ACHIEVING ENERGY EFFICIENCY IN MANUFACTURING: ORGANIZATION, PROCEDURES AND IMPLEMENTATION

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By

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ABSTRACT

The industrial sector has one of the highest levels of energy consumption and therefore greatly impacts sustainable development around the world. Transitioning to renewable energy sources and becoming energy efficient are two ways to reduce greenhouse gas emissions, but the latter approach will take the least amount of initial investment, provide the quickest payback, and immediate rewards (i.e., cost savings, employee/company morale, and emissions reduction).

Energy efficiency is not a new concept, but its implementation has been slow and sometimes non existent in some factories. This is due to many factors, including: lack of in-house expertise and resources to initiate and implement an energy efficiency program, lack of funding for implementation of energy efficiency measures, lack of user-friendly tools, lack of institutionalized operational procedures and standards to set the energy efficiency program in the facilities, and most importantly energy efficiency has not been a part of the overall strategy.

To overcome these obstacles, this research proposes the introduction of energy efficiency into every layer of the company's overall framework, i.e. the Manufacturing/Supply Process, Human and Organizational, and Information and Control layers. This will be achieved by creating a complete methodology to help industrial organizations to plan and institutionalize energy efficiency solutions as a company wide program. While a systems' approach provides the foundation for the methodology, a web-based Task-Centered Workbook will provide the necessary tools for technical implementation.

Using such a methodology provides all the necessary elements to achieve a successful energy efficiency initiative. That is, a initiative with participation from all levels of the organization, where clear goals and targets are well defined, roles and responsibilities are clear, both financial and human resources are properly allocated, data is easily accessible and standard throughout the organization, easy to use tools and experts are available to support the implementation, training is provided, success is well publicized and employees rewarded, best practices are shared, and finally data is monitored and targets revised for continuous improvements.

The conceptual structure is now being implemented in ABB Inc., which is one of the largest industrial organizations in power and automation. So far the top management has approved the conceptual design, formed a steering committee, nominated key energy efficiency positions, has completed a project plan for the initiative and is currently working on the technical implementation of the needed web tools and institutionalization of best practices.

With an integrated energy efficiency methodology for factories, the industrial sector will no longer be the highest energy consumer but a contributor to sustainable development. This is an integral part of industrial ecology, which can also benefit from a structured framework that unifies all available tools to better support sustainable development.

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1 INTRODUCTION

Is i*ndustrial ecology* possible? Although this concept has been around since the late 1970s, most people still believe that industrial systems cannot successfully coexist with the environment. The traditional view of industries and how they relate to the environment is the so called “cradle to grave” approach (McDonough and Braungart 2002, 27). That is, the factory processes natural resources but the industrial waste returns to the ecosystem in landfills and the atmosphere as oppose to being re-used. In this traditional scenario industrial sites and cities are kept away from natural environments and the byproducts are contained as well as possible from contaminating the outside natural world. This creates a familiar dispute between environmentalists who tend to believe industries are destructive to human health and the environment and industrialists who often believe environmentalists are an obstacle to growth (McDonough and Braungart 2002, 6).

Industrial ecology, with its distinctive systems approach, may provide the answers to this old dispute between environmental sustainability and industrial development through the architecture of *sustainable development*. Sustainable development has been defined in the 1987 United Nations General Assembly Report as follows: “Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs” (24). This includes three key points: continuous preservation of economical, social and environmental systems (Adams 2006, 2). Thus, for industrial developments to be sustainable they shall also take into account the limitations of natural resources and how the entire product life cycle will affect our descendents. Robert White (1994, v) provides a similar definition of industrial ecology in that it covers the three key dimensions of sustainable development, i.e. economical, social and environmental:

> Industrial Ecology is the study of the flows of materials and energy in industrial and consumer activities, of the effects of these flows on the environment, and of the influences of economic, political, regulatory, and social factors on the flow, use, and transformation of resources.

The term industrial ecology, however, dates back to 1977 when American paleontologist and geochemist Preston Cloud first introduced the term in a paper for the German journal *Geologische Rundschau* (Erkman 1997, 2). Preston Cloud seems to have been one of the first to realize that sustainability would be an inevitable issue in the future if humans didn't cease to extract all of Earth's natural resources (Dutro 1999, 16-17). According to this account of Preston Cloud's work by Dutro, at a minimum, one should be alerted to imbalances in the world, which are caused by poor human interactions with the natural environment and therefore the need to search for more sustainable methods of resource utilization (1999). In "Strategies for Manufacturing" by Frosch and Gallopoulos, one key message given by authors is the acknowledgment that even thou technology has improved our living standards, it may become our downfall if the rest of the growing human population continues to strive for living standards comparable to that of the United States and Japan (Frosh and Gallopoulos 1989, 144). To exemplify, they point out that the solid waste generated by 10 billion people (1989 human population prediction for year 2030) with living standards comparable to that of the U.S. would reach 400 billion tons per year. 400 billion tons of waste cannot be absorbed by the environment without significantly impacting the quality of life on earth. The authors go on to say that "these calculations are not meant to be forecasts of a grim future, but instead they emphasize the incentives for recycling, conservation and a switch to alternative materials" (Frosch and Gallopoulos 1989, 144).

The world population has increased from 5.2 billion in 1989 to 6.9 billion in 2010 (UN Department of Economic and Social Affairs 2009), along with a greater need for energy. The side effects from an unsustainable growth can be seen today by the increase in greenhouse gases which in turn creates global climate change (World Development Report 2010). The effects of climate change can be seen particularly in costal areas and represent an even greater threat for small islands as explained by the president of the Island State of Palau Johnson Toribiong during the 2010 U.N. Climate Change Conference in Cancun, Mexico: "while Palau is safe for the time being, the ocean's warming, the rise in acidification, threaten everyone's existence. The world cannot continue to treat climate change as a subject of negotiation…The world must take action to immediately reduce greenhouse emissions…"

The question is no longer whether climate change exists, but rather what can consumers, environmentalists, industrialists, law makers and the scientific community do today to move into what can possibly become the new industrial ecology revolution. The current question for the industrial sector is how can we continue to meet the demands of an ever growing population while reducing greenhouse gas emissions?

1.1 Need for the study

The industrial sector alone accounts for 28% of the energy used world wide (see fig. 1), 25.6% of which is by means of burning coal (International Energy Agency). To reduce greenhouse emissions, the industrial sector needs to focus on ways to reduce the need for non-renewable energy sources, that is, use renewable energy sources and become energy efficient.

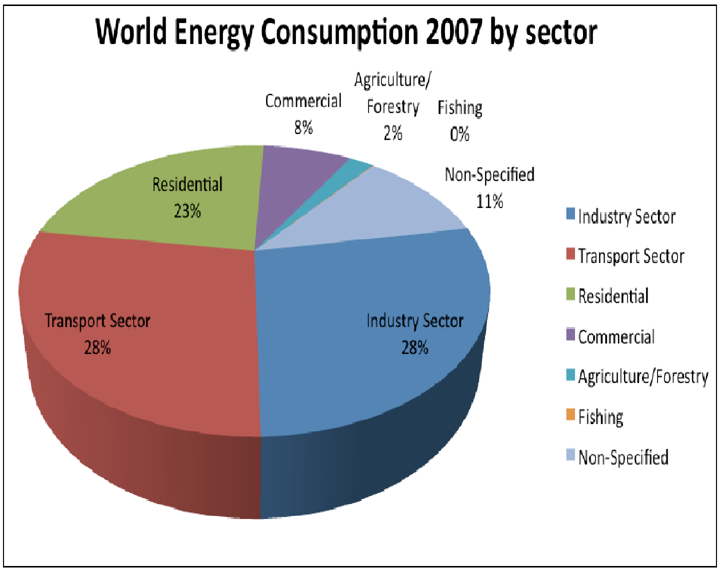


Figure 1 – 2007 World Energy Consumption by sector (IEA)

The three countries with the highest industrial energy intensity, China, United States and Russia, produce energy by coal burning and natural gas power plants. In the United States alone, 1.1 Quadrillion BTUs used by the industrial sector is solely produced from coal power plants (International Energy Agency). According to the United States Environmental Protection Agency (EPA 2007), this equates to approximately 745 Billion lbs of CO2 dumped in the atmosphere (average emission rate 2,249 lbs CO2/MWh). Time is of the essence if one looks at the projected energy needs for the next twenty five years and probable effects on the environment and standards of living. For example, coal burning power plants require large amounts of water for steam and cooling, but as water is removed from rivers or lakes the aquatic life is affected and humans can no longer depend on that water supply (EPA 2007). Rain that falls on stored coal piles or water from cleaning coal can also flush heavy metals onto the water supply making the water no longer suited for humans or animal consumption (EPA 2007). With such dependency on coal and gas, the transition to renewable energy sources will not be easy and therefore an immediate first step is needed to begin moving the industrial sector towards a *lean and green* way of production.

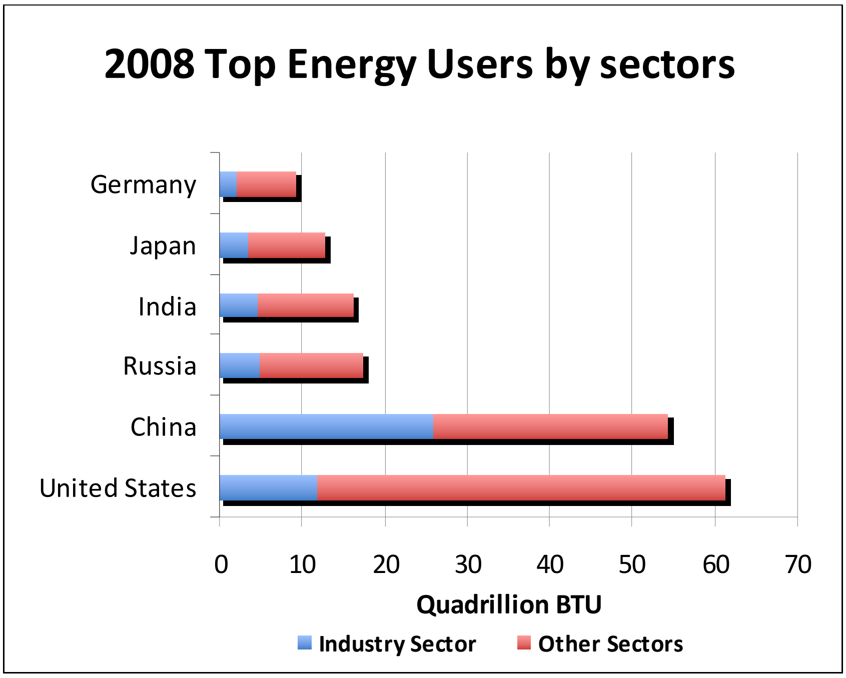


Figure 2 - 2008 Top energy consuming countries by sectors (IAC 2008)

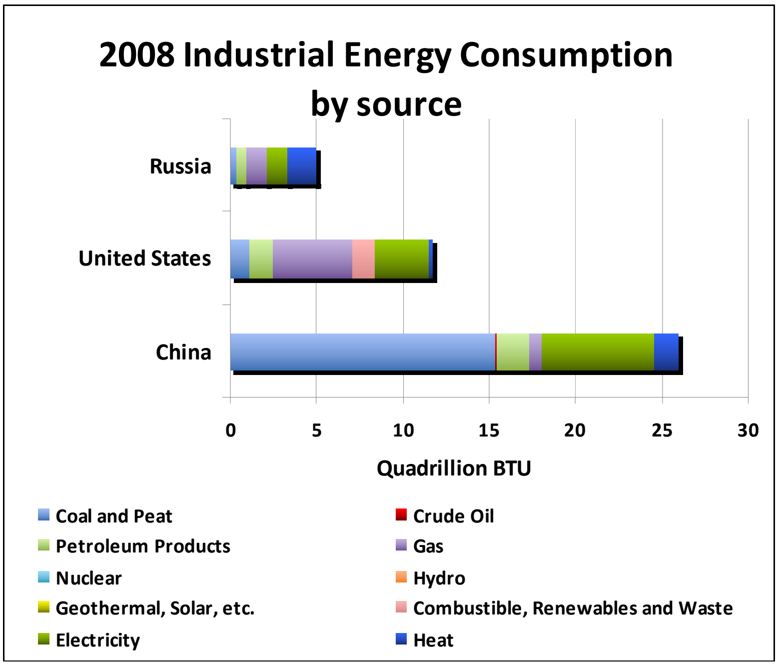


Figure 3 – 2008 Top industrial energy users by source

This first step is an Energy Efficiency Initiative, i.e., a cost effective and easy to implement solution that can provide great savings and reduction in CO2 emissions. Through the implementation of such initiative, companies will soon realize that being green can also be cost effective, and embracing long term solutions such as renewable energy sources will not be as challenging. As little as a 10% improvement in energy efficiency can translate into significant reductions in the need for coal plants. If the industrial sector of the United States committed to an energy consumption reduction of 10% by 2015, 25 power plants with 1300 MW/year capacity would become obsolete. This means 2.4 billion metric tonnes of carbon dioxide per year and 195,000 metric tonnes of sulfur dioxide per year would not be released to the atmosphere (average emission rate of 13lbs/MWh of sulfur dioxide and 2,249lbs/MWh of carbon dioxide provided by the EPA).

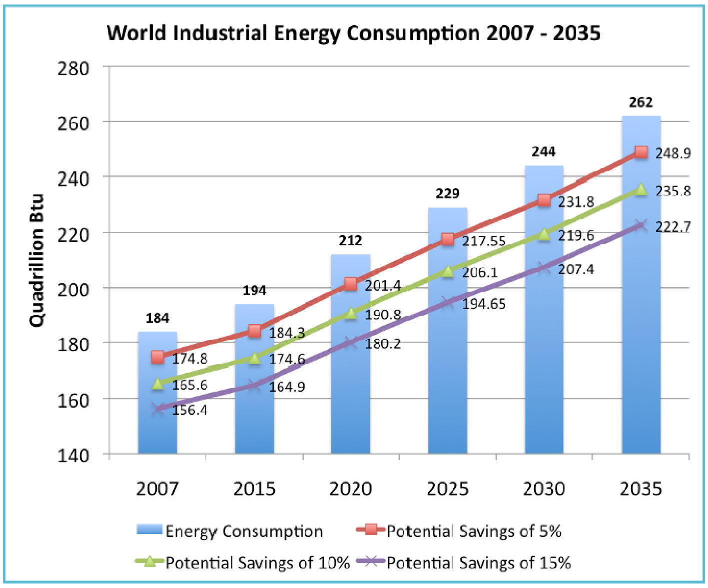


Figure 4 – Projected Energy Consumption and Potential Savings

Such an initiative will be perfectly in line with the sustainable development direction, which calls for the preservation of our economical, social and environmental systems. The Kyoto Protocol, which has committed 37 nations to reduce 10% of greenhouse emissions by 2012, states that in order to achieve sustainable development, countries shall implement policies such as Energy Efficiency (article 2, 1.a). Given that the industrial sector is one of the larger energy consumers, sustainable development depends on industries to reduce their greenhouse gas emissions in order to be successful. This can be achieved by transitioning to renewable energy sources and becoming energy efficient. The latter approach will take the least amount of initial investment, will provide direct cost savings, and give a significant reduction in greenhouse gas emissions.

1.2 Opportunities and Obstacles: project hypothesis

Energy Efficiency is not a new concept and over the years several best practices have been created and implemented successfully. For example, a large amount of information is readily available regarding the current technologies and general best practices: The United States Department of Energy (DOE) (http://www.eere.energy.gov) and its Industrial Assessment Centers around the country (http://iac.rutgers.edu).

However, despite the potentials and the increasing level of awareness, quite often industrial organizations in reality are still not motivated to implement energy efficiency measures. In addition to some of the reasons previously identified (for example, Prindle 2010), the following provide a more complete list of reasons why energy efficiency programs in the actual industrial settings still are in the low-priority list:

- Lack of in-house expertise or team, know-how, and resources to initiate and implement energy program,
- Lack of effective methodology to help industrial organizations to plan, adopt and institutionalize energy efficiency solutions as a company wide program,

- Lack of user-friendly tools,
- Lack of institutionalized operational procedures and standard to set the energy efficiency program in the facilities,
- Lack of partnership with governments and other energy efficiency organizations.
- Lack of funding for implementation of energy efficiency measures, or lack of awareness of available funding from the government agencies and other entities to support such measures for local companies

To overcome the obstacles, a systematic approach is needed to help the industrial sectors to effectively initiate and implement an energy efficiency program in a logical manner. Approaches and tools are needed by the industrial organizations to help tasks in the key areas:

- *Create a company wide initiative where the Organization, Processes and Control Measures are taken into account.*
- *Institutionalization of best practices* in the organizational and operational structure: analysis and investigation of a organization's specific needs, identification of best practices guides and operational procedures, documentation
- *Culture Change* through education and training of personnel and by rewarding results.
- *Planning and execution of energy efficiency projects*: planning, data collection and analysis, identification of opportunities, detailing and justification of recommendations, implementation tasks.
- *User friendly tools* for implementation, measuring, and monitoring

1.3 A Systems Approach to achieving industrial energy efficiency: organizational structure, procedures and implementation

In the industrial sector, it is a well understood fact that a complete cycle is required to achieve continuous improvement of system performance: setting strategy and goals – analysis and design – implementation and operation, performance monitoring and setting of new goals (Wu 2000). When related to the improvement of industrial energy efficiency, this cycle can be presented by a close-loop as shown in Figure 5.

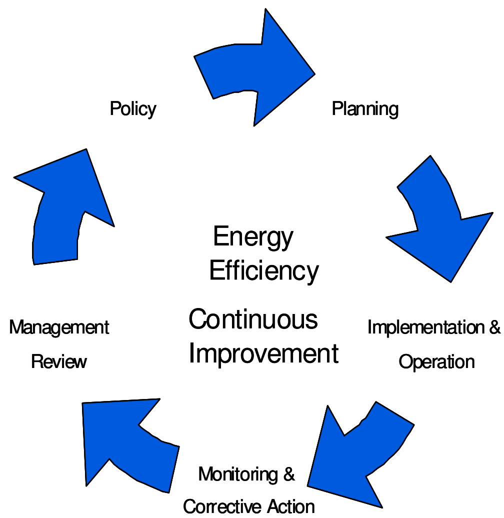


Figure 5- The complete cycle of continuous improvement of industrial energy efficiency: strategy, planning, implementation, monitoring

However, this continuous improvement cycle cannot be successful if running independently from other initiatives within the company. That is, each step of the energy efficiency initiative (from planning to policy statement) must all be aligned with those of the overall organization. Wu (2000) describes this as the overall company strategy within a unified framework of a Manufacturing and Supply Systems Management (MSM). The unified structure shows the interconnectedness of the key areas of the MSM system: the Manufacturing/Supply Strategy Analysis (MSA), Manufacturing/Supply Systems

Operation (MSO), and Manufacturing/Supply Systems Design (MSD) including the three supporting layers that comprise them. In order to successfully develop an MSM framework, each layer (Manufacturing Process, Human and Organizational, and Information and Control) must also be structured so that it will support the overall goals and objectives of the business.

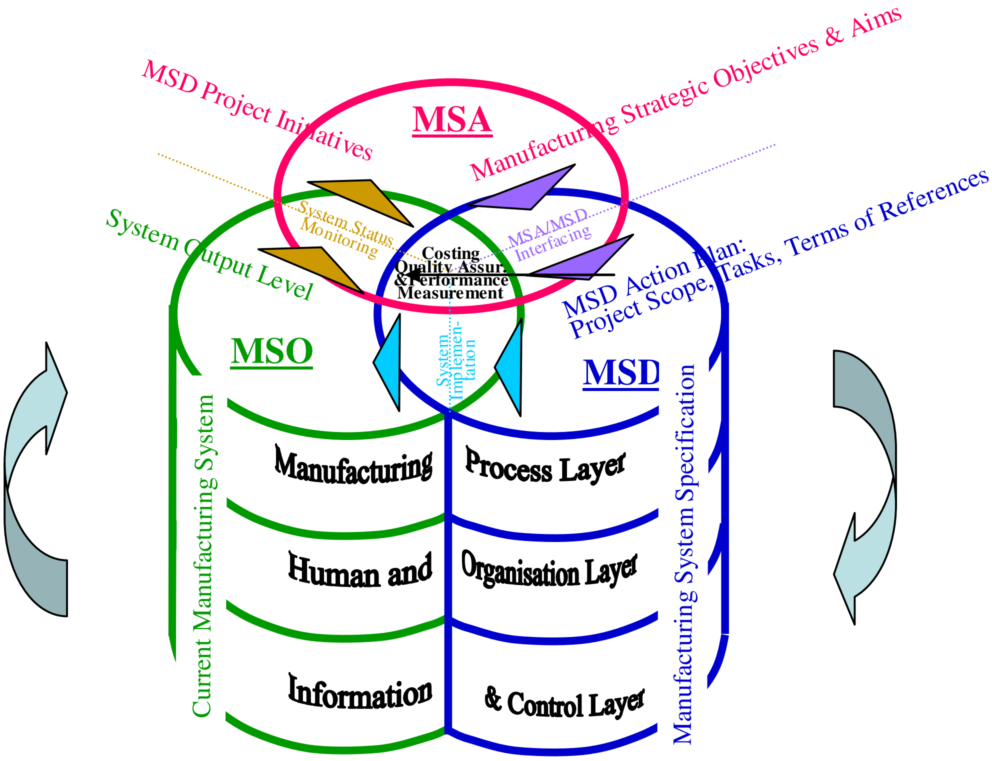


Figure 6 - "Overall functional structure and flow of a unified MSM framework" (Wu 2000, figure 1.6)

The current work attempts to insert energy efficiency in each layer of the MSM framework from analysis to design and to operations where each layer will have subtasks related to energy efficiency:

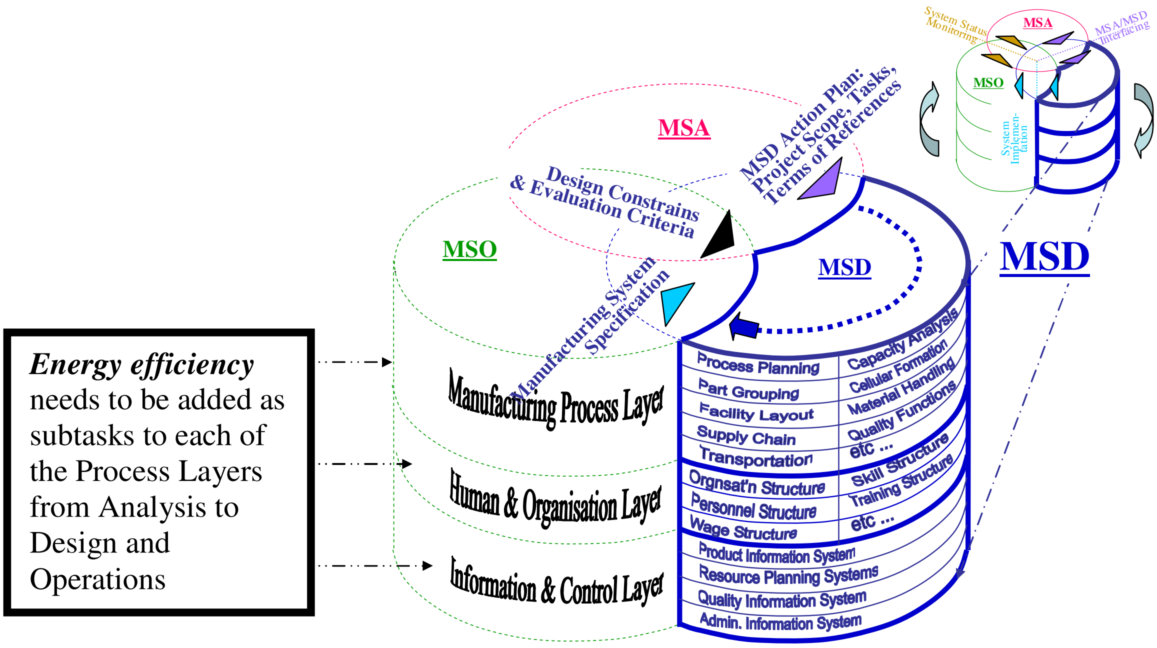


Figure 7 – Example of the MSD tasks within MSM with the inclusion of energy efficiency

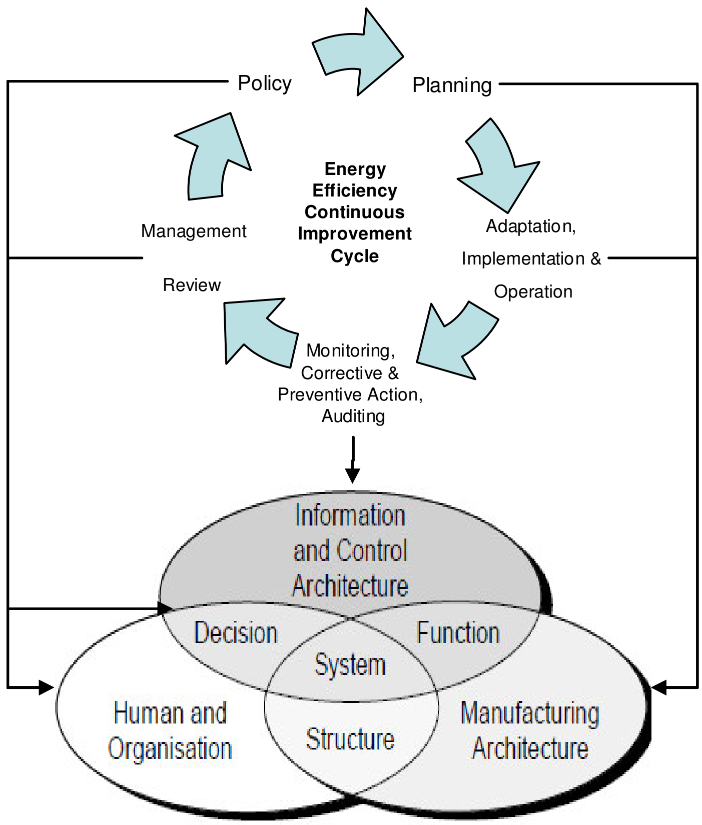


Figure 8 – Energy efficiency continuous improvement cycle is incorporated in sub-tasks of the MSM framework

Energy efficiency being a part of the overall framework, the goals and strategies will be guaranteed to be aligned with that of the overall system. While systems thinking will be used to develop the overall energy efficiency initiative for the entire company, its implementation shall follow the same methodology as Wu's Task-Centered framework (Wu 2000, 2001 and 2002).

Following one of the key recommendations from the Kyoto Protocol and green economics, energy efficiency implementation in industrial companies will be the focus of this paper. A systems approach for continuous improvement will provide the foundation for the energy efficiency initiative, while a task centered (Wu 2000, 2001 and 2002) approach will be used to institutionalize exiting best practices related to energy efficiency and hence provide a complete methodology for implementing energy efficiency in industries. This presents a novel framework to help industrial organizations to achieve energy efficiency, which is currently lacking. In addition, this methodology will follow the further coming ISO 50001 Energy Management Standard so that once implemented, a company will be ready for certification (ISO/DIS 50001).

The conceptual structure is now being implemented in ABB Inc., which is one of the largest industrial organizations in power and automation. With approximately 400 manufacturing sites and offices based in more than 100 countries, ABB Inc. offer a great potential for energy efficiency improvements. The company has already engaged in providing its customers with energy efficiency products, but the factories and offices had not yet seen a corporate initiative in energy efficiency. So far the top management has approved the conceptual design, formed a steering committee, nominated key energy efficiency positions, has completed a project plan for the initiative and is currently working on the technical implementation of the needed web tools and institutionalization of best practices.

In the following text, section 2 provides the literature review which is divided into theoretical and empirical studies on industrial ecology tools including energy efficiency and its implementation. Section 3 explains the proposed methodology for implementing a company wide energy efficiency initiative based on the implementation at ABB Inc. with current status shown in section 4. Section 5 will conclude the study by discussing the results and further research on the subject.

2 LITERATURE REVIEW

Many scholars deserve credit for developing the concepts which laid the foundation for the modern industrial ecology of today, which now provides the industrial sector with various tools for sustainable development. This chapter reviews both theoretical and empirical studies on industrial ecology tools including energy efficiency and its implementation. The theoretical study on industrial ecology will give the foundation for energy efficiency including a review of systems approach and task centered methodologies that will later be proposed for its implementation. The empirical literature will focus on energy efficiency implementation examples from various industrial companies and green building projects.

2.1 Review of industrial ecology and its implementation

The origins of industrial ecology can be found by reviewing the works of Eugene P. Odum, author of *Fundamentals of Ecology*[1] (1953) and Jay Forrester who wrote *Principles of Systems* (1968). Both works are important milestones in the fields of ecology and systems engineering respectively which are the key aspects of industrial ecology. Given that industrial ecology is a fairly new discipline, however, the tools and concepts are still not well integrated and therefore are difficult to implement. On the other hand, industrial engineering combined with industrial ecology gives a unique advantage in that concepts already familiar to industrial engineers can be easily adapted to fit the additional industrial ecology requirements, that is, achieve a lean and green manufacturing system.

[1] For the first edition see Odum, E. P. 1953. *Fundamentals of Ecology*. Philadelphia: Saunders.

2.1.1 Origins of industrial ecology

Eugene Odum's *Fundamentals of Ecology* was the first book written on ecosystems ecology and according to Graige (2002) it helped students "see the world in terms of interrelated systems and to look at 'the big picture'" (105). Just as Odum was important to the development of Ecosystems Ecology, Jay Forrester was to the field of systems engineering. Forester's career began as an electrical engineer for the United States Navy and became known for developing the magnetic core memory for computers used for simulating new aircraft designs (Forrester 1989). His greatest contribution however, happened later in his career as a professor of Industrial Management at the Massachusetts Institute of Technology. There he implemented his understanding of feedback control systems into human systems (corporate dynamics) creating the concept of system dynamics (Forrester 1989 and 1991). System dynamics follows the same approach of systems thinking with the addition of computer simulation models. *Principles of Systems* was followed by *World Dynamics* in 1971, when Forrester applied system dynamics to world issues. Today, system dynamics continues to be applied to an array of subjects from corporate planning to environmental issues.

In 1972, a year after the release of *World Dynamics*, the Japanese Industry-Ecology Working group led by Chihiro Watanabe published a report that delineates several industrial ecology concepts, such as "recognizing system boundaries for industrial activities, understanding industry-environment interactions, recognizing redundancies and response relationships in systems, and developing mechanisms of control over human activities to promote ecological equilibrium" (O'Rourke, Connelly, and Koshland 1996, 92).

2.1.2 Need for an industrial ecology framework

The theoretical work has been laid out since the late 70's however there is still no clear methodology for its implementation, that is, the concepts and tools are often interconnected and yet there is no clear framework on how to integrate them. As means of clarification, the following table is provided in an attempt to categorize some of the concepts currently under the industrial ecology umbrella and how they affect sustainable development; it is not a complete picture of field however:

	Discipline	Subtopics and Tools	Environment	Economic	Social
Industrial Ecology	Industrial metabolism	Material Flow Analysis (MFA) or Substance Flow Analsyis (SFA)	X		
	Life Cycle Analysis (LCA)	Cradle to cradle or cradle to grave	X		
		Life Cycle Costing (LCC)	X	X	
		Life Cycle Energy Analysis (LCEA)	X	X	
	Industrial parks (ecoparks)	Social Return on Ivestment (SRI)	X	X	X
		Input-Output Analysis (IOA)	X	X	
		Agent Based Models (ABM)	X	X	X
	Cleaner Production	**Waste reduction**	X	X	X
		Polution prevention	X		X
		Toxics Use Reduction (TUR)	X		X
		Design For Environment (DfE), i.e., Design for	X	X	X
		Recycling (DFR), Design for Disassembly (DFD)	X	X	X
	Green Economics	Ecological Economics	X	X	X
		Environmental Economics	X	X	
		Energy economics	X	X	
		Energy accounting and balance	X	X	
		Environmental services	X	X	
		Ecological economic modeling	X	X	
		Full Cost Accounting (FCA) or True Cost Accounting (TCA)	X	X	
		Renewable energy	X	X	X
		Green buildings	X	X	X
		Clean transportation	X	X	X
		Water management	X	X	X
		Waste management	X	X	X
		Land management	X	X	X
	Environmental Policy	ISO 14000 Environmental Management (14001, 14004, 14015, 14020, 14031, 14040, 14050, 14062, 14063, 14064)	X		X
		ISO 50001 Energy Efficiency	X		X
		Organisation for Economic Co-operation and Development (OECD)	X	X	X
		Kyoto Protocol	X	X	X
		market-based instruments such as taxes and tax exemptions	X	X	X

Table 1. Industrial ecology and sustainable development

Although the subtopics and tools are shown as sub points of certain industrial ecology disciplines, they are however interrelated. For example, a cradle to cradle life cycle analysis can be used as a tool to evaluate an existing process or it can be used to forecast a future product as part of its life cycle based design. Agent based models is a simulation tool that can be used for an array of topics including how industries adapt to new ecological policies (Teitelbaun 1998). Clearly universities have a role to play in better formulating the "industrial ecology framework" (Ehrenfeld 1994, 230). Such framework need to follow a systems approach and include but not be limited to: Initial system review (i.e. LCA, MFA), policy (i.e. ecological economic policies), planning, implementation and operation (tools to close the gap), checking and corrective action (i.e. continuous improvement tools and ISO management tools including audits), and policy review for a continuous improvement cycle.

2.1.3 Industrial ecology and industrial engineering

Furthermore, the traditional work of the industrial ecologist is to first understand the industrial system at hand: what are the inputs from other systems, e.g. products from other industries, raw materials, and energy resources, and what are the outputs to other systems, e.g. products to be used in other industries, services to the community, and byproducts to the environment. Once these input / output relationships are clearly understood, the next step is then to make this industrial subsystem more compatible to the way ecological systems work (Erkman, 1997). Moreover, the key to industrial ecology is to understand that industrial systems are subsystems of the biosphere from which resources are taken in and outputs are given out to be re-used as input to other sub-systems of the biosphere. But as Erkman (1997) explains, industrial ecology should not be confused with industrial metabolism, which aims at "understanding the circulation of the materials and energy flows linked to human activity, from their initial extraction to their inevitable reintegration" (p.1). Instead, industrial ecology looks at the whole picture through a systems thinking approach.

Industrial engineers also look at the overall picture of a process and analyze the distribution of materials, energy and information flow using systems analysis. In addition, industrial engineers use systems analysis to break down a system into subsystems in order to understand how the inputs and outputs of the different systems' levels relate to one another thus creating sub models of the overall picture (Wu 1992). That is, by breaking down a larger problem into sub problems one can concentrate on one level at a time while contributing to the overall system success. Together, the principles of industrial ecology and the tools used by industrial engineers provide the ideal combination between professions, i.e., familiar concepts for the manufacturing sector and a practical methodology to implement industrial ecology.

2.1.4 Lean and green

The commonly used industrial engineering tools for process improvement such as Value Stream Mapping, Theory of Constraints, 5S, Kaizen, Visual Management, Lean Manufacturing and Six Sigma use common performance measurements that ideally should not contradict with one another. For example, increase throughput, quality and profitability, while lowering waste in the form of inventory or non-value added tasks and production costs. A balancing act that is normally difficult to achieve. What happens when key environmental performance measurements (KEPM) are added to the list of previously mentioned common performance measurements? Unfortunately, environmental manufacturing solutions are often equated to an increase in production costs and lower throughput rate because these concepts are still new to most manufacturing plants. Hence the challenge: If it can be shown that KEPM such as lower carbon emissions, lower energy use, lower amounts of natural resources can be achieved while maintaining throughput, quality, profitability, adequate inventory levels and production costs, then industrial ecology can be successfully implemented.

The new Lean and Green framework then shall revise industrial engineering tools to include Key Environmental Performance Measures such as:

1. Energy Efficiency Cost Savings (measure in MMBtu)
2. Greenhouse Gas Emissions (measured in lbs)
3. Waste recuperation % (for example: material scrap and heat)
4. % of wasted Non-Renewable Resources (for example petroleum based products).
5. Volatile Organic Compounds (VOC) emissions (parts per million).

Value stream mapping, for example, shall also be used to track environmental waste through the factory such as carbon emissions, scrap and % of non-renewable materials wasted. Theory of constraints must also take into account the most energy efficient times to run certain equipment, the use proper buffers to reduce the use of equipment in peak hours, and proper machine set up to reduce material scrap. 5S and Kaizen events can also include metrics to reduce and re-use environmental waste. Visual Management is an easy tool for supervisors to manage the factory output, inventory levels and also waste management. Lean manufacturing, which aims at the elimination of waste passed on to the end customer, shall also include the elimination of environmental waste for a Lean and Green solution. Finally, the Environmental Protection Agency (EPA 2011) in the United States provides a "Lean and Energy Toolkit" which promotes the use of Six Sigma to control variations in energy use and to identify root causes for energy waste. The Lean and Green is a logical and simple step in that it simply introduces environmental metrics into already familiar tools used by industrial engineers. This will not be seen as the new "wave" and no new training is required.

2.1.5 Definitions

1. Industrial ecology is systemic in nature. In order to fully comprehend the inputs and outputs of an industrial system one must treat it as a sub-system of the biosphere.
2. Industrial ecology takes into account the limited amount of natural resources in the planet by focusing on conserving these limited recourses and relying on renewable ones.
3. Industrial ecology proposes to mimic biological systems which are closed looped in nature.
4. Industrial ecology must have a global scope. That is, the damage of one ecosystem impacts local, regional and often global systems.

2.2 Waste minimization through design for the environment

Waste minimization is an important goal both in industrial engineering and industrial ecology. One key factor in waste minimization is for industries to be proactive by considering waste through a product's entire life cycle and do so from an early stage of the product's development. That is, use tools such as design for the environment to minimize waste from resource extraction to the product disposal or recycling. Based on concurrent engineering, design for the environment allows the designer to consider several aspects of the product's life cycle simultaneously or to focus on specific goals such as minimizing energy consumption.

2.2.1 Waste redefined

Before Billen et al. (1983) redefined waste as the outcome of an open material flow system; waste was considered a consequence of increased production and consumption levels (Erkman 1997, 3). This subtle but important shift puts forth the differences between open versus closed looped systems, where in closed loop systems the waste of one process is used as input to another process and therefore is no longer considered waste. Through the use of design for the environment, industrial ecology encourages industrial designers to mimic closed loop systems found in nature so that waste is reintroduced into the system and does not end up in land fills or the atmosphere.

2.2.2 Concurrent engineering

Concurrent engineering is a design management system that takes into account all of the product's design requirements and manufacturability simultaneously in order to better meet corporate demands of reduced cycle time, improve quality and design (Jo, Parsaei, and Sullivan 1993). The positive aspect of this method is that it considers the product life cycle during the early design stage including its environmental impact, working conditions, resource optimization (energy and materials), manufacturing and product properties, company policy and life-cycle costs (Alting 1993). Concurrent engineering relies on computer based environments that can provide a robust computer-aided design (CAD) tool while integrating other life-cycle requirements (Jo, Parsaei, and Sullivan 1993, 17). There are several challenges implementing concurrent engineering, however, such as how to schedule development activities in the concurrent environment, what type of information needs to be shared between cross functional teams, and how information is shared through a flexible and yet robust Common Information Model (CIM) (Moenaert, R.K., W.E. Souder 1996).

2.2.3 Design for the environment

Design for environment (DFE) is the next logical step following concurrent engineering. DEF incorporates concepts such as waste reduction, pollution prevention and toxics use reduction, which can be considered “end-of-pipe” approaches, into a higher systems approach to environmental management (Allenby 1994, 140). Furthermore, rather than seeing environmental needs as limiting, environmental objectives are part of the regular design goals in the early part of the design process (Berkel, Willems and Lafleur 1997). DFE can be used to design new products or to redesign existing products and their manufacturing systems through the use of an already existing tool, design for X (DFX). For example, “design for product life cycle extension,” “design for minimal materials use,” and “design for energy conservation” (Berkel, Willems and Lafleur 1997, 56).

2.3 Green economics

Another key factor in industrial ecology, economics plays an important role when one looks at the overall implementation of sustainable development. Economics, as with many other fields, has been challenged with concerns for the environment and hence how to “maintain human happiness with ecological constraints” (Wall 2006, 202).

This section reviews a few subfields of economics concerned with the environment starting with a review energy economics. Energy economics mimics closed loop systems found in nature and applies the same concept of resource transformation to form a new economic system. Green economics and ecological economics are paralleled in their common view of the economy as a subsystem of the environment and at first glance seem to contradict environmental economics, which does not challenge the capitalist framework. Instead, environmental economics attempts to bridge the gap between environmental needs and the existing capitalist system (Munasinghe 1993). A more modern version on green economics is then presented which neither attempts to redefine capitalism nor does it propose a new economical system, instead it focuses on green job creation that goes across race and class while focusing on the following key areas: energy, food, waste, water and transportation.

2.3.1 Energy economics

The concept of open versus closed looped systems was used by Hall, Cleveland and Kaufmann to exemplify the flaws in the often portrayed cyclical flow of our economical system. This simple diagram shows a closed loop relationship between Households which provide natural resources, land, labor and capital to Firms who in turn provide goods and services to Households (Hall, Cleveland, and Kaufmann 1986, 39). According to the authors this closed looped, self-renewing relationship is not accurate since energy flows must be depicted according to the laws of physics, where fuels are not self renewable cyclical commodities (39). Instead, changes in resource quality which can be measured by the energy return on investment (EROI) shall be used to define what is and what is not possible in the human economy (28). EROI is defined as the gross amount of fuel extracted in the energy transformation process to the economic energy required to make that fuel economically available to society (28):

$$\text{EROI} = \frac{\text{Kcal of fuel extracted}}{\begin{array}{l}\text{kcal of direct and indirect energy required} \\ \text{to locate, extract, and refine that fuel}\end{array}}$$

Moreover, Hall, Cleveland and Kaufmann parallel the principles of energy fitness[2] used to describe organisms' and ecosystems' reproductive and survival capacities with our industrialized society. In order for an organism to grow, maintain health and reproduce the organism must get more energy from the acquired food than the amount of energy used to acquire the food. That is, "the *energy return on energy invested* for capture must be greater than 1" (Hall, Cleveland, and Kaufmann 1986, 16). This parallel between ecological and human economical systems relies on the fact that both systems use, allocate and regulate energy flows simply because goods and services can only be produced when solar, human or fossil energy is applied to raw materials (21). Hence, if energy were to be removed from our economic system, the system would cease to exist. One of the key differences between the traditional economic analysis and this proposed energy economic analysis is that the latter uses the physical laws of thermodynamics and conservation of mass as the core for the economical model. Hall, Cleveland, and Kaufmann explain as follows: "Recall that the first law limits our supply of matter and energy, and hence the goods and services derived from them, because matter and energy can be neither created nor destroyed, only changed in form" (1986, 35).

2.3.2 Green economics, ecological economics and environmental economics

Similar to ecological economics, green economics criticizes the current main stream economical system and challenges the notion of continuous economic growth, i.e., that society needs to increase production each year (Wall 2006, 204). Green economics goes beyond ecological economics however in that it is deeply rooted in political and

[2] Hall (1986) uses the term Fitness as an energy based approach to understanding natural selection, that is, "organisms behave as to maximize their reproductive potential by selection for the largest difference between energy gains and energy losses over time" (12).

social movements such as the UK anti-pollution laws in the 13th century, the Vegetarian Society, Open spaces Society and Sierra Club in the 19th century, and more recently Green Parties around the world (Wall 2006). Green economics therefore supports a sustainable development for it takes into account economical, social and environmental preservation. Despite of its criticism of environmental economics, which supports the current economic system and tries to bridge the gap by introducing ecological issues into the "traditional techniques of decision making" (Munasinghe 1993, 5), green economics need to engage in a similar approach in order to be successful. That is, green economists must research the future of modern capitalism while connecting economic and environmental concerns with political and social awareness (Wall 2006, 209).

2.3.3 Green economics and energy efficiency

At the forefront of modern green economics is Van Jones, author and former Special Advisor for Green Jobs, Enterprise and Innovation at the White House Council on Environmental Quality. In his book *The green collar Economy, How One Solution Can Fix Our Two Biggest Problems (2008),* Jones gives a refreshing uplift of green economics where the focus shifts to "green collar jobs" (39) that cut across race and income level to solve the two biggest problems facing the United States today: "socioeconomic inequality" (53) and "environmental destruction" (58). Jones defines green collar jobs as an upgrade of a blue collar job to "better respect the environment" (13-14) with the focus on the following key areas: energy, food, waste, water, and transportation.

Energy is the foundation of green economics in that if approached correctly, these initiatives can reduce the need for fossil fuels, reduce carbon emissions, and reduce illnesses resulting from pollution while improving the economy (Jones 143-144). The key areas for green jobs are in renewable energy applications such as wind and solar and energy efficiency. A great example of energy efficiency green jobs can be seen in the implementation of Green Buildings. For example, in Los Angeles more than eleven hundred buildings which are run by the city are being retrofitted with energy efficiency technologies which will save the city $10MUSD once completed (Jones 145-147). Milwaukee has a similar initiative Me2 (Milwaukee Energy Efficiency) which is a great example of how to pay for retrofitting buildings to become green through a long term plan that does not require any upfront investments, with immediate savings while generating long term employment (Rogers 2007). This case study will be further discussed in the empirical review of energy efficiency implementation.

2.4 Environmental policy and ISO 50001

Governmental organizations also play an important role in the successful implementation of sustainable development through regulation, investments, and collaboration with the public, schools and universities, industrial sector, and non profit organizations. When regulation is not sufficient, available or not followed, however, motivation for change may also be seen through standards such as the ISO 50001. These standards are important drivers to set the base line for customers and companies to seek improvements in quality, safety and or the environment.

2.4.1 Industrial ecology milestones

There are key milestones in industrial ecology during the 1990s that influenced policy makers around the world to support sustainable development including several symposiums held around the world on the subject, the dedication of several journals to industrial ecology, and book publications. Following are a few examples:

- In May 1991, Lynn W. Jelinski chaired a colloquium created by the National Academy of Sciences of the USA entitled "Industrial Ecology" (Jelinski et al. 1992).
- In 1992, the United Nations Framework Convention on Climate Change was created which sets a framework for governments around the globe to face the challenges brought about by climate change in that it recognizes that the climate is a shared resource (UNFCCC).
- In 1992 the United Nations organized the ECO 92 symposium in the city of Rio de Janeiro, Brazil and proposed the need for sustainable development (UN General Assembly 1992).
- In 1994 Braden Allenby and Deanna Richards published *The Greening of Industrial Ecosystems* which was the first book on industrial ecology.
- In 1994 the Norwegian University of Science and Technology (NTNU) established an academic program in industrial ecology.
- In 1995, Graedel, T.E., and B.R. Allenby wrote *Industrial Ecology*, the first university textbook on the subject which focused on lifecycle assessment and design for the environment.
- In 1997 the Kyoto Protocol agreement which is linked to the UNFCCC was signed by 37 nations and sets binding targets for reducing greenhouse gases. (UNFCCC 2010).

- In 1997 the *Journal of Industrial Ecology* was created (Lifset 1997, vol. 1) and the *Journal of Cleaner Production* published an entire issue on industrial ecology (Huisingh 1997, vol.5).
- Starting in 1998, a Gordon Research Conference chaired by Thomas Graedel was held on the topic industrial ecology, with a main focus on material flow analysis and the future of industrial ecology. Every two years since then an industrial ecology conference has been organized by different scholars (Gordon Research Conferences).

2.4.2 ISO 50001 Energy Management Standard

Non governmental organizations play an important role in that they can motivate companies to improve their products, production methods, and services without being a mandatory regulation. The International Organization for Standardization (ISO) is one of the most recognized standards in the world for their standards for quality, safety and environment which have become benchmark for companies to achieve. This low cost certification makes companies and their products more desirable to customers whom in turn see this standard a minimum qualification.

Given the recognized focus on energy efficiency, ISO 50001 Energy Management Standard is currently being developed. The standard focuses on the management system necessary for a company to "improve energy performance, including energy efficiency, use, consumption and intensity" (ISO/DIS 50001). The key components for the continuous improvement of the energy management system are: Energy Policy, Planning, Implementation and Operation, Checking, Corrective and Preventive Action, Management Review (ISO/DIS 50001).

2.5 Task-Centered Framework for Industrial Energy Efficiency

A task-centered approach provides an ideal framework to help implement energy efficiency tasks effectively. In Wu 2002, a task-centered methodology was used to introduce the manufacturing system design and management (MSM) workbook with a systemic approach for industrial manufacturers. The concept is based on the integration of all tasks to accomplish the work in one easy to use tool. That is, tasks descriptions, instructions, processes, drawings, tools, data, etc. are all are integrated into one single platform. Within the web environment, this can be further enhanced by a web-based design in a focused way to provide good usability, so that the users can focus only on the tasks at hand and ignore the irrelevant contents and the system structure and navigation needs.

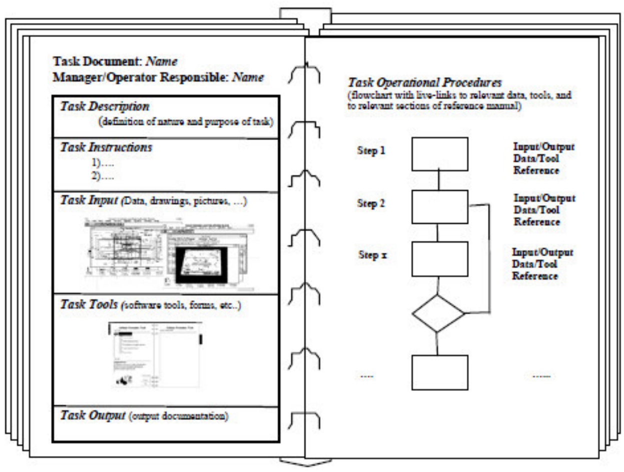


Figure 9 – "The structure of an MSM task document" (Wu 2002, figure 1.18).

In particular, Wu proposed a task-centered approach for the development of computer-aided environment for the education and application in industrial energy efficiency (Wu 2007). For example, since an industrial energy audit involves a large number of documents and multitude of analysis and decisions, the concept of task-centered approach can be used as the basis for the development of a computer-aided workbook to incorporate energy audit procedures, processes, and tasks, following the life-cycle of an energy efficiency analysis. Wu described the conceptual structure of a task-center workbook as shown in Figure 10 (Wu 2007), so that, a computer-aided workbook can be developed and implemented to provide a complete guide to the processes, tasks and outcomes of an energy audit. From the initial audit planning to the final recommendation and follow-up, the workbook utilizes a front-end flowchart to specify the steps and tasks involved, and then logically integrate all the relevant entities such as instructions (Figure 10, a), data collecting tools, procedures of analysis and calculation, and worksheets to support task execution and project management (Figure 10, b, c). Other notable features include links to other resources (Figure 3, a), the experts/expertise database (Figure 10, e), and a specially developed worksheet for calculating organization-wide energy consumption (Figure 3, d). With the completion of the necessary steps, the workbook provides templates for generating final recommendations and report (Figure 10, f). In essence, it is a unified project tool that organizes and links instructional materials, worksheets, analytical tools, and resources in a logical and task-centered manner.

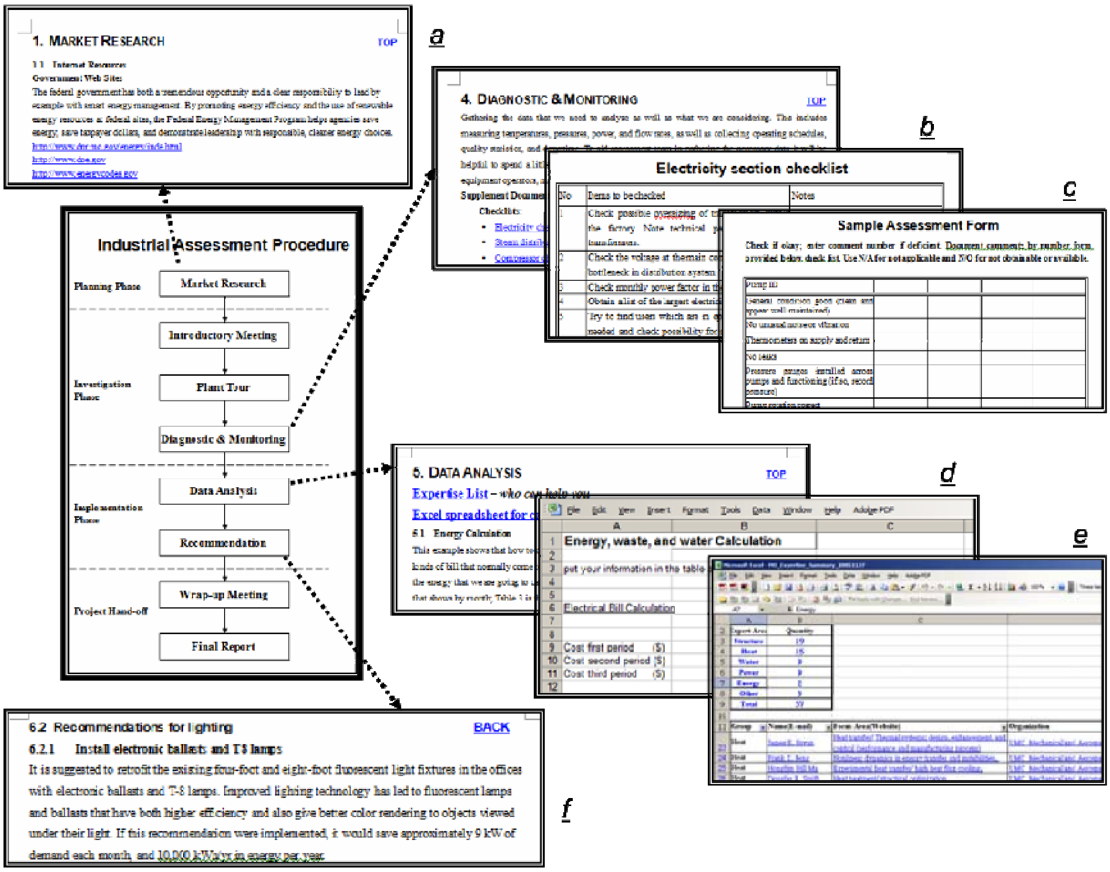


Figure 10 - Task-centered framework for the analysis of energy efficiency (Wu 2007)

The conceptual design has been adapted and a web-based Task-Centered Workbook for Industrial Energy Efficiency has been developed and implemented by Wu and his research team (Wu, Ponte and Pinthuprapa 2011). The web tool provides a complete guide to the processes, tasks and outcomes of an industrial energy analysis, as shown in Figure 11. From the initial audit planning to the final recommendation and follow-up, the workbook should utilize a front-end flowchart to specify the steps and tasks involved, and then logically integrate all the relevant entities such as training materials and instructions, data collecting tools, procedures of analysis and calculation, and worksheets to support task execution and project management. In essence, it is a unified project tool that organizes and links instructional materials, worksheets, analytical tools, and resources in a logical and task-centered manner.

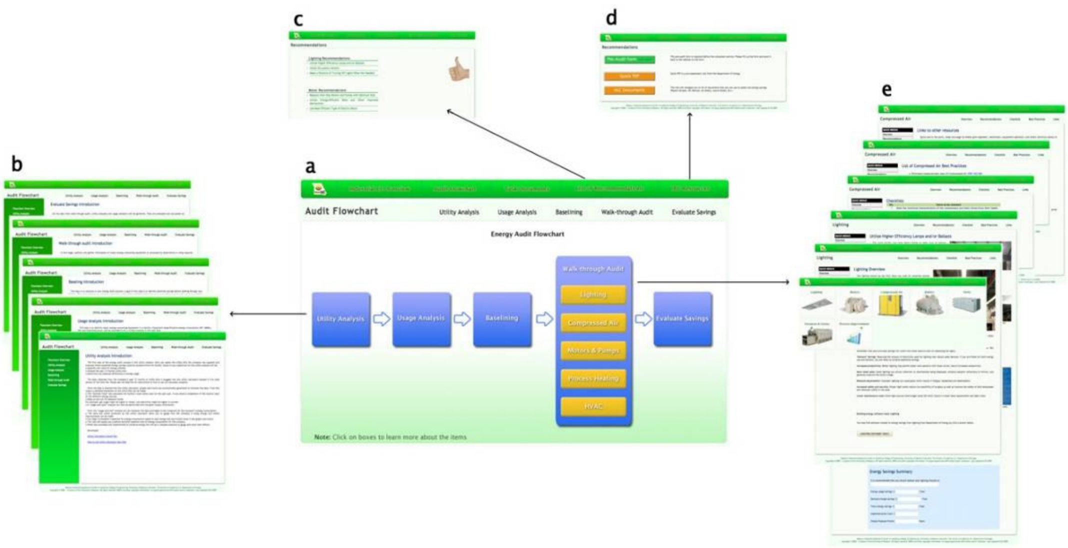


Figure 11 - MoIAC's web-based task-centered workbook of MoIAC's: frontend and collections of "task documents" (Wu, Ponte and Pinthuprapa 2011).

The tool has been used effectively during the energy audits performed by the Missouri Industrial Assessment Center based at the University of Missouri, Columbia by providing:

- Interactive learning and training, i.e. providing learning materials and best practice guides and resources in a focused way, see Figure 12. Each of the recommendations in the best practices' list is supported by a task document that provides both theoretical details and tools.
- Application in actual energy improvement project through the provision of a collection of "task documents" that: (a) aid diagnosis and solution identification by providing on-line and up-to-date on-line checklist, and (b) help with the

problem-solving tasks required through live tools for data collection, calculation and justification (Figure 13).

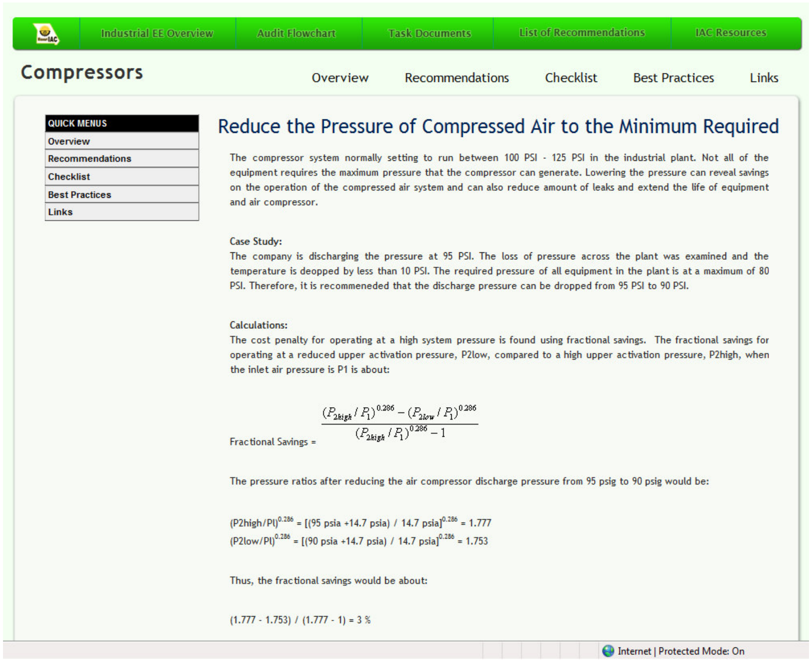


Figure 12 - MoIAC's web-based task-centered workbook of MoIAC's: sample training materials and task document providing details to specific best practice measures (Wu, Ponte and Pinthuprapa 2011).

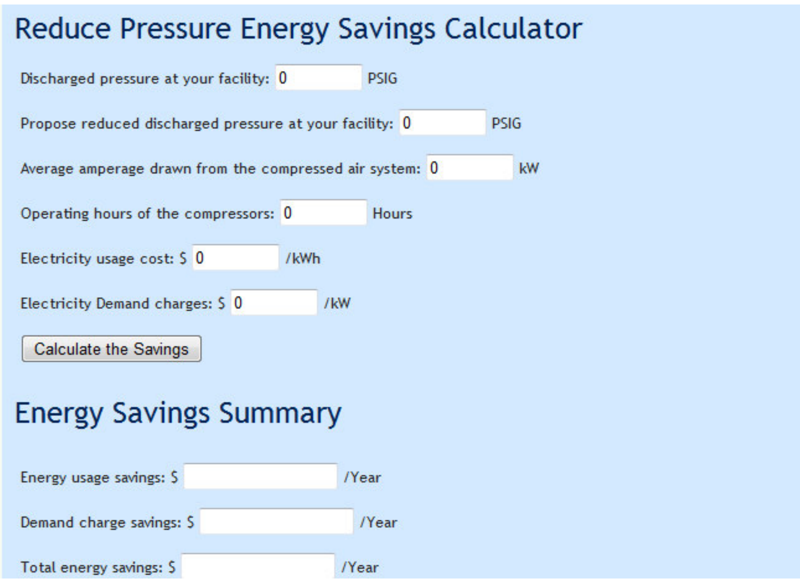


Figure 13 - MoIAC's web-based task-centered workbook of MoIAC's: live calculator to support data collection and calculation for specific best-practice (Wu, Ponte and Pinthuprapa 2011).

Since its development and implementation, the framework has proven to be effective in helping educating the next generation of energy-savvy engineers amongst the current college student population, as well as helping industrial organizations to achieve energy efficiency in practice. According to statistics, this is a popular site, resulting for example above 6,500 visits over a period of two months in 2009 when statistical data were collected.

The tool alone however is not sufficient for an effective energy efficiency initiative. Instead an overall company initiative is needed and the tool is a support function to help implement the needed tasks.

2.6 Empirical methodologies for energy efficiency implementation

This section gives three examples of existing methodologies for the implementation of energy efficiency. The first case study is an industrial application of energy efficiency in the 3M company and it is a great example of how to used Lean Manufacturing Tools to implement energy efficiency projects. Given that energy efficiency starts in the buildings, i.e. lighting and heating and cooling, the next case study review a green building project from Wisconsin which shows a great planning process and creative energy efficiency funding opportunities for businesses.

2.6.1 Lean manufacturing and energy efficiency - The 3M company case

Since 1990, 3M started to track and worked on reducing greenhouse gas emissions world wide. Between 1990 and 2009, they were able to reduce 77% of greenhouse gases and between 2006 and 2011 they set an additional target of a 5% reduction (3M 2011). In 2009, they exceeded this target and were actually able to reduce 56% of their GHG emissions.

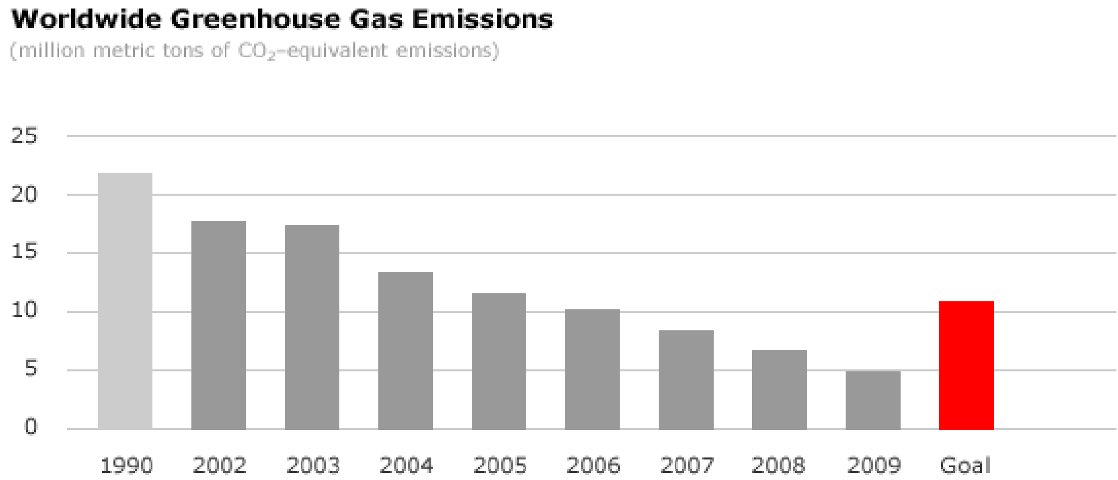


Figure 14 – 3M global GHG emission reduction trend (3M 2011)

Energy efficiency has been a large contributor to the success in reducing greenhouse emissions by the company. Between 2000 and 2005 the company was able to reduce world wide energy use (indexed to next sales) by 27% through the use of Six Sigma projects (EPA 2011). The impact is not just beneficial to the environment, as the company was also able to save money and was recognized for its efforts to become green. During 2008, the company implemented 212 energy efficiency related projects for a total savings of $9.7 million USD (Gogreen). 3M has also received the Energy Star Sustainability Excellence Award for Energy Management from the EPA and the US Department of Energy six times in a roll which a record for an industrial company (Gogreen).

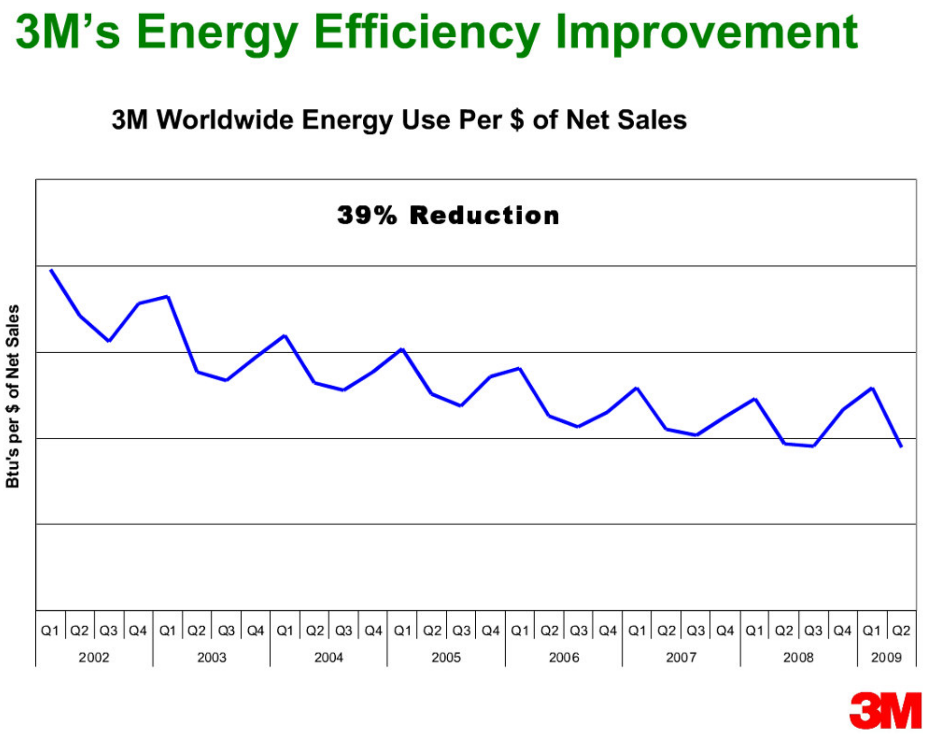


Figure 15 – 3M worldwide energy use, BTU's per $ of net sales (Woodworth 2009)

2.6.2 Green Buildings

The Wisconsin Energy Efficiency (We2) is a success story that can and should be copied all over the United States. The program targets residential, commercial and industrial buildings to become energy efficient and as a side benefit they have proven great cost savings for the owner and or occupant of the building while creating thousands of jobs in the process. The key lesson is in the creative way to pay for the energy efficiency improvements. This is done by creating a payment plan for the energy efficiency investment that is added to the building owner's municipal bill but the payment is always less than the cost savings associated with the investments (Irwin 2011). Irwin explains that if the occupant leaves the property before the completion of all payments, the repayment can continue with the new owner as he/she will also benefit from the cost savings.

The Center on Wisconsin Strategy (COWS) had the first stakeholders' meeting in 2007 which included labor, community and business leaders, state and city official after which the project had enough support to get started. COWS joined forces with the city of Milwaukee and in 2008 began meeting with the local energy utility and a state funded energy efficiency program called Focus on Energy. A pilot project was done in 2009-2010 in a residential area and using grant funding, but since then the Wisconsin legislature was amended to allow local government to bill for the Property Assessed Clean Energy (PACE) program in the municipal bill or taxes.

Now the Milwaukee Energy Efficiency (Me2) focus in 2011 is to also target business. Their website provides homeowners and business owners the opportunity to visit with an "Energy Advocate" whom will then guide them through the process of an "energy evaluation," funding opportunities and payment plans.

2.6.3 Energy efficiency implementation in industrial companies

In April 2010 the Pew Center on Global Climate Change released the report "From Shop Floor to Top Floor: Best Business Practices in Energy Efficiency," which is a result of a 2 year research on energy efficiency best practices from leading companies. The project also entailed several workshops, research in the corporate energy field, and development of a website with resources for companies that wish to undertake an energy efficiency initiative. The findings are organized in the following main sections: organization wide principles and practices ("The Seven Habits of Highly Efficient Companies"), internal operations which focuses on best practices for manufacturing processes and facilities, supply chains where companies work with suppliers to improve their energy efficiency and hence improve the entire value chain, and products and services which focuses on ways to design and market energy-efficient products. Following is an overview of the organization wide and internal operations best practices which is the focus of this research.

2.6.3.1 Organization wide principles and practices

A key lesson from the study is that today, an energy efficiency initiative needs to go beyond improving lighting, compressed air, boilers, HVAC and motors which they call the “boiler-room mentality of the 1970’s” (9). Instead, a company widespread approach is necessary in order to achieve: 1. Improvements in “bottom line values,” i.e. through energy efficiency investments with quick payback that immediately affects the bottom line (13), 2. Improvements in productivity, i.e., when using innovative technologies, reducing waste, and reducing non value added time, 3. Innovation by engaging employees in coming up with energy efficiency ideas so as to meet company targets for energy use reduction, 4. Risk reduction by having a well managed energy use program and hence become less volatile to market price changes, 5. “Top line benefits” by transferring the knowledge gained when applying energy efficiency internally to customers as new products and services (14), 6. “Human capital value” by engaging employees in a positive initiative, which in turn improves morale and job satisfaction (14), 7. “Reputational value” among employees and the public by publishing improvements in carbon footprint (14). Thus for such improvements to be realized, the company need to include energy efficiency a part of the company’s strategy, establish clear leadership, accountability and goals, have a robust data collection system, provide resources (human and capital), reward and publish success. These are the 7 Habits of Highly Efficient Companies presented in report:

1. Efficiency is a Core Strategy

- Efficiency is an integral part of corporate strategic planning and risk assessment and not just another cost management issue or sustainability "hoop" to jump through.
- Efficiency is an ongoing part of the organization's aspirations and metrics for itself.

2. Leadership & Organizational Support is Real & Sustained

- At least one full-time staff person is accountable for energy performance.
- Corporate energy management leadership interacts with teams in all business units.
- Energy performance results affect individuals' performance reviews and career advancement paths.
- Energy efficiency is part of the company's culture and core operations.
- Employees are empowered and rewarded for energy innovation.

3. The Company Has SMART[29] Energy Efficiency Goals

- Goals are organization-wide.
- Goals are translated into operating/business unit goals.
- Goals are specific enough to be measured.
- Goals have specific target dates.
- Goals are linked to action plans in all business units.
- Goals are updated and strengthened over time.

4. The Strategy Relies on a Robust Tracking & Measurement System

- The system collects data regularly from all business units.
- The data is normalized and baselined.
- Data collection and reporting is as granular as possible.
- The system tracks performance against goals in a regular reporting cycle.
- Performance data is visible to senior management in a form they can understand and act upon.
- Energy performance data is shared internally and externally.
- The system is linked to a commitment to continuous improvement.

5. The Organization Puts Substantial Resources into Efficiency

- The energy manager/team has adequate operating resources.
- Business leaders find capital to fund projects.
- Companies invest in human capital.

6. The Energy Efficiency Strategy Shows Demonstrated Results

- The company has met or beat its energy performance goal.
- Successful energy innovators are rewarded and recognized.
- Resources are sustained over a multi-year period.

7. The Company Effectively Communicates Efficiency Results

- An internal communications plan raises awareness and engages employees.
- Successes are communicated externally.

Figure 16 – The Seven Habits of Highly Efficient Companies, extracted from the PEW Center on Global Climate Change report "From Shop Floor to Top Floor: Best Business Practices in Energy Efficiency" (26).

2.6.3.2 Internal operations

The best practices related to internal operations are also organizational but focused on manufacturing challenges. The first best practice discusses how the energy efficiency team shall be selected and how the organization chart may look like in the overall organization. One key message is that the team must be cross functional, that is include "technical or engineering function, an operations function with direct management responsibility for key facilities, an environmental/health and safety function, an energy procurement/accounting function, and the sustainability function" (35). Given the variety of backgrounds, participants most likely will not spend 100% of their time on the energy efficiency team. The resources selected must also come from different levels of the organization, i.e. from senior management all the way down to line operations supervisors.

The next recommendation is to overcome organizational barriers, for example by getting buy in from operations managers. Toyota used energy efficiency teams from different factories in the "treasure hunts" the company performs in all factories (37). Pilot projects are also essential to prove the solution before wide implementation and hence minimize disruptions in manufacturing. Another great suggestion to overcome organizational barriers is to catalogue all projects in a centralized database so that small scale projects when combined with all other energy efficiency projects will also show its value.

Data collection and reporting is also discussed as an important element for a successful implementation of energy efficiency projects. The report highlights that all business units must report energy data that can be used to track consumption as well as cost, that the data must be normalized and baselined for all units (i.e., BTU / product produced), and that the reporting must be as detailed as possible (i.e, per machine or process) specially for those high energy consuming sites. Furthermore, the data need to be used as a monitoring tool that will drive continuous improvement.

The financial obstacle is another topic explored by the report as projects requiring funding usually are driven by internal operations. One way to overcome financial obstacles is to set strong energy efficiency targets and to make sure that the company's management team's priority is energy efficiency. In addition, project justifications must also take into account productivity improvements, risk management as companies become less vulnerable to energy price changes, better workplace for employees, and improved company reputation.

Last but not least the report addresses perhaps the most important aspect of a successful energy efficiency initiative: cultural change within the organization. Recommendations in this area include going beyond the "energy box," that is instead of just reducing energy consumption, ask the question do we need this process at all? How can waste of one process become the input of another, for example heat recuperation. Fostering innovation through involvement of all people in the organization and encouraging them to look at their processes closer and engage in continuous improvement projects. Recognition of employees from the workshop to the top management plays an important role in changing culture. Energy efficiency initiative furthermore has the benefit of reaching out to most people's core beliefs; that energy efficiency is needed and hence employees have not difficulties supporting the initiative and most are energized by such projects.

2.7 Summary

Although systems engineering and ecology were combined decades ago to lay the foundation for industrial ecology, the concept remains a foreign topic for most manufacturers. Systems engineering concepts have since been used to map the interconnectedness of the different inputs and outputs to industrial systems, but the problem remained a large one. Hence, a manufacturing company cannot easily implement industrial ecology tools because the process lacks a clear unified methodology. There are, however, many useful industrial ecology tools currently being implemented by the industry such as design for the environment, which expanded a familiar tool (design for x) and applied for environmental needs. Converting a familiar tool to also tackle environmental concerns is the also the idea behind a Lean and Green way of production. That is, energy efficiency needs to be incorporated into existing lean manufacturing tools and new KPIs developed to track energy consumption and cost just as important as cost of poor quality, health and safety, and productivity. Six Sigma, Kaizen, and Lean Manufacturing are examples of industrial engineering tools that are currently being used for industrial ecology applications. This has been the case for 3M which was able to reduce greenhouse gas emissions through the implementation of six sigma projects, 212 of which were related to energy efficiency in the year 2008. This resulted in 9.4 billion USD in savings for the company and put them in a leading position as an environmentally conscious company.

The activity that followed the 1989 “Strategies for Manufacturing” article is certainly exciting, but the industrial ecology revolution is yet to come about. Industrial ecology is still not a focus point on the agenda of major corporations and politicians. James Kay (2002) mentions three basic reasons why industrial ecology hasn't been implemented since its initial attempts in the late seventies: a lack of ecological economics, the inability to fully analyze mass-energy flow systems, and the lack of a complete understanding of how ecological systems work (p. 73). Hall et al., 1986, provides a comprehensive study on the energy framework necessary for economic analysis and more recently John Ikerd (2005) in Sustainable Capitalism agrees that the cost of nonrenewable resources should be incorporated in the economical models of today. A new economical model is certainly needed in the long run in order to take into account the true value of non renewable resources and to correct the fact that non-renewable resources are finite. This will require time and for several sectors of the community to work together, that is, governments to improve environmental policies, economists to agree on proper value of non renewable resources, and the public to quickly adapt to the new prices for commodities.

A new green economics framework which emphasizes the need for green collar jobs focused on energy efficiency, food, water, waste and transportation present an immediate solution to two pressing issues: environmental degradation and social inequalities. Energy waste being a key source of greenhouse gases emitted by the industrial sector provides the immediate solution that is needed today to reverse the effects of climate change. Green economics together with the supporting environmental policies provide a stronger motivation for change. That is, binding agreements to reduce greenhouse gas emissions propel nations into investing in renewable resources, becoming leaner in the way we utilize natural resources, and developing new technologies for sustainable development. Unfortunately not all nations have signed legal binding agreements such as the Kyoto protocol and therefore it is crucial that the scientific community provides the industrial sector with tools to implement sustainable development from a proactive way rather than having to comply with regulations. The ISO 50001 Energy Management Standard provides the key ingredients for the management system that if combined with a task centered approach for implementation will give any company independent of size a low cost way to implement an energy efficiency program. The key for a successful implementation however rely on a few key ingredients: overall company involvement from employees in the work shop to top management, proper structure for the incorporation of energy efficiency into the company's existing goals, proper resources starting with a multifunctional organizational structure that will work on energy efficiency tasks and overcoming funding obstacles, proper data collection and monitoring, easy to use tools for implementation, continuous improvement through innovation, and specially culture change through training and employee recognition.

3 METHODS

To overcome the obstacles, a systematic approach is needed to help the industrial sector to effectively initiate and implement an energy efficiency program in a logical manner. Approaches and tools are needed by industrial organizations to help tasks in the key areas:

- *Institutionalization of best practices* in the organizational and operational structure: analysis and investigation of a organization's specific needs, identification of best practices guides and operational procedures, documentation
- *Education and training of personnel*
- *Selection and execution of energy efficiency projects*: planning, data collection and analysis, identification of opportunities, detailing and justification of recommendations, implementation tasks

The solution provided is based on the actual institutionalization of best practices and task based implementation of an energy efficiency program at ABB Inc. The key steps can be organized as:

1. Create a project definition including project stages with identified owners and due date,

2. Define roles and responsibilities,

3. Identify needed resources necessary for the energy efficiency initiative,

4. Define key energy performance indicators,

5. Create a system for data collection to set the base line and later for monitoring and continuous improvements,

6. Benchmark,

7. Institutionalize best practices,

8. Implement pilot projects and training,

9. Institutionalize a web tool

10. Roll out initiative,

11. Measure and monitor data,

12. Start over as a continuous improvement program.

At first this process will follow a project format with a finite due date, however the goal is to have a continuous cycle where improvements are made each round (see fig. 10). That is, the process will start with a commitment from the managers through a project definition which will then become a Policy Statement. The next step is the adaptation of best practices as company rules, but as the project evolves, the tool will be institutionalized and further improved to fit the organization needs along with process specific instructions. Implementation and Operation of the instructions shall have a finite date, but advances in technology will require future revisions to the instructions and new implementation phases. Through constant monitoring of data, energy audits, and employee incentives for innovations, new opportunities for improvements will be identified. Through management reviews the Policy shall be revised and the continuous improvement cycle starts again. The process is by no means stagnant. Instead, the process follows a systems approach which requires continues improvement to be successful.

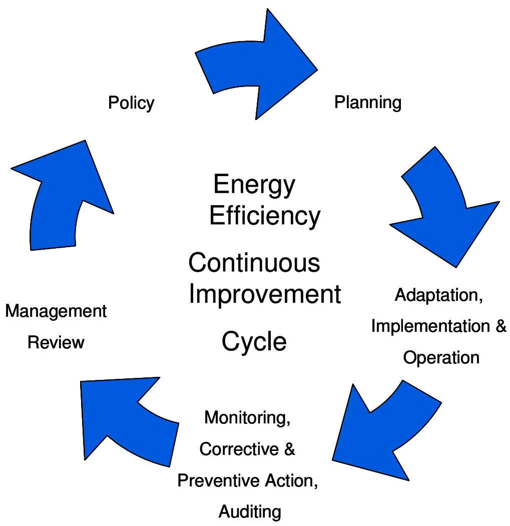


Figure 17 - Energy Efficiency Continuous Improvement Cycle

The actual implementation of each step shall be supported through a task based framework detailing what is needed based on each layer of the framework. See fig. 18.

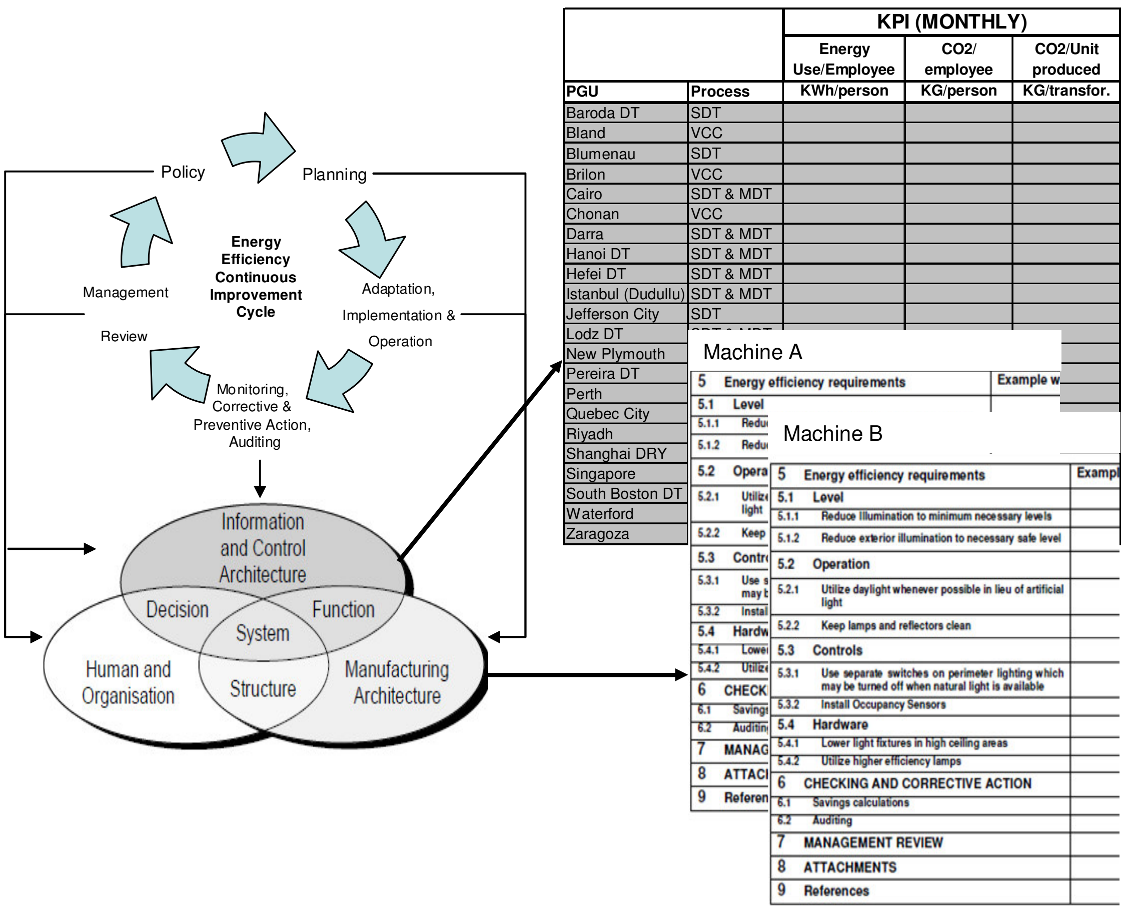


Figure 18 – Energy efficiency overall initiative including tasks examples

3.1 Planning

This case study involves one of the largest industrial organizations in power and automation, with approximately 400 manufacturing sites and offices based in 100 countries and employing 117,000 people. The company's management model is vertically integrated, where 2 organizations, e.g. Sustainability and Facilities worked in parallel without a clear alignment of goals (see fig.7).

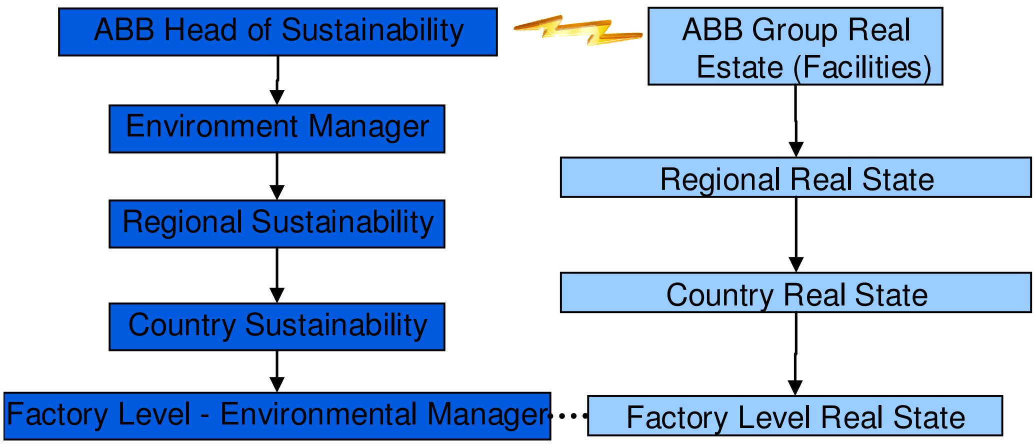


Figure 19 – Sustainability and real state organization chart (recreated as courtesy of ABB Inc.)

In some levels of the organization chart there are several employees holding the same function, for example at least 6 regional sustainability managers, 150 country managers, 400 or more environmental and real state (facilities) managers. Despite of a large number of employees involved in environmental and facility improvement functions, very little had been done to initiate real change in the factory floor regarding energy efficiency. Where projects had taken place successfully, they were isolated and not copied in other locations. The facilities managers main focus are maintenance issues while the environmental managers' main concerns were with fulfilling of local legislation regarding environmental law both without direction for energy efficiency.

Energy efficiency was addressed in the development of new products, which were designed and marketed as energy-efficient products. The factory floor however was not addressed and this was due to the following obstacles at ABB Inc.:

- Two vertically integrated hierarchies working in parallel with little cooperation and no real intention to implement energy efficiency,
- Lack of an energy efficiency manager at the corporate level,
- Lack of technical expertise, poor data collection, no accountability, i.e. impact in the employees' culture or performance reviews,
- No meaningful recognition for energy efficiency improvement internally or externally. The improvements that did occur within the organization were not shared, i.e. the vertical hierarchy that was in place for decades allowed for local solutions where each country was re-inventing the wheel and best practices were not being shared.
- The operations people where not involved and hence resisted any initiative that did not directly effect their key performance measurements which did not include energy efficiency.
- Although people resources were available, they did not have the right direction, tools or expertise to start the process.

Hence this became a clear case to illustrate the current situation and case study for an energy efficiency initiative.

3.1.1 Define roles and responsibilities

The first step to plan the energy efficiency initiative is to change the current perspective of energy efficiency at the corporate level. Both the corporate sustainability and facilities teams need to see that energy efficiency has to be a part of every day life throughout the entire organization and not just the facilities and environmental groups. That is, energy efficiency affects that entire value chain and hence needed to be a part of the overall company strategy.

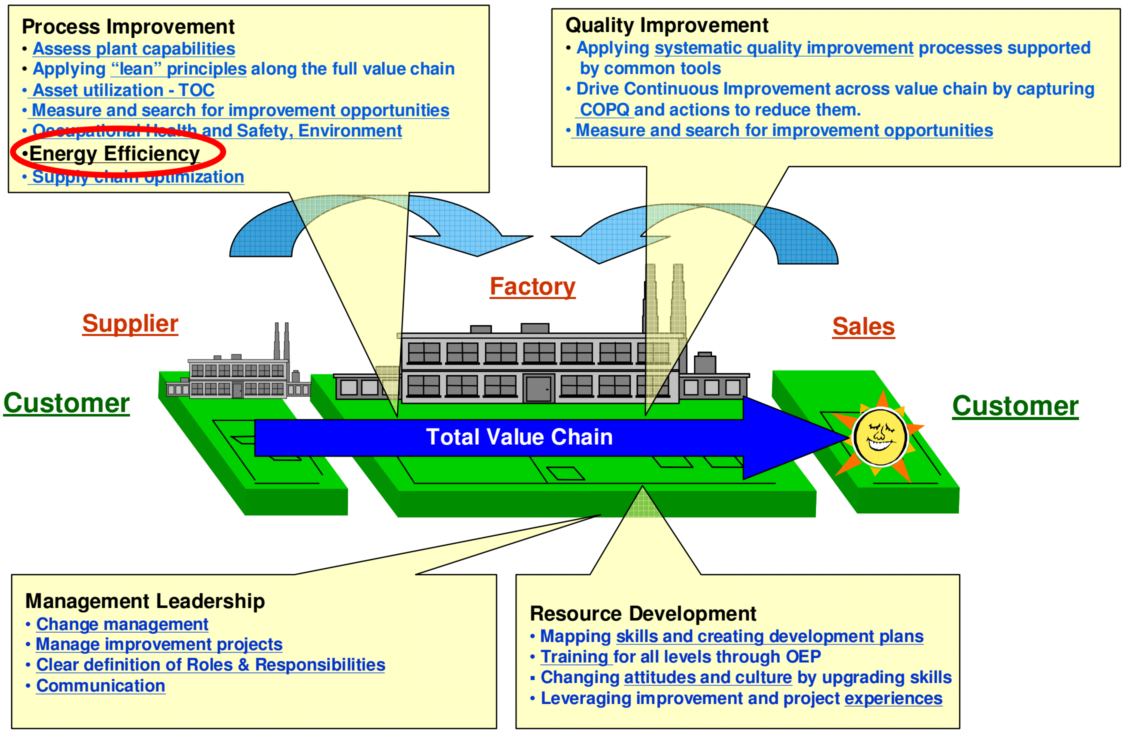


Figure 20– Excellence in operations lacked energy efficiency (courtesy of ABB Inc. 2011).

Support for the initiative need to exist at the top level or at least managers at the division level must support the project so that there is buy in and support throughout all levels of the organization. Next, a clear definition of roles and responsibilities must be established at this first stage beginning with an energy efficiency position at the corporate level. The role of the energy efficiency manager is to lead the initiative for that business unit while involving resources throughout the entire organization and not just facilities and environmental managers. With the technical expertise, sharing of best practices across countries and regions, and a leader to coordinate the initiative, the company is ready to start.

3.1.2 Establish a base-line data

Perhaps the most important piece of the planning phase is to create a systemic and comprehensive data collection system that is uniform to the entire organization. Management shall expect that every factory around the globe collect data in the same manner and report on time each reporting period. A common global database is ideal, but a simple standard spread sheet can accomplish the same. At this stage is important to establish a baseline based on meaningful Energy Performance Indicators. The more detailed the data the better and this can vary based on the level of consumption of each process and/or factory.

3.1.3 Benchmark

Reviewing the data will give some direction of where to focus, i.e. which locations are most energy efficient or not and which have the most energy needs. Based on findings, begin a company wide benchmark for best practices, current solutions and company standards. If available, the current global standards should be used as starting point along with international standards such as ISO 50001 Energy Management Standard and EN Directive on Energy Performance of Buildings (2002/91/EC). Choosing an international standard early on is important so that the company instructions will follow the same logic and flow as that of ISO 50001 for example. Also, the company rules shall not contradict those of the chosen international standard, but go beyond those rules when deemed necessary. Once the company rules are formally issued, factories in different countries will have to do a gap analysis between their local country rules and global company standards, and always follow the highest requirement. The next step is to Benchmark factories in different countries within the organization and also visit factories outside the corporation, if possible, so that best practices are collected and can be used in the future standards to be developed.

Once baseline data is analyzed, international standards are selected, existing instructions and policies are reviewed, benchmark is completed and best practices selected, the company is ready to move to phase 2 of the initiative. Figure 21 shows the key implementation phases and subtasks.

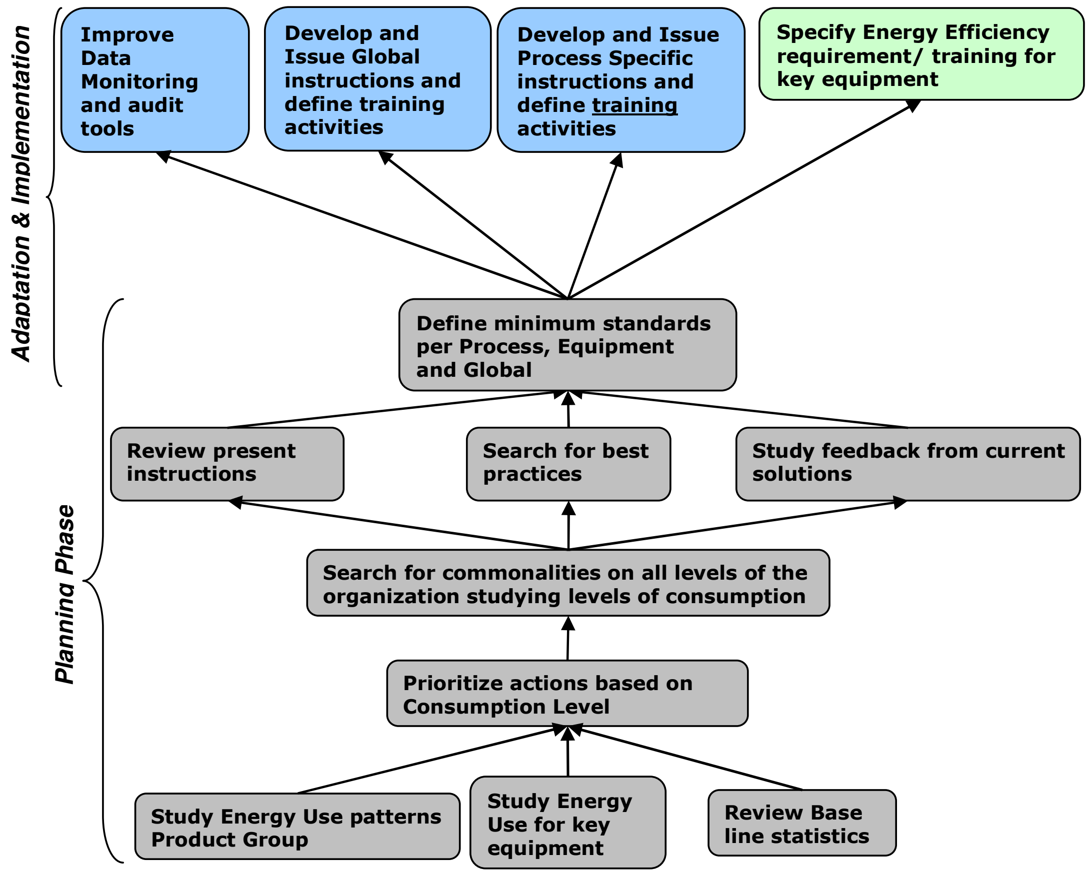


Figure 21– Bottom up solutions with the support from top down management approach

3.2 Adaptation, Implementation & Operation

During the Adaptation, Implementation and Operations stage, an energy efficiency team must adapt existing best practices and international standards and create the company's task based instructions. The instructions need to be detailed on how to implement the standards and best practices collected, i.e. they shall not be high level but provide the tools needed to implement the requirements through the use of best practices.

One of the Human and Organization tasks is to provide a task based instruction stating roles and responsibilities including who is responsible for setting yearly targets for energy efficiency. For example, the corporate energy efficiency manager is to set a yearly target for carbon reduction. The regional manager then has to make sure that the country and local factory managers have the resources and select the correct projects to achieve the target. Information and Control task instructions will include a KPI reporting instructions to describe the method for data collection, how often to report and the definition of each target and auditing instruction shall be developed to describe internal audits process, audit tool, and audit frequency.

Through adaptation and institutionalization of the web tool, the next level of instructions will be developed. The instructions will cover 5 key areas that will provide detailed instructions on how to comply with the EN green building directives. These are lighting, Compressors, HVAC, Motors and Heat Recuperation.

The last group of instructions to be developed will be process specific and will depend on the type of production. The key is to map the process and identify high energy consumption equipment or frequently used equipment and write a supplier agreement instruction stating all requirements from the energy efficiency point of view. This document will be given during the request for quotation along with the requirements for quality, capacity and safety.

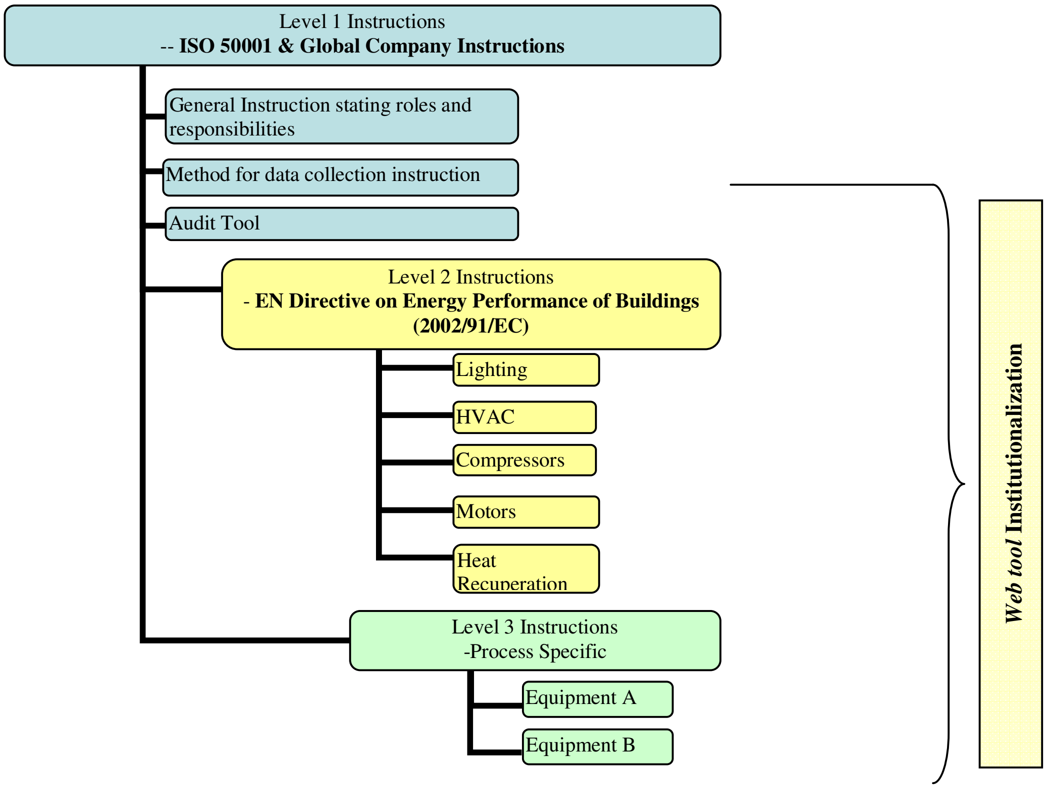


Figure 22 –Adaptation and Institutionalization of Best Practices

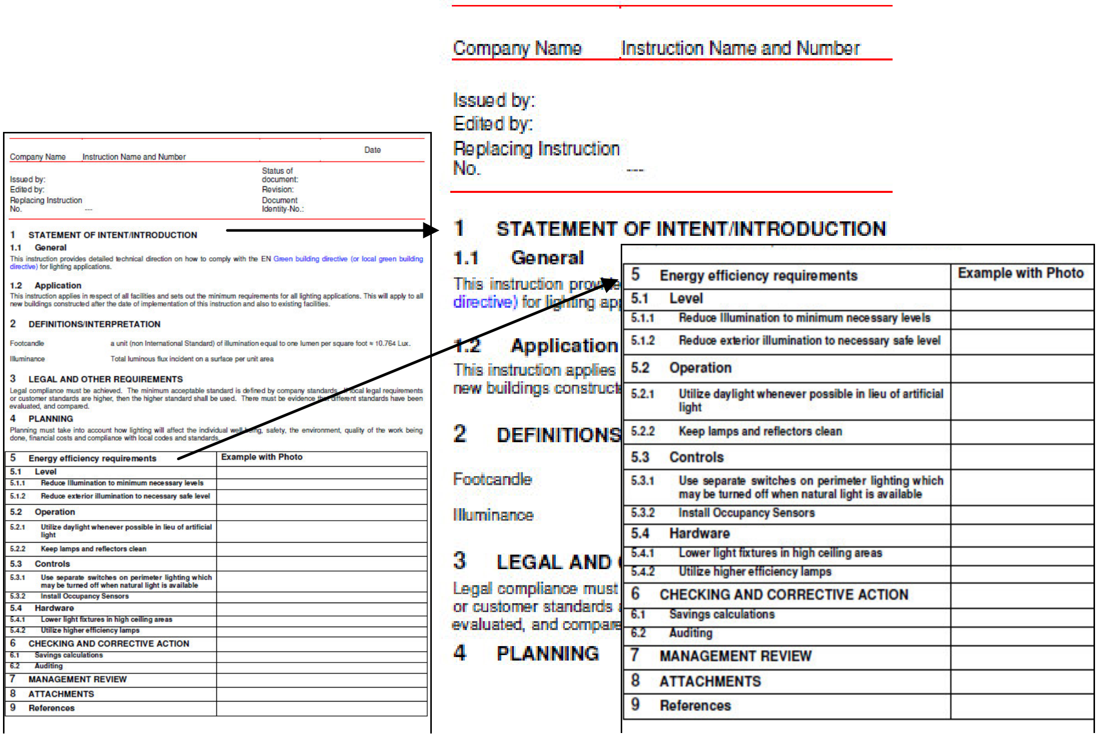


Figure 23 – Instruction template following ISO 50001 framework

Once the instructions are developed and formally issued, a training session should be given to the general managers, operations managers, engineers, facilities managers and environmental advisors of the factories. The training will serve as a brainstorming session and to give a chance for the participants to discuss the instructions and answer questions. During the training, the participants from the factories whom are assigned to implement the instructions are required to provide a time line for the project which agrees with the final due date determined at the division level.

Both financial commitments and people resources shall be defined and agreed upon during the training phase so that projects will be completed within the established due date and budget. Investment monitoring, payback calculations and technical support shall be done by the energy efficiency teams, whom shall be supported by the corporate energy efficiency manager periodically.

For equipment specific instructions (level 3), the company should aim for a common solution and therefore select common suppliers and do a pilot projects before rolling out in the different sites. This will ensure that the new requirements will not interfere with the equipment performance and cost is kept under control.

3.3 Continuous Improvement

The proposed methodology shall follow the upcoming ISO 50001 Energy Management Standard. Figure 17 depicts the system thinking process, and as explained, the project will be institutionalized as the company strives for continuous improvement. This can only be achieved by constant monitoring of data, which will trigger audits, which in turn will generate the need for innovative solutions from within all levels of the organization. This creative atmosphere can be achieved through setting of aggressive KPIs, rewarding employees for their innovations, and publishing achievements.

3.3.1 Checking and corrective action

From the start of the project, through the implementation phase and finally to achieve a successful continuous improvement process, data collection and evaluation need to be done properly and periodically. The level one instruction, “Method for Data Collection,” shall describe the process to collect, report, and analyze the data.

The data will trigger the need for an Energy Audit which shall be conducted based on the Energy Efficiency Instructions and Audit tool and as a result provide a corrective action report. The audit report shall be issued to the company that will in turn assign a responsible and due date to correct all infractions by implementing innovative solutions that will become the new best practices.

3.3.2 Management review

For the continuous improvement cycle to be complete there needs to be a regular review of objectives and achievements by the management team. That is, based on the achievements and/or shortcomings from the previous year, management need to review the current status, policy statement, and establish new higher goals for a continuous improvement energy efficiency system.

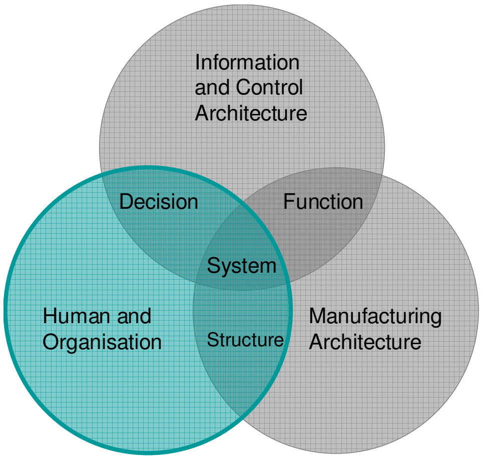
3.4 Policy statement

The last step of the continuous improvement cycle is to go back to the beginning, i.e., based on the current results adjust the goals for the next cycle. As with any management system, a policy statement must be defined in order to clearly state objectives and commitment from upper management for the upcoming year and to define roles and responsibilities regarding energy efficiency. The policy must contain a clearly defined objective, e.g., based on annual CO2 emissions in kg/year and annual energy savings in MMBTU per year. Having a reliable and standard data collection method is therefore a key part of the implementation if improvements are to be measured correctly. The policy must also have the standards and commitment through which the objectives will be achieved. The standards will be the set of instructions containing the rules and guidelines for the organization to follow. The commitment will be achieved by properly defining roles and responsibilities for all levels of the organization (i.e. Regional, Country, General Manager, Operations Manager, and Local Environment and Facilities Managers).

4 CURRENT STATUS

The actual energy efficiency initiative at ABB Inc. started in October 2010 when the first meeting was held. Since then the project has been steadily making progress and current results are shared below.

4.1 Human and Organization Layer



From the analysis to design and finally to operations, energy efficiency has been added as an intergral part of the the Human and Organisation layer. A corporate level instruction is in the process of being developed that delineates roles and responsibilities regarding energy efficiency in all levels of the organization. In addition, a new energy efficiency manager function has been added to drive the initiative. In this case the steering committee nominated the existing occupational health and safety manager to also become the energy efficiency manager at the corporate level. The energy efficiency manager's responsibility as described in the methods section is to roll out the initiative in a given division unifying all regions and countries within that division as they implement in factories world wide. The new organizational chart is as follows:

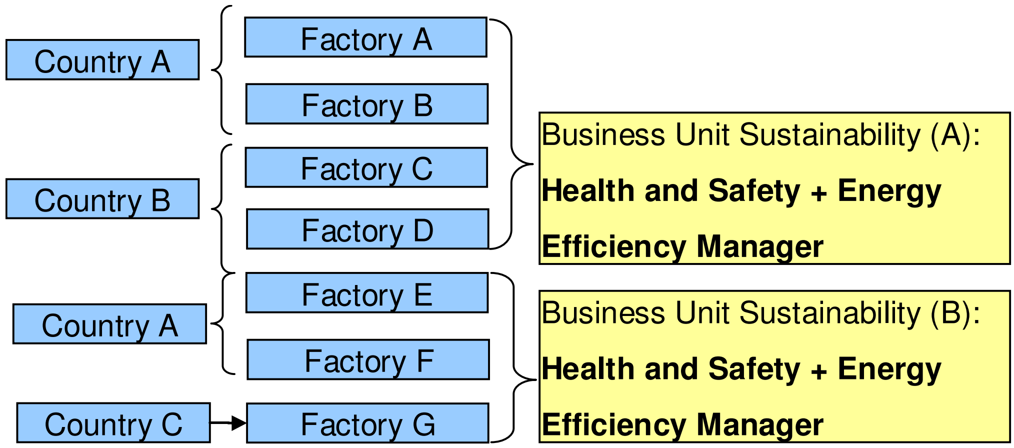
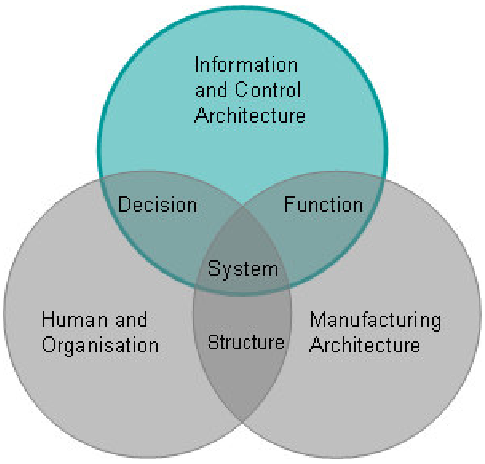


Figure 24 – Addition of Energy Efficiency Manager at the cooperate level (courtesy of ABB Inc. 2011)

Once the improvements are proven in terms of less carbon emissions and energy savings for one division, the same model will then be copied, improved and implemented on other divisions. Currently the initiative is focused on one division – Transformers.

4.2 Information and control architecture



The existing data collection methods were far from ideal for the following reasons:

1. Data looked at the country level and did not go into the necessary details, i.e. per factory, per process as needed.
2. The data was only collected once per year
3. Data based was on Lotus Notes platform and was not user friendly to download and manipulate.

The new system:

1. The addition of new meters in each factory allows data to be compared between factories with equal processes.

2. A monitoring device in some high usage equipment is currently under development that will give instant readings on energy consumption.

3. Data now has to be reported monthly as oppose to yearly.

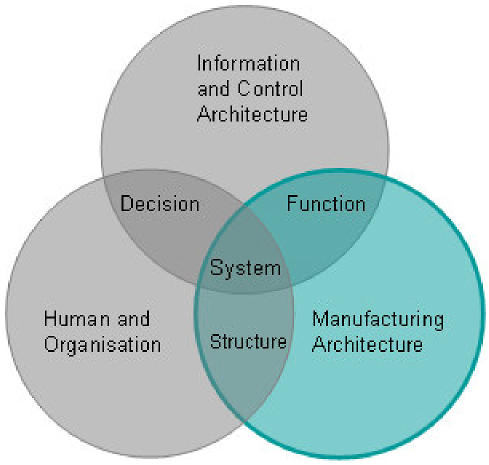
4. Data is web based and can be extracted into a spreadsheet for ease of use.

				KPIs (monthly)				
				Energy Use	Energy Use/Employee	CO2	CO2/ employee	CO2/Unit produced
Region	Country	PGU	Product Line	KWh	KWh/person	KG	KG/person	KG/transfor.
SAS - Sou	IN - INDIA	Baroda DT	SDT					
NAM - No	US - UNITED	Bland	VCC, Resibloc and OW					
SAM - So	BR - BRAZIL	Blumenau	SDT, MDT & DRY					
CEU - Ce	DE - GERMA	Brilon	VCC and Resibloc					
MEA - Mi	EG - EGYPT	Cairo	SDT & MDT					
NAS - No	KR - KOREA	Chonan	VCC					
SAS - Sou	AU - AUSTRA	Darra	SDT & MDT					
SAS - Sou	VN - VIETNA	Hanoi DT	SDT & MDT					
NAS - No	CN - CHINA	Hefei DT	SDT & MDT					
MED - Me	TR - TURKEY	Istanbul (Du	SDT & MDT					
NAM - No	US - UNITED	Jefferson Ci	SDT, MDT and Substation					
CEU - Ce	PL - POLAND	Lodz DT	SDT & MDT					
SAS - Sou	NZ - NEW ZE	New Plymou	SDT & MDT					
SAM - So	CO - COLOM	Pereira DT	SDT & MDT					
SAS - Sou	AU - AUSTRA	Perth	MDT					
NAM - No	CA - CANAD	Quebec City	SDT					
MEA - Mi	SA - SAUDI A	Riyadh	SDT & MDT					
NAS - No	CN - CHINA	Shanghai DT	VCC and Resibloc					
SAS - Sou	SG - SINGAP	Singapore	MDT					
NAM - No	US - UNITED	South Bosto	MDT and LMDT					
NEU - No	IE - IRELAND	Waterford	SDT and MDT					
MED - Me	ES - SPAIN	Zaragoza	VCC					

Figure 25 – ABB data revised (sample) - extracted to a spreadsheet format

4.3 Manufacturing Architecture

4.3.1 Institutionalization of web tool



The existing web tool developed by the University of Missouri is being used as a model for the companys' own system. So far, the best practices available in the tool are being compiled as company corporate instructions. Lighting and Compressors are completed. Motors and HVAC are the next step.

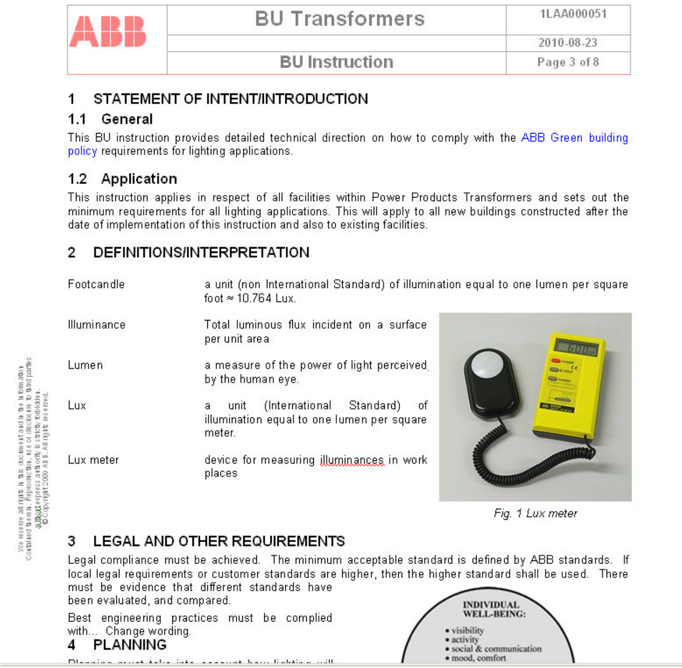


ABB	BU Transformers	1LAA000051
		2010-08-23
	BU Instruction	Page 3 of 8

1 STATEMENT OF INTENT/INTRODUCTION

1.1 General

This BU instruction provides detailed technical direction on how to comply with the ABB Green building policy requirements for lighting applications.

1.2 Application

This instruction applies in respect of all facilities within Power Products Transformers and sets out the minimum requirements for all lighting applications. This will apply to all new buildings constructed after the date of implementation of this instruction and also to existing facilities.

2 DEFINITIONS/INTERPRETATION

Footcandle	a unit (non International Standard) of illumination equal to one lumen per square foot ≈ 10.764 Lux.
Illuminance	Total luminous flux incident on a surface per unit area
Lumen	a measure of the power of light perceived by the human eye.
Lux	a unit (International Standard) of illumination equal to one lumen per square meter.
Lux meter	device for measuring illuminances in work places

Fig. 1 Lux meter

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3 LEGAL AND OTHER REQUIREMENTS

Legal compliance must be achieved. The minimum acceptable standard is defined by ABB standards. If local legal requirements or customer standards are higher, then the higher standard shall be used. There must be evidence that different standards have been evaluated, and compared.

Best engineering practices must be complied with... Change wording.

4 PLANNING

Figure 26 – Lighting instruction example following ISO 50001 format (courtesy of ABB Inc 2011).

The web tool is designed by following the actual manufacturing process. That is, by clicking on one process or task, a list of instructions becomes available, i.e. work instructions, quality instructions, safety instructions and now energy efficiency instructions. All documents shall be available at the operator workstation.

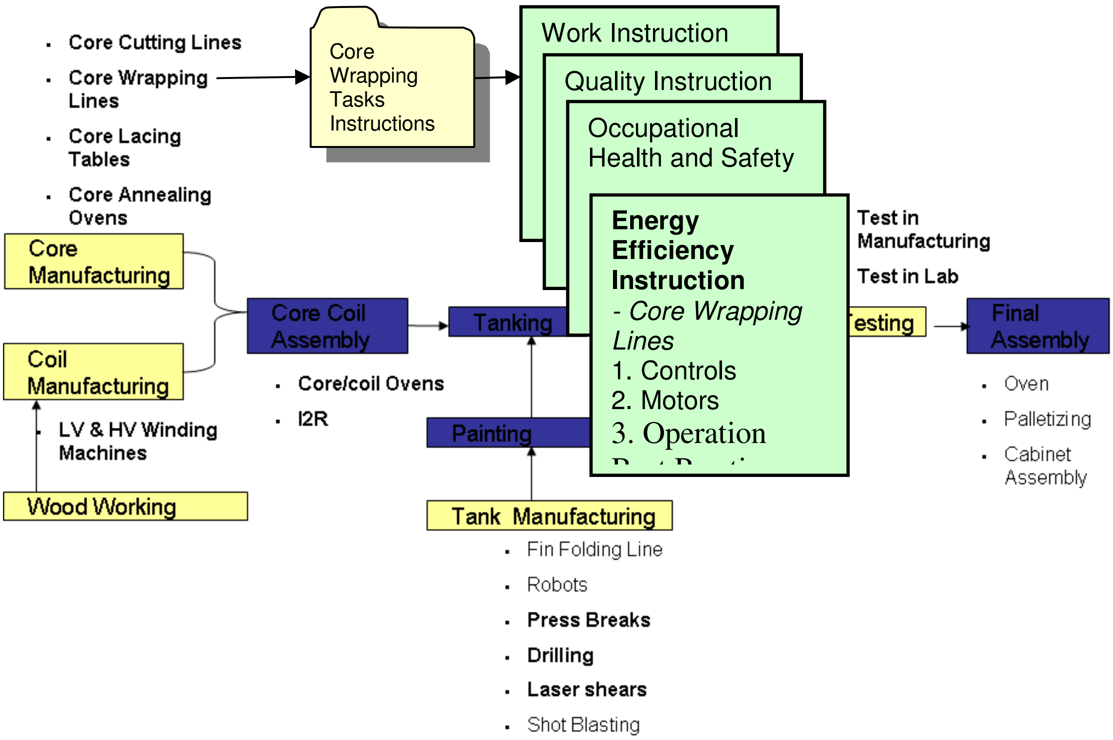

Figure 27- Web tool institutionalized to follow ABB's processes- design phase (courtesy of ABB Inc 2011)

Next the MoIAC's web-based task-centered workbook audit tool shall be also institutionalized to better fit the company needs.

4.3.2 Transformers division expected savings

Based on the current pilot projects taking place in two manufacturing sites, the total cost savings and reduction in CO2 emissions show exciting numbers. For the one site, which employs 150 people in a 243,000 square feet facility, improvements in energy efficiency projects are estimated to $480,000 USD savings per year and a reduction of 14,581,188 lbs or CO2 annually. See Table 2.

Assessment Recommendation (AR)	Annual Energy Savings (MMBtu)	Annual Savings (kW)	Annual Energy Savings (kWh)	Annual CO2 Emissions Reduced (lbs.)	Annual Demand Savings ($)	Annual Cost Savings ($)	Implementation Cost ($)	Payback Period (Yrs.)
AR 1: Apply reflective films reduce solar gain		5,314.20	3,571,154.58	6,570,924.43	$9,193.57	$259,174.39	$46,607.50	0.18
AR 2: Replace windows	7,537.00		1,501,642.00	2,763,021.28	$0.00	$105,114.94	$40,250.00	0.38
AR 3: Clean windows to let heat in during winter months	1,076.00			2,763,021.00	$0.00	$5,750.00	$0.00	Immediate
AR 4: Replace broken windows and/or window sash			22,822.00	41,992.48	$0.00	$1,597.54	$250.00	0.16
AR 5: Install occupancy sensors in areas of infrequent usage			17,326.40	31,880.58	$0.00	$1,212.85	$2,410.00	1.99
AR 6: Replace metal halide with T5 lighting		584.64	202,675.20	372,922.37	$1,011.43	$15,198.69	$10,240.00	0.67
AR 7: Replace T12 with T5 lighting		160.68	14,820.00	27,268.80	$277.98	$1,315.38	$9,660.00	7.34
AR 8: Use separate switches on perimeter lighting which may be turned off when natural light is avaliable			2,662.40	4,898.82	$0.00	$186.37	$300.00	1.61
AR 9: Maintain air filters by cleaning or replacement		49.45	28,847.37	53,079.16	$85.55	$2,104.86	$100.00	0.05
AR 10: Replace drive belts on large motors with energy efficient cog belts		76.58	44,674.22	82,200.56	$132.48	$3,259.68	$0.00	Immediate
AR 11: Eliminate leaks in compressed air lines		167.40	94,720.50	174,285.72	$289.60	$6,920.04	$1,300.00	0.19
AR 12: Power management o desktop computer			43,094.60	79,294.06	$0.00	$3,016.62	$0.00	Immediate
AR 13: Reduce space conditioning during non-working hours			42,000.00	77,280.00	$0.00	$2,940.00	$0.00	Immediate
AR 14: Keep doors and windows shut when not in use			45,644.48	83,985.84	$0.00	$3,195.11	$2,000.00	0.63
AR 15: Insulate product units while heated and tested			168,984.76	310,931.96	$0.00	$11,828.93	$5,000.00	0.42
AR 16: Insulate oven in the air conditioned area			754.40	1,388.10	$0.00	$52.81	$50.00	0.95
AR 17: De-lamping to reduce lighting level		54.72	7,980.00	14,683.20	$94.67	$653.27	$0.00	Immediate
AR 18: Off-peak electrical test		1,200.00		0.00	$12,000.00	$12,000.00		0.00
AR 19: HVAC - Lower temperature during the winter season and vice-versa	1,107.00		401,686.00	739,102.24	$0.00	$28,118.02	$18,000.00	0.64
AR 20: Replace existing HVAC unit with high efficiency model			211,428.00	389,027.52	$0.00	$14,799.96	$48,840.00	3.30
AR 21: Insulate bare equipment	73.50			0.00	$0.00	$1,454.00	$300.00	0.21
Total	9,793.50	7,607.67	6,422,916.91	14,581,188.11	$23,085.27	$479,893.45	$185,307.50	

Table 2. Summary of the assessment recommendations for one ABB Inc. factory including estimated annual savings and annual reduction in CO2 emission

Similar results were observed at the second site where the savings estimation of 3 projects amounts to approximately 939,628 Kwh savings per year (see table 3) and $65,000 USD per year.

#	Energy Savings Opportunity	Annual Energy Savings, Kwh / yr
1	Reduce operating pressure of Air Compressors	58,820
2	Replace Metal Halide Fixtures with 8-Lamp Fluorescent Lamp Fixtures w/ Sensors.	472,000
3	Install Varial Frenquency Drives on Cooling Tower Water Pump Motors	408,808

Table 3 Summary of energy savings recommendations for the second ABB Inc. site

When these numbers are strapolated (based on size and number of employees) to 209 factories that comprise one division of the ABB Inc., the total savings are estimated to be: 50 MUSD.

5 CONCLUSION

The application of the proposed methodology at ABB is proving to be successful. Through a systematic approach and implementation of a task based web tool for ease of use the energy efficiency initiative is starting to show positive results. The creation of an energy efficiency manager at the corporate level is the first sign of commitment from the company to take the project off the ground. The data collection is a crucial step that has been implemented; however meaningful data will take time to be established as the sites become more consistent in reporting. The application of resources to begin institutionalizing the best practices is ongoing and the next step will be to take the web tool design and implement it and launch the site. There is still quite a bit of work but the company is committed to the implementation and the estimated cost savings presented is just the beginning. Culture change through implementation of the task based projects has not yet been realized, but this will happen once the training sessions are given to the employees and energy efficiency becomes part of their yearly reviews and bonus system. The following sections will provide a detailed analysis of the results and a brief discussion on further research.

5.1 Results

The conceptual methodology for the energy efficiency initiative as presented in the methodology section has been approved by ABB Inc. and currently being implemented. A project plan has been designed and includes all aspects of the proposed methodology, i.e. using a systems approach to incorporate energy efficiency in all layers of the organization (organizational, manufacturing and information and control) and implement the technical structured as a task based web tool.

One of the goals of the methodology was to *Create a company wide initiative where the Organization, Processes and Control Measures are taken into account.* This is being accomplished starting at the organization layer. By introducing an energy efficiency manager at the corporate level, the company now has the needed expertise and level of commitment needed to support the factories. Most importantly, an instruction is being developed to define energy efficiency responsibilities for all managers in all levels of the organization which will then ensure that energy efficiency is part of the overall company strategy and not just a topic of the month. The organizational layer is also affecting the *Culture Change* by influencing how energy efficiency is seen by the employees. That is, employees' yearly reviews shall include key performance indicators related to energy efficiency which will elevate the priority of the initiative.

The methodology has provided the needed framework for *Planning and execution of energy efficiency projects*, that is, through a systems approach the project plan required a thorough data collection and analysis at the start, an extensive benchmark of energy efficiency projects inside and outside of ABB Inc., identification and prioritization of opportunities before the implementation.

For the next step, the methodology requires the *Institutionalization of best practices* found through benchmarking inside and outside ABB Inc. This way, ABB's specific needs based on existing manufacturing platforms are being addressed through the development of *User friendly tools* for implementation (i.e., web based audit tool, instructions, payback calculation formulas all in one central location), measuring progress by having a centralized and detailed data collection database which allows managers to easily download and monitor KPIs. Before the roll out of projects a training program will be launched so that employees will have a chance to brainstorm on best solutions, form energy efficiency teams, set goals for the upcoming year and thus begin the company wide *Culture Change.*

Through this research and implementation at ABB inc. both academic and practical achievements were possible and the results are summarized as follows:

Academically:

- Development of a framework to help manufacturing companies achieve energy efficiency, providing a complete structure based on systems analysis, and including a task based web-tool for training and implementation.
- Incorporation of energy efficiency considerations into every layer of an organization.
- Means to institutionalize best practices, tools and procedures that can be used for training and during implementation.

From a practical point of view:

- The conceptual framework has been globally implemented within the organizational structure of a major industrial organization, and integrated within the organization's web-based information structure
- Prototype document procedures have been developed within the framework
- A number of detailed operational procedures have been developed and tested
- Work is ongoing to complete the complete set of operational procedures.

5.2 Further research

Future areas of research include expanding the energy efficiency initiative to include suppliers and possible customers of wasted materials hence creating the industrial park concept. The application on Key Environmental Performance Measurements into existing engineering tools was briefly mentioned but is an area that needs further research. That is, incorporating Key Environmental Performance Measurements into familiar tools such as Value Stream Mapping, Theory of Constraints, 5S, Kaizen, and Visual Management is the logical approach to industrial ecology and can be an integral part of the continuous improvement to programs such as energy efficiency.

Industrial ecology as a discipline lacks an overall framework which can unify all available tools that support sustainable development. Table 1 gives an example of the various topics and how they support sustainable development, however this needs to be expended and tools categorized for industrial, commercial and residential sectors.

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