Only powered down for weekends
- Never powered down

Even though it was determined some pieces of equipment in the cell needed to be left on continuously, these labels eliminated the ambiguity of which machines this applied to, allowing employees to shut off all other equipment.

**Results of this Kaizen Improvement:**
Energy Improvements?: 3 pieces equipment labeled to allow for daily power downs

**Team Members:**
Mistake Proofing

Mistake Proof Example

Problem Description:
On average, when an oven in CCA is left on, it uses 8 kW of electricity (about the equivalent power usage of 3 homes) in a 24 hour period. Using an average blended rate of electricity of $0.13/kWh, leaving an oven on for 24 hrs. a day, 365 days a year equates to $9 per day or $2,278 per year or 22,360 lbs of carbon dioxide emissions.

Solution Details:
Programmable timer installed on oven in the cell.

Results of this Kaizen/Improvement:
Reduction in energy and emissions for just 1 oven figuring 250 work days per year and the oven being on 30% of the time would bring a annual savings of $1,822 and a reduction of carbon dioxide emissions of 17,795 lbs.

Team Name:

Problem Description:
Air pressure on handheld compressed air nozzles was higher than process needed. This wasted energy and made area unnecessarily noisy.

Solution Details:
Found that another cell in a different department had a similar problem. They installed cheap regulators on the back of the air nozzles to reduce the amount of air being used. We are ordering these same regulators for our nozzles.

Results of this Kaizen/Improvement:
Energy Improvements?: 1

Team Members:
Problem Description:
The cost of our gas/chemicals was extremely high due to a high consumption rate of fluorine gas.

Solution Details:
Developed standard work procedure to turn back the gas pressure during idle times and off shifts from 20psi to 8psi.

Our daily consumption dropped from ~275 lbs a day to ~60 lbs. In turn we went from replacing a tank every 8 days to every 23 days or 16 tanks a year at $3,375 a tank.

Results of this Kaizen/Improvement:
Annual Material Savings: 30 x 3375 = $101,250
Annual Time Savings: (hrs) 2.5 hrs x 30 = 75 Hours
Safety/Ergonomics/FOD reduction?: Fewer tank change overs reducing the amount of heavy lifting by 2/3 and also reducing the exposure to harmful gases by 2/3
Energy Improvements?: In addition, we now put the lasers into idle mode to reduce the electrical energy consumption.

Team Members:
Total Preventative Maintenance (TPM)

TPM Example

Kaizen Plaque

Problem Description:
The ICT vacuum pumps were found not to be shutting off when there is not a draw from the line. This means if they were not in use they were running continuously and wasting a lot of energy. Ideally, when these pumps are not in use they should shut down.

Solution Details:
An investigation found there was a major leak in the line. When the leak was found it was temporary sealed with duct tape. Then a repair order was initiated and the line was repaired.

Results of this Kaizen/Improvement:
Energy Savings: $1,654

Team Members:

Technology Change

Technology Change Example

Kaizen Plaque

Problem Description:
The thermal chamber in our cell has an interior volume of 2000 ft³ to heat and cool. The parts that are processed in these thermal chambers are approximately 60 ft³ in volume. The current chamber uses approx. $25k of electricity/yr. With the proposed work flow increase, the expected energy costs will rise to $52k.

Solution Details:
Purchased a new thermal chamber that will be one-half the footprint. Not only will this decrease energy costs but will reduce thermal cycle time because less volume to heat/cool.

Results of this Kaizen/Improvement:
Floor Space Reduction: 200 sqft
Annual Time Savings: 4 hrs/cycle x 250 cycles = 1000 (hrs)
Energy improvements? 1) Small chamber requires less energy to heat/cool. 2) Newer design (25 years) is more energy efficient.

Team Members: