Counting Energy Savings from Industrial New Production Programs: A Baselining Methodology

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ABSTRACT

New commercial and residential buildings increase electricity demand. It is typical for energy efficiency programs to incent these new loads to be as efficient as possible through "new construction" programs. New Construction programs commonly use state energy codes and/or a version of ASHRAE's 90.1 energy standard to simulate baseline energy consumption. Energy savings from the baseline can then be calculated by simulating the proposed building's energy use.

Industrial facilities can also add new load to the grid. As with the commercial sector, it is often most economical to invest in efficiency when this new load is designed and constructed, either as a new facility, or additional production equipment or lines within an existing plant. However, industrial production is so unique that a standard set of guidelines like ASHRAE 90.1 would be extraordinarily challenging to construct. Thus, energy efficiency programs have virtually no "new production" program offerings, though a few incent lean manufacturing events, which can result in increased production. We use new production to refer to increased production from productivity improvements, addition of new production equipment, or building of a new manufacturing facility. Perhaps because of the lack of programs that incent new production, there is not a clear method on how to establish baseline energy use or count resulting energy savings.

This paper will present and discuss methods for creating a baseline for new production. The method will rely on statistical regression models of industrial energy use, or energy intensity curves of the production process. The regression models and energy intensity curves are related. We discuss similar regression modeling approaches for programs like Bonneville Power Authority's "Track & Tune", CL&P's Process Reengineering for Increased Manufacturing Efficiency, and NYSERDA's Industrial and Process Efficiency programs. The goal is to establish a reliable and scalable industrial baselining method such that new production programs can be justified to utilities, state agencies, and electric regulatory committees and achieve wide acceptance in the US.

Introduction

The industrial sector accounts for 31% of US energy consumption, compared to 22% and 19% for the residential and commercial sectors, respectively (US DOE, 2011). Thus, promoting energy efficiency in the manufacturing sector is critical toward achieving the U.S.'s energy efficiency goals. However, whereas the commercial and residential sectors have a wide breadth of types of efficiency programmatic approaches and prescriptive measures, there are relatively few for the manufacturing sector. As a result, it may be more difficult for manufacturers to access energy efficiency programs than other businesses and organizations. For example, common program types which are under-offered to the industrial sector include:

- Prescriptive measures – Most prescriptive measures cover lighting, heating ventilation and air-conditioning (HVAC) equipment, motors and drives, and often commercial kitchen equipment. While these measures may apply to manufacturing facilities, they do not address the majority of industrial energy consuming equipment and processes. Some utilities have prescriptive measures for compressed air equipment, but in general a much larger percentage of industrial energy savings projects would be categorized as a custom measure as compared to the commercial and residential sectors.
- Point of Sales – Many efficiency programs rely heavily on point-of-sales (POS) programs for small budget items like compact fluorescents (CFLs). These programs make sense where the cost of filling out and filing a rebate application is potentially more costly than the value of the rebate. While there are many industrial efficiency technologies that fit this criteria (air-saving nozzles, notched V-belts), there is a lack of POS programs targeted at manufacturers.
- Low/no-cost measure programs - The commercial and residential sectors do have some programs targeting low/no-cost measures, such as retro-commissioning and HVAC tune-ups. Recently, the manufacturing sector has also seen efficiency programs which target low/no-cost measures. This includes BPA's Track & Tune program, AEP-Ohio's Continuous Energy Improvement program, and others.
- New Construction/Production – As discussed, New Construction programs are fairly common, while there is little in the way of incenting new production. Connecticut Light & Power (CL&P), the New York State Energy Research and Development Authority (NYSERDA), and Efficient Vermont (EVT) all have programs which incent lean manufacturing events.

We see that the lack of new production programs offered by energy efficiency programs is part of a larger trend – manufacturers in general have less choice in program offerings than the residential or commercial sector. A fundamental difficulty in creating non-custom programs for the manufacturing sector is the establishment of a baseline. In the remainder of this paper we discuss the conceptual framework for establishing a new production baseline, discuss other manufacturing-specific programs which establish similar baselines, provide several specific examples, and draw conclusions.

New Production Conceptual Framework

New production borrows from the new construction conceptual framework. New production and new construction programs incent energy efficiency, but not always energy conservation. That is, new production loads, like new buildings, likely increase overall energy consumption. While new construction programs have been widely adopted, there are few new production or like programs for production equipment and processes. New construction is likely a popular program because stakeholders realize that the new building will use less energy than it would have absent the incentive. We argue that similarly reducing the energy-intensity of a process below an established baseline energy intensity results in claimable, verifiable energy savings.

We are careful to note the baseline energy intensity for any manufacturer is not a single value, but instead a function of production quantity. The range of energy intensity values can be represented by a curve for many manufacturers. Establishing a baseline curve avoids counting energy savings from simply increasing production, as any production increase is likely to reduce energy intensity of the parts without realizing any permanent energy efficiency improvement.

Existing Programs

NYSERDA: Industrial and Process Efficiency (IPE) Program

The New York State Energy and Research Development Authority (NYSERDA) offers the Industrial and Process Efficiency (IPE) Program. According to the NYSERDA website, the IPE program's goal is to increase product output for manufacturers. NYSERDA staff, at this writing, are compiling a white-paper on their counting method. Based on correspondence with NYSERDA program staff, we understand their calculation methodology as:

$$(\text{kWh/unit}_{old} - \text{kWh/unit}_{new}) \text{ x Annual New Production Volume} = \text{kWh}_{savings}\text{/year}$$

The baseline energy intensity is established in one of two ways. First, if there is already existing process equipment in the plant, or in other similar manufacturing plants, that equipment is established as the baseline equipment. Engineering calculations are then used to calculate the kWh per unit. Second, especially for more complex, plant-wide additions, empirical metered data is used to establish the baseline kWh per unit. NYSERDA then conducts extended metering for measurement & verification (M&V). Projects must have an associated cost to receive incentives, which could act as a check against claiming savings from simply increasing production.

NYSERDA's approach with two baseline paths is common to what we recommend in this paper. However, we propose creating energy intensity curves, or production normalized regression baselines, instead of relying on a single intensity metric. By showing that energy intensity changes significantly depending on where any given manufacturer is on their production curve, we argue that the former method is both more effective and realistic. Establishing curves prevents incenting manufacturers from simply increasing production with no efficiency improvement to their system. Without establishing a curve as the baseline, if and when production levels decreased, all claimed energy savings would be lost.

Connecticut Light & Power (CL&P): Process Reengineering for Increased Manufacturing Efficiency (PRIME)

CL&P's PRIME program incents energy savings through lean manufacturing techniques. This should not be confused with events focused on improving energy efficiency of a process. Instead, PRIME incents traditional lean manufacturing events with a focus on improving productivity or reducing waste. The productivity improvement also produces a reduction in energy intensity. Savings are claimed from this reduction.

Based on correspondence with CL&P program staff, the PRIME program accounts for a relatively small savings percentage compared to their overall portfolio of programs – about 1%. However, the total benefit to cost ratio (TBCR) is a conservative 7.9, and is thus recognized as an economical use of utility funds.

The counting methodology CL&P uses is well documented in a previous publication (Seryak, et. all, 2007). This publication suggested two methods of establishing a baseline. First, at the plant level, multi-variable change-point regression models were suggested for establishing a baseline normalized for production and weather effects. Because many lean manufacturing events are focused on specific areas or processes, an equipment-level methodology was also proposed. This method focused on breaking down equipment into four categories, and calculating baseline and post-implementation energy use for each category. The four categories are:

- Equipment with production-independent energy use
- Production quantity dependent equipment
- Operating hours dependent equipment
- Production quantity & operating-hours dependent equipment

The paper then illustrates how to calculate savings from several specific lean manufacturing improvements, including recycled cycle time, change-over time reduction, reduction in rework or scrap, and reduction in set-up time. In each case, a baseline, production-adjusted baseline, and post-event energy use is calculated. In general, there is an increase in energy use from the baseline to the post-event energy use, but a decrease in energy from the production-adjusted baseline to the post-event energy use.

Similar to NYSERDA's methods, there is a choice of establishing an empirical baseline, or one calculated with engineering equations.

Efficiency Vermont: Energy Efficiency through Lean Improvements

Efficiency Vermont (EVT) offers a program called Energy Efficiency through Lean Improvements, targeted at large manufacturers' processes. Based on correspondence with EVT staff, the projects have screened utility cost testing when non-electric benefits (NEBs) are included. However, these projects are implemented minimally in their territory, and are not currently tracked. According to the EVT Technical Reference User Manual (2012), there is not an established algorithm or methodology by which to calculate savings.

Bonneville Power Authority: Track and Tune

The Bonneville Power Authority (BPA) offers the Track and Tune operations and maintenance programs as a subset of their Energy Smart Industrial program. Track and Tune targets low-cost operations and maintenances saving, not productivity improvements or production increases. However, to claim savings a production-normalized baseline is established for the equipment, against which future energy consumption is compared.

According to the BPA Energy Efficiency Implementation Manual (2013), a number of acceptable regression models are suggested, including those coded in the ASHRAE Inverse Model Toolkit (Kissock, 2003), which includes mean models, models with two or more parameters, one or more change-points, and potentially multi-variables, sometimes referred to as change-point multi-variable regressions (CP-MVR). These models are essentially the same as the plant-level models suggested by Patil, et. al. (2005).

Establishing the Baseline

We have identified two cases in which a production normalized baseline of process energy consumption can be established. First, the baseline production energy curve can be calculated with energy engineering equations if the less-efficient baseline production equipment under consideration is known. We refer to this case as the "Calculated Baseline" case. Calculating a baseline with an engineering analysis is consistent with CL&P and NYSERDA's approach. Practically speaking, the Calculated Baseline case would occur when a manufacturer approaches efficiency program staff with the schematic design, equipment selection, or other documentation of the planned equipment to be installed. Or, similar equipment exists elsewhere in the plant, in a sister plant, or competitor's plant. In any case, the baseline equipment is known. From this, the baseline energy use can be calculated. We present a simple example of this in the next section.

The second case is when a manufacturer has claimed to have selected and/or designed an efficient process. Here, the efficient equipment is known, and the efficient production energy curve can be calculated. However, the baseline energy equipment and curve must be assumed. We suggest that if the new efficient equipment is being added to an existing facility or set of facilities, the production energy curve for the previously existing equipment should be assumed as the baseline equipment. In this case, existing utility and production data could be used to calculate a baseline energy curve. We refer to this as the "Empirical Baseline" case. We present a simple example of this case as well.

There are still cases in which a baseline would not be able to be established without custom engineering judgment. If a completely new manufacturing process was being proposed, claimed to be efficient, and there is no alternative type of equipment in existence, we believe it would be difficult to establish a baseline for comparison.

Calculated Baseline Example: IR Curing Oven

Consider an infrared-curing (IR) oven with a monorail hangar that continuously transports parts through the oven. The curing system has two energy consuming components – the motor which drives the monorail, and the infrared heating elements which cure the parts and must replace heat lost through the oven shell. This is a common type of continuous drying system, and this example could be substituted with a conveyor system, ultra-violet light curving, etc, for our illustrative purposes, we'll assume the following characteristics of the curing oven:

Table 1. IR Curing Oven Characteristics

Dimensions			
Length (ft)	Height (ft)	Width (ft)	
30	8	10	
Temperatures			
Oven (F)	Exterior Surface (F)	Plant (F)	Leaving (F)
600	180	75	500
Motor			
Horsepower		Power Draw	
10 HP		6.2 kW	
Heat Losses (kW)			
Low Insulation	59.2	High Insulation	15.6

We calculated motor power assuming a 75% load and 90% efficiency. We estimated heat loss from the oven assuming no open surfaces, and using a public domain simulation package called HeatSim available from the University of Dayton Industrial Assessment. For the baseline scenario, we consider a curing oven with a constant-speed motor, and an under-insulated oven (180 F surface temperatures). Here, the only variable energy consumption would come from the energy absorbed by the curing part. We assumed that each part was plain carbon steel weighing 5 pounds. We can then calculate the energy consumption at any production quantity. For example, the consumption at 50,000 units per year would be:

- IR Energy to Parts:
  - 434 J/kg-K x 2.27 kg x 491 K / (3600 seconds/hour x 1000 watts/kW) = 0.134 kWh/unit
  - 50,000 units/year x 0.134 kWh/unit = 6,718 kWh/year
- IR Energy Loss through Oven Shell:
  - 59.2 kW x 8,760 hours/year = 518,592 kWh/year
- Motor Energy:
  - 6.2 kW x 8,760 hours/year = 54,458 kWh/year
- Total Energy:
  - 6,718 kWh/year + 518,592 kWh/year + 54,458 kWh/year = 579,768 kWh/year

To calculate the proposed energy curve, two energy-saving factors should be considered. First, the energy consumption of the process could be made more variable. As production rates go down, ideally the monorail speed could slow down. To keep a constant cure time, the length of infrared heating would also be need to be reduced, producing energy savings. This could be done by staging heating elements off. The second factor would be to account for the reduction in non-production related energy consumption, such as reducing the heat loss from the oven by increasing insulation thickness. We can then calculate the energy consumption at 50 thousand units per year for a production variable, highly-insulated curing oven. The energy to parts would stay the same:

- IR Energy to Parts:
  - 50,000 units/year x 0.134 kWh/unit = 6,718 kWh/year

The energy loss of a perfectly variable process would vary linearly as a function of production quantity. The maximum power draw of the IR elements and the motor would occur at the maximum production rate, which based on the following assumptions would be:

- Maximum production rate:
  - 1 unit/foot x 3 feet/minute x 60 minutes/hour x 8,760 hours/year = 1,576,800 units/year
- IR Energy Loss through Oven Shell:
  - 15.6 kW x 8,760 hours/year x 50,000 units/yr / 1,576,800 units/yr = 4,333 kWh/year
- Motor Energy:
  - 6.2 kW x 8,760 hours/year x 50,000 units/yr / 1,576,800 units/yr = 1,727 kWh/year
- Total Energy:
  - 6,718 kWh/year + 4,333 kWh/year + 1,727 kWh/year = 12,779 kWh/year

Using this engineering approach, energy performance curves can be generated for the baseline and proposed processes. We present the same information in two ways. Figure 1 shows the baseline and potential alternatives' total energy consumption as a function of production quantity. This is a similar graphical output to the typical CP-MVR models earlier referenced. Another way of presenting the information is to graph energy intensity against production quantity. This creates a curve which shows that the energy intensity approaches an asymptote for any process. This is important – illustrating energy performance with an energy intensity curve makes clear that there are reductions in energy per unit produced from simply increasing production. Without acknowledging this, manufacturing processes could be incented simply for increasing production quantity with no efficiency improvement. While increased production benefits should be pursued in industry, manufacturers should not require an incentive to pursue these savings. Instead, the overall performance curve of the production system should become more efficient at all production quantities.

Figure 1. Energy Consumption Curves

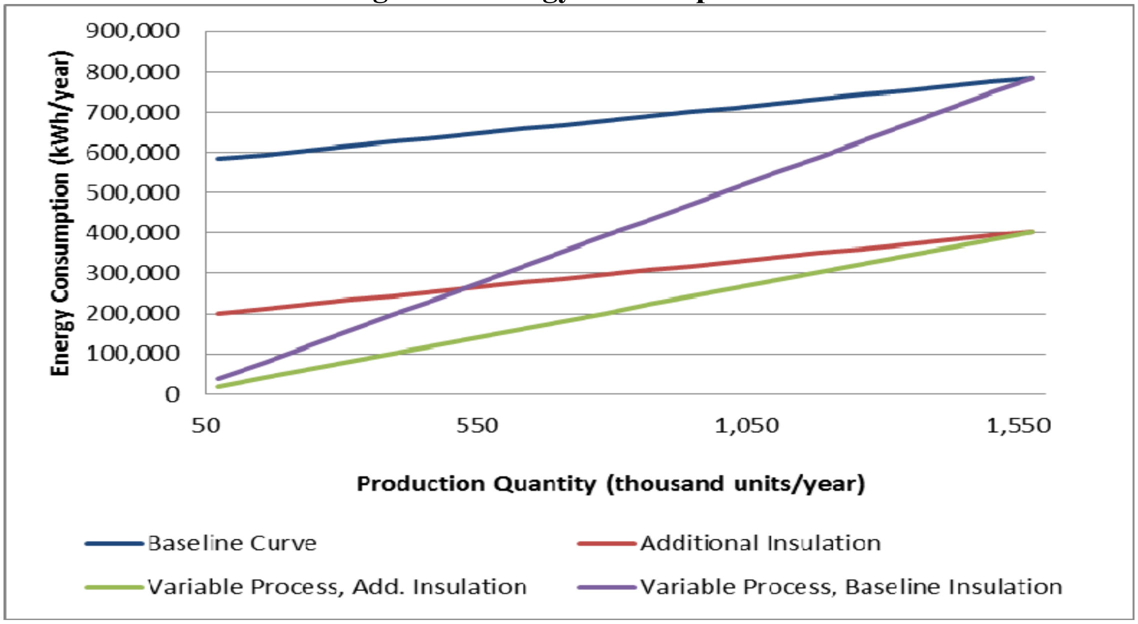
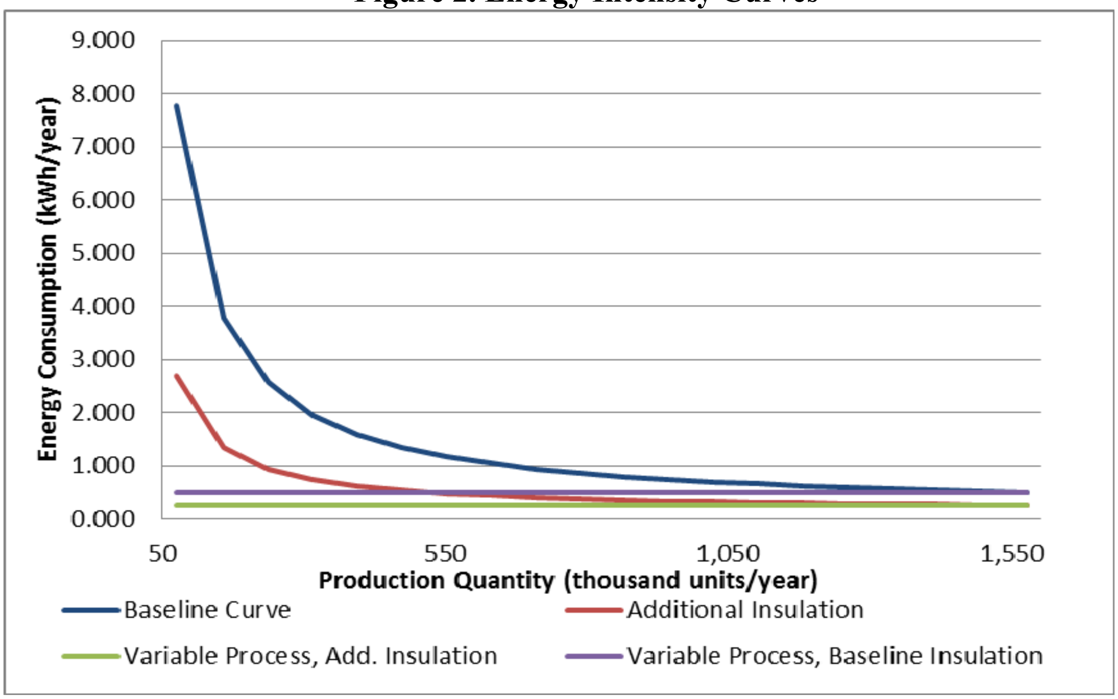


Figure 2. Energy Intensity Curves



A secondary, but highly important issue then emerges – at which production rate should energy savings be counted? Currently, engineering judgment should be used to establish the production operating point at which savings should be counted. Or, as NYSERDA suggests, the new production quantity could be used. However, because manufacturing production quantities can vary significantly from year to year for a given manufacturer, at some point industry guidelines for determining production profiles may be needed.

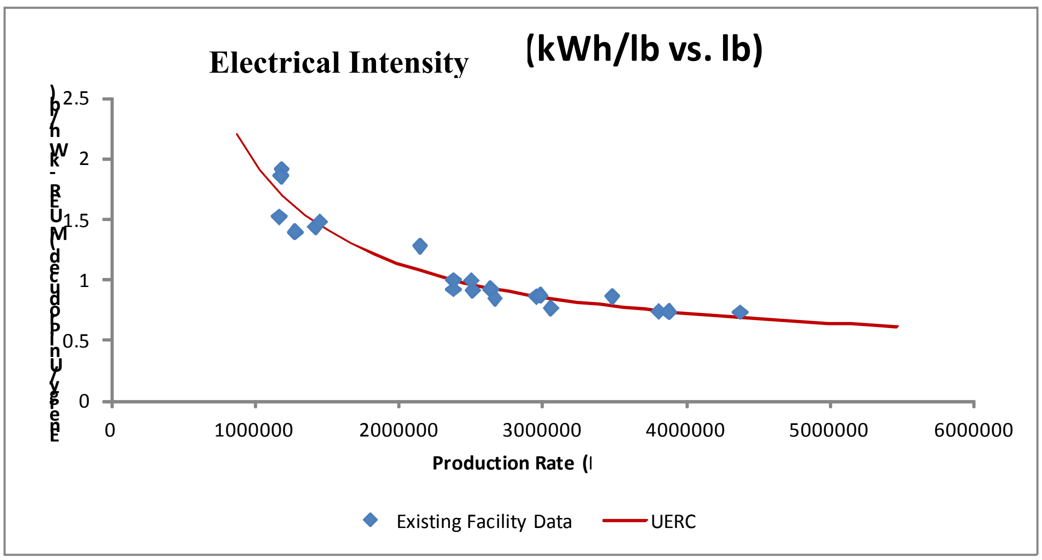
Empirical Baseline Case Example: Manufacturing Plant Production Curve

When creating a baseline for a process which is already in operation by a manufacturer, whether for an additional line or a new facility, the benchmark upon which improvements are to be measured should be the typical current practice.

Historical production and energy consumption history of the facility will reflect current practice. Using this information, numerical regression techniques can be used to determine dependency of energy consumption on production as well as the base load. We display an example of this method below, using real electricity and production values from a manufacturing facility. Consumption values were scaled to protect this client's identity. The adjustments merely scaled the values of regressed parameters and do not compromise the analysis methodology.

Using the consumption and production values provided by the manufacturer for an existing facility, the energy required per unit is calculated for each utility billing period and plotted against each associated production rate. Using statistical regression of these data points we can then derive the unit energy performance curve.

Figure 3. Regressed Unit Energy Performance Curve



New production generally falls into three categories, creating a new production line in a new plant, adding an additional line to an existing facility, or increasing output from an existing line through equipment replacement or productivity changes. When production is increased from an additional line, often there is an increased base-load that comes with it. This results in a step function increase on both the energy consumption and energy intensity curves. To illustrate this, we will assume that the implementation of a new production line results in a doubling of the entire base-load if an additional line is to become operational. This is shown in Figures 4 and 5, which show energy performance curves for a plant with a single line, and a plant with a second line (or double line).

Unlike when a new production line is added, production increases resulting from operational changes, such as those made through a lean manufacturing improvement, do not result in a similar step increase. Thus, thus, the "double line" curve can serve as a baseline from which energy savings can be claimed for lean manufacturing events.

Energy-efficient new production is shown in the performance curves in one of two ways, either through improving the variability of the process or reducing the non-production-dependent, or base load, component of energy use. Improving the variability of the process essentially shifts energy out of the base-load, and into the production-variable component, as shown in Figures 4 and 5 by the "baseload to variable" trend.

As the plots show, when the non-production base-load is made more variable with production, this manifests itself as energy consumption reductions within the full operating range. Interestingly, the greatest savings from this type of improvement occurs at the lowest capacity for all operating lines. In contrast as the production rate nears the total capacity of either a single or double production line, the energy consumption approaches the baseline energy consumption. If a facility were able to create an entirely variable production process the base-load energy would approach zero.

Figure 4. Production Performance Models

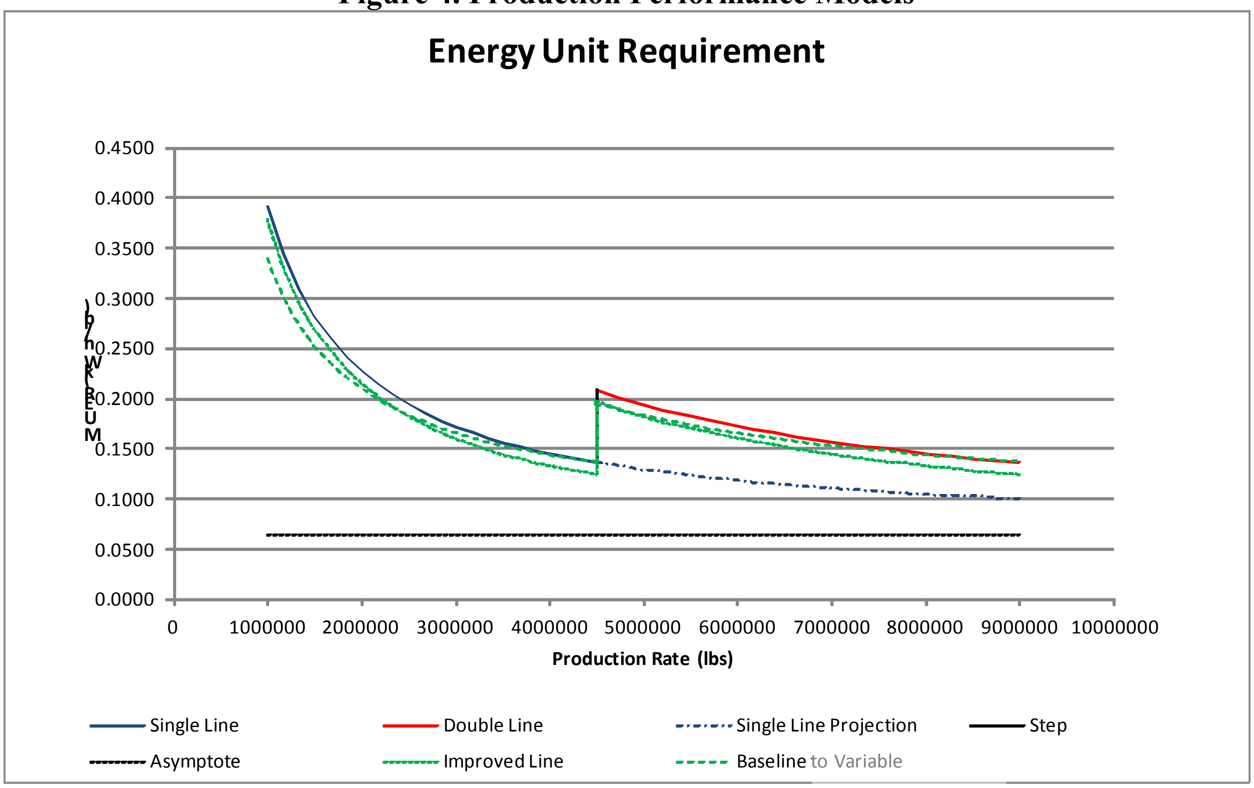
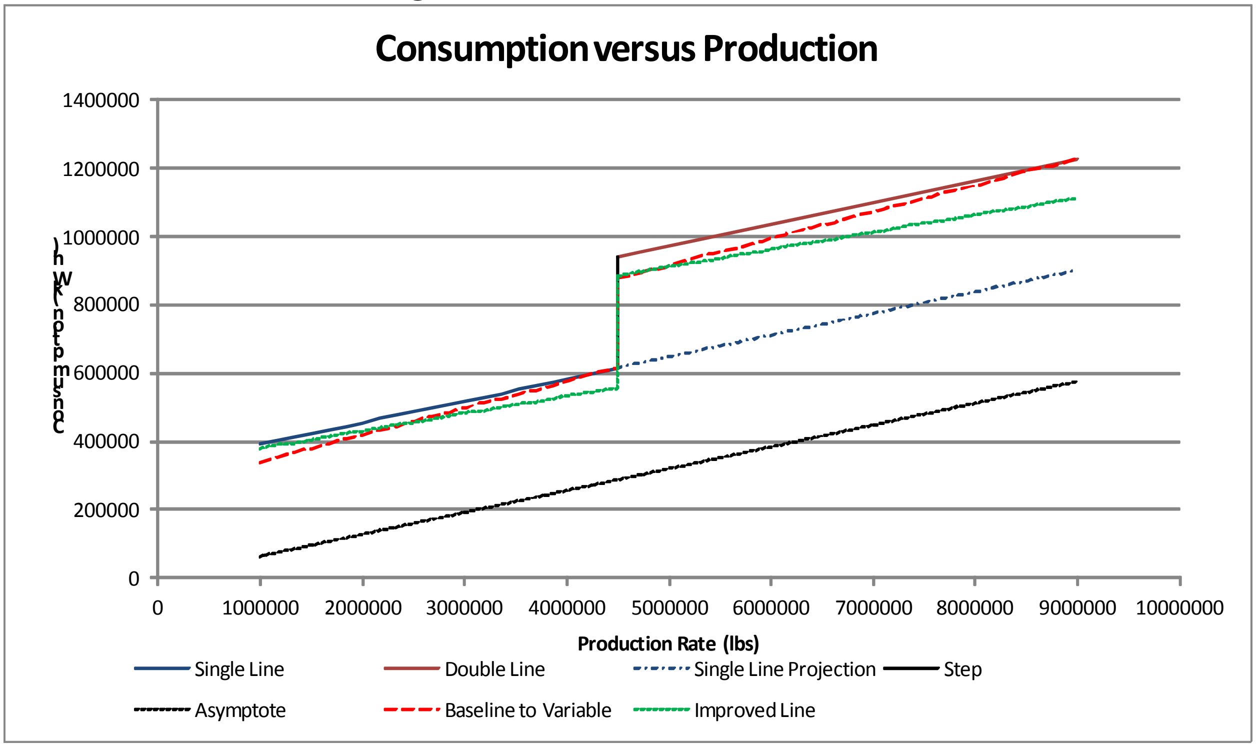


Figure 1. Production Performance Models



Conclusions

New construction energy efficiency programs are common for the residential and commercial sectors. However, there is no equivalent for the manufacturing sector. Several utility or state run energy efficiency programs incent lean manufacturing events in industry. Lean manufacturing events may result in increased production, and may result in energy-efficiency. Thus, there is some precedence for claiming energy savings when production has also increased. However, to the author's knowledge there are no new production programs which specifically incent energy savings that occur when new production equipment is installed with an increase in production quantity.

A main challenge to claiming energy savings when new production is occurring is to establish baseline energy consumption. In this paper, we argue that production-normalized baselines can be established from which to claim energy savings, paving the way for new production programs. We also discuss several efficiency programs which use statistical regression to establish their baselines as precedent. It is common to have both engineering calculated baselines, and production-normalized empirical baselines. While these methods will not be successful in establishing baselines for all new production scenarios, we believe they can account for a significant percentage of them.

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