EXPERIENCES INTEGRATING PRODUCTIVITY, POLLUTION PREVENTION, AND ENERGY CONSERVATION INCLUDING CASE STUDIES

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ABSTRACT

Energy auditors have traditionally considered energy conservation opportunities as being independent of other industrial opportunities, such as waste reduction/pollution prevention, and other management issues relating to productivity. Our experience has indicated that energy conservation decisions are not viewed as independent by management in industry, and that many otherwise attractive modifications are not undertaken due to their relation to other production issues. The energy audit team cannot afford to be naive to the bottom line corporate mentality of the industrial managers involved. If a recommendation cannot be shown to have a secondary or even tertiary benefit to the company, the project cannot be "sold" to management.

In this paper we introduce an integrated system approach in which we consider such factors as risk, internal yields, and defect rates, and a procedure we call "industrial triage", using experiences gathered from assessments at a styrofoam cup manufacturer, glass bottle manufacturer, and a tire manufacturer. These companies are similar in that the raw materials can be recycled back into the product in the event these materials are spilled, misused, are incorporated in "internal" defects, or otherwise wasted. Such firms consistently report that they have little or no defects, since they do not have a specific expense in disposing of the defective product.

Energy-only recommendations can have little or no impact on the productivity of a manufacturing plant. Worse, these recommendations can have a negative effect, or be considered too risky. In many industries, energy costs are a small portion of the production costs. Competition for capital is strong, and equipment purchases that increase production, or profits, will generally be favored. Internal defects have costs that are difficult to measure or estimate, such as labor for rework, moving or relocating the materials, space to warehouse raw materials or products, or even space to expand operations. An intimate knowledge of a corporation's burden, market share, and financial stability is necessary in order for the assessment team to gain the confidence of management; failure to do so can be disastrous. Excessive movement, redundant inspections, scheduling issues, and floor layout are critical issues, and ones that are sometimes impossible to evaluate during a short visit to a plant.

Before an energy audit is made, much information must be gathered, such as tax rates and purchasing policies (including acceptable defect rates of the raw materials from suppliers). These issues are forcing the one-dimensional energy "expert" to expand into previously uncharted territories. This paper will attempt to illustrate some generic necessities, but also use actual experiences of the Office of Industrial Productivity and Energy Assessment team at Rutgers University in three facilities to highlight the industrial triage method of presenting the client with an integrated package of analysis of the efficiency of their production facility and methods.

INTRODUCTION

The concept of energy auditing was born of necessity shortly after the oil crisis in the early 1970s. While the concept was obviously modeled after the accounting profession, the methodology was immature, and the specialization was not the province of any one existing profession. Energy auditors came out of many different professions. An auditor typically took a shotgun approach to identify energy saving opportunities, and there were many easy targets for conservation in the typical manufacturing plant. Companies were in a panic over the meteoric rise of energy prices, the instability of the oil industry, and the lack of predictability in the market. It was not difficult for an energy auditor to find many inefficient uses of energy, and energy efficiency increased dramatically in the following years. Times have changed, and so has the energy auditing industry; the engineering and architecture professions have accepted the lead. New design of a building, a manufacturing process, procedure, or pieces of equipment now automatically include energy efficiency considerations.

There are many extremely lean manufacturing companies in America today. Those energy auditors who have struggled to find any inefficiencies in such modern manufacturing industries as pharmaceuticals or cosmetics can attest to this fact. The purpose of this paper is two-fold. First to address the concept of re-engineering, that is utilizing existing facilities and equipment, and second to address the concept of the preliminary or reconnaissance audit. It is not difficult to walk into a company, ask what the bottleneck of the production is and simply recommend that they either purchase new capital intensive equipment, or simply construct a new facility on a new site. The challenge is to interrogate, inspect, analyze, and recommend innovative new uses of all of a company's resources - not just energy - to maximize the output with a minimum of investment. This approach may only be useful in fairly modern facilities. Stories abound of attempts to apply this procedure in other countries, only to finally accede to the hard reality that in fact the facility cannot be re-engineered, and really should be torn down, and started over.

Energy auditing can no longer stand on its own; a thorough knowledge of a company's procedures, overhead, yield, and profit are necessary to maintain a credible image. For this and other reasons, the term "audit" will be replaced in this paper by "assessment" defined as an investigation into energy use, waste reduction, pollution production, and productivity. A simpler definition might simply be resource utilization, or sustainable manufacturing.

Some of the experiences outlined in this paper are from the Industrial Assessment Center Program funded by the U.S. Department of Energy. This program has been in existence since 1976, and is a component of the National Energy Strategy. Following an extensive data gathering effort, faculty and students from major engineering schools conduct one day site visits at industrial plants. After the visit the team prepares a report for the manufacturer which has several recommendations written up in sufficient detail to provide anticipated savings, implementation costs and payback times.

Generally speaking, two types of assessments are conducted today. The first is the deep audit in which an engineering consulting firm spends several weeks or months metering, monitoring, and measuring data such as equipment runtime, loading, and electricity consumption. After this a very detailed report is presented to the company. This is a very complete and reliable method, however it is expensive and these firms struggle in the marketplace, since the client does not know what to expect for their money. The second type of audit is the "walk-though". This involves an auditor, usually not intensively trained, going through a plant in a short amount of time, and producing what could be called a "wish list", without numbers to estimate savings or costs. What we are proposing is a type of assessment that lies between the two; a relatively inexpensive assessment that does not take a lot of time in the facility, is non-intrusive, and produces values for anticipated savings and implemented costs. In order to accomplish so much in a short time frame, we propose instituting an integrated team approach with groups concentrating on energy, waste reduction/pollution prevention, and productivity.

INDUSTRIAL TRIAGE

A concept borrowed from the medical profession, triage is a system of priorities designed to maximize success, when confronted with limited time and resources. The trick is to have as much in your toolbox as possible before, and especially during the on-site visit. The first step in our industrial triage procedure is data gathering, both from the client and from available resources, such as the IAC database which contains the results of thousands of industrial assessments. There is no shortcut to getting the information you need (utility bills, sales figures, labor costs) from the plant personnel - it takes questioning, cajoling, and badgering. Once as much information as possible is gathered, potential draft recommendations are worked out in advance, both to predict their potential, and to determine what information will need to be gathered on site. In order to focus recommendations on company priorities or areas of interest, two separate categories are examined which relate directly to productivity.

Increasing Pieces per Person per Hour This includes bottleneck reduction, defect reduction, quick changeouts, labor optimization, and preventive/predictive maintenance.

Decreasing Cost per Piece This includes purchasing, floor layout, inventory, burden/overhead, and scheduling.

These categories are overlapping and somewhat arbitrary. They are only used as a guideline to identify the area of concern to the factory. Now the assessment team will need to make a second attempt at getting the numbers they need from the client by creating a metrics sheet with places for such information as:

Labor Costs -	Skilled union, unskilled union
	Skilled non-union, unskilled non-union
	Fringe Cost of Labor
Cost of Inventory -	Carrying Cost
	Cost of Raw Material
Cost of Space -	Warehouse
	Manufacturing
	Office
Cost/ Per Piece -	(Overhead + Labor + Materials) Cost / Piece
Overhead -	Cost of virtually everything besides direct raw material and direct labor. This number includes energy and waste.
Profit -	(Sales Price/Piece) minus (Cost / Piece)

A sample metrics sheet is offered in appendix A at the end of this paper.

Many times you will not be successful in getting these figures from the client, who will often be unwilling or unable to provide such information. Your final attempt is to prepare default values for every variable. Inform the client that you are going to use these values as you interview them, and try to get him or her to either agree or disagree to the reasonableness of the values. If they disagree, attempt to get them to offer a better approach. This allows the client to keep the information they feel is most private from appearing in a report. It will also allow you to present the strongest case for your recommendations. We suggest that you show all of these figures in your calculations so that the client can modify any of them with more accurate information. Remember to make sure your estimate of cost/piece adds up to 100%. Another piece to develop for your toolbox is ballpark savings estimates. Create a table of a number of typical recommendations using reasonable numbers for your part of the country. A sample of such a exercise is shown tables 1 and 2.

Cost savings numbers are based on the following assumptions:

- The average cost of electricity is $0.05/kWh
- The average cost of natural gas is $0.350/ccf.
- There are 2,000 hours per year per shift (based on the assumption that one shift is 8 hours per day, 5 days per week, 50 weeks per year)

Table 1. Rules of Thumb and Cost Estimates For Energy Systems

Cost of high pressure steam leaks	**$150 to $500/leak/shift/year**
Cost of low pressure steam leaks	**$30 to $110/leak/shift/year**
Cost of compressed air leaks	**$30 to $90/leak/shift/year**
Evaporation of water in a cooling tower	**$9/ton/shift/year**
	$3/gpm/shift/year
Operating cost of a typical motor	**$62/hp/shift/year**
Heat lost through hot, uninsulated pipes	**$375 - $515/100 ft/shift/year**
Costs for comfort heating	**$0.24/ft^2/yr - $0.35/ft^2/yr**
Costs for cooling office spaces	**$0.12 to $0.52/ft^2/yr**
Cost of standard fluorescent lighting	**$4.60 $/bulb/shift/year**
Cost of T8 fluorescent lighting	**$3.10 $/bulb/shift/year**
Cost Savings for Demand Reduction	**$120/kW/year**

Table 2. Rules of Thumb and Cost Estimates for Waste Minimization

Cost per Cubic Yard of Solid Waste	$ 30 per cubic yard
Landfill (Hazardous)	$ 250 / 55 gal. drum
Typical Water Costs	Water Consumption = $2.50 / ccf
	Sewer Charge = $2.00 / ccf
Minimum Ventilation Requirements	0.1 to 0.25 cfm per square foot
	5 to 15 cfm per person
Conventional air atomized paint spray	30 - 60 %
Powder Coating	90 - 99 %

NOTE: These values are never used directly in the end result of an assessment report, but they are only referred to while in the plant to quickly evaluate whether or not to proceed with an idea. Remember, the plant manager's time is an extremely valuable commodity. The three case studies are presented here to illustrate these principles.

PLASTIC CUP FACTORY

The first case study is a company that produces expanded polystyrene cups. The process of manufacturing cups is briefly described. Expandable polystyrene is screened to obtain the desired size of material for the process. The polystyrene is mixed with zinc stearate then with steam and compressed air in a "pre-expander". Steam and polystyrene are injected into a mold, the polystyrene expands, and is cooled by approximately 120°F water. Cups are ejected from the mold by compressed air, tested, labeled and packaged. Cups are moved throughout the process by compressed air eductors.

The use of compressed air was extensive and seemed a likely candidate for examination relating to energy savings since there was over 1000 horsepower of compressors. As in many plants, there were substantial leaks, and these were counted and recorded. Another typical point of investigation is the location of the intake air, since many companies inject warm inside air instead of piping cooler outside air to the compressors. In this factory the intake ducting was followed to the roof where we were surprised to find that hot, humid mist from the cooling towers was being drawn directly into the system. A considerable amount of energy was used to remove water from the air before and after compression. Initial calculations showed that the company could save over 700 million (MM)Btu/yr and $17,000 by moving the intakes of the compressors. A compressor manufacturer stated that there was also likely to be a maintenance saving by implementing this recommendation, however they were hesitant to put a number on it. Maintaining the compressors was costing the company $11/hp, so we conservatively estimated a 10% reduction of compressor maintenance costs.

In addition to these finds, compressed air was used extensively to move the product; by ejecting the cups from the molds, by moving them to the tester, to the printer, and then by moving them to the stacker. Compressed air "boosters" fabricated on site consisted of two concentric tubes with the air injected to create a moving force on the cups. A more efficient way to perform this task is by the use of blowers creating a larger volume of air at lower pressures. The amount of energy used to move the cups by blowers was estimated at .5 hp compared the .91 hp it that was required for the compressed air system (reference 1). This resulted in a 825 MMBtu/yr. savings amounting to a dollar savings of over $20,000/yr. Modifying screw injectors to eliminate the need for compressed air use at the printing station saved 716 MMBtu/yr. ($18,000).

One of the more interesting recommendations involved accounting for the nature of human behavior. The plant managers recognized that the open 1/8" tubes were using a significant amount of air and had purchased plastic fittings with smaller orifices. Operators, however, had difficulty with the lower air flow, and would soon drill out the fittings to the original size. Engineered nozzles are made that allow the same moving force with 10% of the compressed air usage by entraining the surrounding air. Use of these nozzles would have reduced the plant's entire need for compressed air by 15%, saving 1400 MMBtu/yr, and $35,000/yr. Energy savings could be accomplished by mechanical removal of the cups, thereby avoiding the scrambling the product and the subsequent work performed by the descrambler, a construction that uses compressed air and a particular sized ramp to arrange the cups. In all, the many improvements in energy efficiency accounted for a considerable cost savings to the plant, however interest in implementing these items was weak until the effect on production was discussed.

During hot, humid weather the limitation of the compressed air production slowed and sometimes stopped the process. Using weather data and information provided by the plant personnel, we determined that by relocating the intakes of the compressors, the factory could operate 30 more hours per year, producing over 28,000 pounds additional product. Since there was no significant increase in materials, labor, or utilities, this increased production accounted for approximately $65,000 in increased profit.

By mechanically removing the cups from the mold, not only was an energy savings accomplished, but productivity went up since it took as long as twenty minutes for the operator to adjust the descrambler whenever the size of the product was changed. Further discussions with the plant manager revealed that they were considering renting additional warehouse space due to the just-in-time delivery demands of their client. Elimination of the descramblers and modification of the blowers would allow for the production lines to be placed closer together. This and the addition of two tiered storage would create an additional 29,000 square feet of warehouse space, eliminating the need to rent, saving the company $130,000/year.

When all suggestions were totaled, the recommendations, if implemented would save the company over $1 million per year with an investment of slightly over $1.2 million. If the approach to energy savings were viewed independently, the payback to the company would have been almost 2 years, a level at which many companies balk. Only a systems approach with a sensitivity to production levels, and even inconveniences such as necessary down time to re-arrange the production line enable the assessment to maintain a creditable presence with management.

BOTTLE MAKING

In the production of bottles sand (silica), lime, and soda, ash, the main ingredients, are mixed and loaded into a furnace operating at approximately 2800°F. The molten glass moves into a heated refiner, and then a fore-hearth, where color may or may not be added. From there it is cut into "gobs" and directed into several separate feeds to one or more molds. It is then blown to expand into the mold, cooled, mechanically removed and placed on a conveyer, which moves them through an annealing oven, to several inspectors, and finally to packaging. In this facility there were two distinct situations that produced waste glass. The first was when the line was changed over to accommodate running a different product. In this situation, the molten glass was redirected to a hole in the floor, and produced a pile of glass in the basement. This procedure was selected because the ovens, or kilns, were virtually never shut down for fear the material would harden in some of the external equipment. From time to time, someone would go into the basement with a small bulldozer and recover the glass. The second situation that produced waste glass involved defects that were detected at the inspection stations.

An investigation of production time compared to acceptable product showed an internal yield of only about 50%! Although it takes somewhat less material (10%, reference 2) and energy (1200 BTU/lb, reference 3) to melt cullet (waste glass) than using virgin materials, this meant that the energy use was approximately double what was theoretically necessary. It is imperative to ask whether or not the company could sell more product if they could produce it. In this case, there was a two-fold answer. First, they could indeed sell more product, but only the higher quality products. This brought about the challenge of attempting to increase the speed and the quality of the product at the same time. Brainstorming with the plant personnel resulted in the discovery that the changeover time from one product line to another could be as much as eight hours. Studies have shown that set-up times can be reduced as much as 95% once this has been identified as a priority, and corrective steps implemented (reference 4). The setup procedure was divided into two categories, internal, which must be accomplished when the line was shut down; and external, operations that could be accomplished while the line was running. Several suggestions were made regarding quick change options -

- Develop Standard Operating Procedures utilizing the most experienced operators
- Design a Tool Kit with all necessary tools, and deliver it to the line prior to the shut down
- Develop Trouble Shooting Guide to reduce guesswork on common startup procedures
- Install strain gauges and temperature sensors

Complicating the situation was the fact that skilled personnel were necessary to set-up and start the line. If the changeover occurred during the night shift, the only option was to either dump the molten glass in the basement, or overproduce the product until the day shift started work. Usually, they chose to overproduce, but this had created a great abundance of product which was taking up space, spoiling, and simply being lost in inventory. After walking us through the paces of a changeover, it was determined that one particular mold change was delayed until the installer was out the way, since the mold was overhead. The solution recommended was to construct a movable scaffold that would allow installation of both molds at the same time. Using a conservative estimate of a 20% reduction in changeout and setup times, we estimated that the company could save $10.06/hr in material and $5.32/hr in energy. More importantly to the company was increased production of finished goods. In all, a cost benefit to the company of $1.8 million was estimated.

Next, we turned out attention to defect reduction. Some solutions were high tech and expensive, such as infrared non-intrusive temperature sensors, that were new to the market. The plant manager was well aware of this solution and was on top of the investigation, so we looked elsewhere. Recommendations were made to

- Reduce tipping with the use of sensors and alarms
- Reduce nuisance shutdowns due to overheating of microprocessors

These measures could save the company an estimated $400,000/yr. Traditional energy recommendations were made, such as use of energy efficient motors, variable speed drives, and reduction of compressed air leaks, but again, the potential energy savings to the company was always made in conjunction with the effect on productivity.

TIRE MAKING

In this case involving a tire manufacturer, we attempted to locate the bottleneck of the production line, as we had in the other cases, but found that the bottleneck that the plant personnel described was not the true bottleneck at all. Making tires starts with bringing non-treated rubber and other ingredients into a mixer to produce an engineered rubber with the desired physical properties. This mixture is then made into ribbons which will eventually become the plies of the tire. Next comes the pre-forming machines where an operator places a plastic hoop onto a circular "wheel". After two of these hoops have been placed on the machine, an extruder oozes a rubber/adhesive product, covering the hoop. This hoop is then routed to the assembly machines where the plies and other parts of the tire are put together. Finally, they are put into the presses where steam is injected, the treads are molded, and the product is cooled using chilled water. Other mysterious chemistry also take place at his juncture to ensure the desired properties of the finished product.

It was observed that the presses were operating with no tires in them much of the time. Due to the design of the equipment it was impossible to turn off single molds, yet as the presses cycled steam was injected, the molds were pressed together, and cooling water was run through the mold. We asked the plant manager why these machines were running in this manner, and he stated that the building machines were the bottleneck. This station had two types of machines, newer machines that could be operated by a single person, and the older equipment that required two operators to put the "hoops" on each side of the tire. The original method of assembly was to locate an operator on each side of the machine which could produce a tire (called "green" tires) in about four minutes. About one half of the machines were replaced with newer models that were designed to allow a single operator to function approximately as fast as two had previously done - producing around 15 tires/hour. On the older machines the company decided to reduce the workforce to one man per tire. One operator moving from side to side in order to place the hoops could produce about 10 tires per hour.

The maximum output of the presses was 25,000 tires per day, so the following recommendations were made with the goal to satisfy the capability of this operation. The first recommendation in this case was to put a second operator on the older machines. Without looking at the total picture, this would seem to be a reduction in productivity, since the two men produced fewer pieces/person/hour than before. We calculated the cost to produce a tire on each machine, then combined them for a cost of $10.08 per tire. If a second operator was added to the older machines, the cost per tire dropped to $9.53 per tire. Only 88 additional operator-shifts were necessary to satisfy the capability of the presses, so at other times the machines would still be run by one operator. There would be no additional labor cost in the press room, since the workers were waiting for tires part of the time. The only additional cost was raw materials, and some maintenance of the equipment. This additional cost was determined to be \$0.33 per tire. Therefore the new cost of the tire was \$9.53 plus \$0.33, or \$9.86 per tire, \$0.22 less than the original value. This amounted to a cost savings of over \$200,000 per year to the company.

Now the bottleneck was the pre-forming area where the tire "hoops" were produced. A plastic bead was placed on a machine by hand. A rubber product was then extruded onto the bead producing a "foot". This bead was to be evenly covered with rubber, however the extruded bead often began to vibrate producing a wavy line in the piece. If this happened, the operator would remove the rubber from the plastic bead, discard the rubber, and start over. The machine was rated at 800 hoops per shift; the typical operator could produce an average of 430 hoops per shift. One operator, however could produce over 600 hoop per shift. Since they operated under a bonus plan, the operator did not tell anyone how he accomplished this feat. Further investigation (coupled with an increase in pay) uncovered the fact that this operator would take as long as 20 minutes to calibrate and set up his machine before starting his shift, while other operators felt compelled to jump into the production line as quickly as possible, often not even missing a tire. After implementing a training program and a set of standard operating procedures, the rest of the operators were able to increase their productivity considerably. These two recommendations accounted for an additional \$2.4 million in sales to the company, eminently more important then the money saved in energy. It was now truly the presses that were the bottleneck in production, and serious evaluation must be given to such a major investment.

CONCLUSION

It is easy to identify a bottleneck (real or apparent) and correct this with major engineering investments, but this is not the focus of what we do, which is re-engineering - making the most of the existing situation. Energy auditing is entering a new age, one where the effects of the recommendations on the manufacturing process cannot be ignored. In some cases energy use will actually increase. For example, a manufacturer of felt had allowed the dryers on their line to fall into disrepair because their clients no longer wanted the heavy paper, and the lighter paper required less drying. Therefore, when the assessor asked if the line couldn't run faster if the heaters were repaired, the response was that the drum used to pick up the fiber could not go any faster. It took only two days of searching to find a firm that could install a faster pick-up unit.

Up to this point, the concentration has been on methods to estimate savings. One important aspect that needs to be added is estimating the cost of implementation, probably the hardest part of the assessment to many of us who do not purchase products, or contract services. Our advice in this matter is - just do it. Force yourself to put numbers on installations, and continuously attempt to verify your estimates. This is obviously a very aggressive approach to the subject, but a necessary one that will lead to confidence later and a much more satisfying result.

In conclusion, we have found that this integrated assessment method coupled with the industrial triage procedure addresses the delicate balance between the need to conserve time, resources, and expenses in conducting an assessment, with the absolute necessity of producing quantifiable results for the industrial manufacturing client.

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Appendix A

PRODUCTIVITY METRICS SHEET

Labor Costs:

Type of Labor	Actual	Assumed
Production Worker:	________/hr	($19.47/man-hour)
Skilled Technician:	________/hr	($25.96/man-hour)
Engineering (contracted):	________/hr	($100/engineer-hour)
Engineering (in-house):	________/hr	($38.94/man-hour)

(Items above in parentheses indicate total cost to the company, including 35% fringe)

Fringe Rate: ______% (35%)

Raw Material Costs:

Material/Resource	Yearly Usage	Unit Price
Water Treatment		
Water Usage:		/hcf ($2.50/hcf, 1 hcf = 100 ft^3)

Production Information:

Overhead: (includes _____ , _____ , _____ , _____) _____% (100%)

Profit Margin: _____% (10%)

Cost per Piece to Produce: $_____/piece

Inventory and Floor space:

Value of Floor space: _______/ft^2/yr ($5.00/$ft^2$/yr)

Inventory Carrying Cost: _____% (15%)

Raw Material Inventory: Quantity = ______ Value = ______

Work-In-Progress Inventory: Quantity = ______ Value = ______

Finished Goods Inventory: Quantity = ______ Value = ______