DEVELOPMENT OF ENERGY STAR® ENERGY PERFORMANCE INDICATORS FOR POWERTRAIN MANUFACTURERS

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ABSTRACT

Organizations that implement strategic energy management programs undertake a set of activities that, if carried out properly, have the potential to deliver sustained energy savings. Energy performance benchmarking is a key activity of strategic energy management and one way to enable companies to set energy efficiency targets for manufacturing facilities. The opportunity to assess plant energy performance through a comparison with similar plants in its industry is a highly desirable and strategic method of benchmarking for industrial energy managers. However, access to energy performance data for conducting industry benchmarking is usually unavailable to most industrial energy managers. The U.S. Environmental Protection Agency (EPA), through its ENERGY STAR program, seeks to overcome this barrier through the development of manufacturing sector-based plant energy performance indicators (EPIs) that encourage U.S. industries to use energy more efficiently. This report describes work with the motor vehicle manufacturing industry to provide plant-level indicators of energy efficiency for facilities that produce engines and transmissions in the United States and Canada. Consideration is given to the role that performance-based indicators play in motivating change; the steps necessary for indicator development, from interacting with an industry in securing adequate data for the indicator; and actual application and use of an indicator when complete. How indicators are employed in EPA's efforts to encourage industries to voluntarily improve their use of energy is discussed as well. The report describes the data and statistical methods used to construct the EPI for plants within the industry. The individual equations are presented, as are the instructions for using those equations as implemented in an associated Microsoft Excel-based spreadsheet tool.

1 INTRODUCTION

ENERGY STAR was introduced by EPA in 1992 as a voluntary, market-based partnership to reduce air pollution and greenhouse gas emissions associated with energy use through increased energy efficiency (U.S. Environmental Protection Agency 2015). This government program enables industrial and commercial businesses as well as consumers to make informed decisions that save energy, reduce costs, and protect the environment. For businesses, a key step in improving energy efficiency is to institutionalize a strategic approach to energy management. Drawing from management standards for quality and environmental performance, EPA developed the *ENERGY STAR Guidelines for Energy Management* that identifies the components of successful energy management practices (U.S. Environmental Protection Agency 2003).

These include:

- Commitment from a senior corporate[1] executive to manage energy across all businesses and facilities operated by the company;
- Appoint a corporate energy director to coordinate and direct the energy program and multi-disciplinary energy team;
- Establish and promote an energy policy;
- Develop a system for assessing performance of the energy management efforts, including tracking energy use as well as benchmarking energy in facilities, operations, and subunits therein;
- Assess performance and set goals at the corporate, facility, and subunit levels;
- Create action plans across all operations and facilities, as well as monitor successful implementation and promote the value to all employees; and
- Pursue recognition and rewards for the success of the program.

Of the major steps in energy management program development, benchmarking energy performance by comparing current energy performance to a baseline or a similar entity is critical. In manufacturing, it may take the form of detailed comparisons of specific production lines or pieces of equipment, or it may be performed at a broader system level by gauging the performance of a single manufacturing plant with respect to its industry. Regardless of the application, benchmarking enables companies to determine whether better energy performance could be expected. It empowers managers to set more informed goals and evaluate their reasonableness.

(Boyd, Dutrow et al. 2008) describes the evolution of a statistically based plant energy performance indicator (EPI) for the purpose of benchmarking manufacturing energy use for ENERGY STAR.

[1] Throughout this report the term "corporate" is used to refer to the business, i.e. company or firm level, rather than the plant or establishment level, not the particular organizational form of the business

(Boyd 2016) describes the basic approach used in developing such an indicator, including the concept of normalization and how variables are chosen to be included in the analysis. To date, ENERGY STAR has developed statistical indicators for a wide range of industries (U.S. Environmental Protection Agency 2015). This report describes the basic concept of benchmarking and the statistical approach employed in developing performance-based energy indicators for the powertrain (engines and transmissions) manufacturing, the evolution of the analysis done for this industry, the final results of this analysis, and ongoing efforts by EPA to improve the energy efficiency of this industry and others.

2 BENCHMARKING THE ENERGY EFFICIENCY OF INDUSTRIAL PLANTS

Among U.S. manufacturers, few industries participate in industry-wide plant energy benchmarking. The petroleum and petrochemical industries each support plant-wide surveys conducted by a private company and are provided with benchmarks that address energy use and other operational parameters related to their facilities. A handful of industry associations, such as the American Forest & Paper Association, provide energy use comparisons to their members. Otherwise, most industries have not benchmarked energy use across their plants. As a result, some energy managers find it difficult to determine how well their plants might perform.

In 2000, EPA began developing a method for developing benchmarks of energy performance for plant-level energy use within a manufacturing industry. Discussions yielded a plan to use a source of data that would be nationally representative of manufacturing plants within a particular industry, create a statistical model of energy performance for the industry's plants based on these data along with other available sources for the industry, and establish the benchmark for the industry. The primary data sources would be the Census of Manufacturing, Annual Survey of Manufacturing, and Manufacturing Energy Consumption Survey collected by the Census Bureau, or data provided by trade associations and individual companies when warranted by the specific industry circumstances and participation. Since then, EPA's ENERGY STAR program has coordinated the development of multiple EPIs across a wide variety of industrial sectors.

3 EVOLUTION OF THE POWERTRAIN EPIS

After the success and wide usage of the Automobile Assembly Plant EPI, EPA along with the motor vehicle industry decided to expand its existing work with the industry to benchmark powertrain (engine & transmission) manufacturing facilities. Many of the same companies influential to the previous work regarding automobile assembly plants continued to be involved with the powertrain process, providing valuable feedback.

3.1 Data Collection and Definition Refinement

The development of most EPI tools begins with a model based on data from the U.S. Census Bureau using the NAICS code specific to that industry. However, an existing relationship with the large companies in the U.S. motor vehicle industry prompted a direct data collection route similar to what was conducted for the Automobile Assembly Plant EPI. Additionally, Census data for this industry lacks total production quantities and would have necessitated the use of an alternative variable (value of shipments) to produce an energy benchmark, which industry representatives felt would have been less accurate. After initial discussions, the broad range of factors listed below were thought to influence energy differences between plants and were submitted by participating companies:

- Production Units
- Equivalent Production Units
- Jobs Per Hour
- Displacement
- Number of Cylinders (4, 6, or 8)
- Engine Block Type (iron or aluminum)
- Engine Component Production
- Air Tempering
- HVAC Ventilation Rate (cubic feet per minute/square foot)
- Minimum Outside Air
- Square Footage
- Transmission Weight
- Transmission Speed (4, 5, 6, or 8)
- Transmission Type
- Onsite Casting Operations
- Weather

Due to the small number of companies that comprise the industry, differences in the way certain variables were reported could have a large impact on the efficiency distribution. Consistency was necessary and ample time was spent ensuring the data were reported properly and variables were clearly defined. Specifically, set definitions for plant area, jobs per hour, and equivalent units were discussed at length due to differences in measurements and the magnitude that these variables had on energy consumption in the statistical model. For plant area, the simplest definition of total plant footprint (area under the roof) was chosen. This excludes any mezzanines or second floors and includes areas of the plant that may not be in use. The jobs per hour variable was designed to be used as a measure of capacity utilization that would help reduce the penalty on efficiency of operating below capacity. The original definition was the number of finished products the plant was designed to produce in an hour. Given the age of, and changes to, many of the automotive plants, this number could have changed over time and the original plant design would no longer be accurate. Instead, the variable could be reported as plant designed rate, or the maximum monthly *realized* rate of production over the last five years.

Equivalent units are the number of additional powertrain pieces a plant produces that do not go into a finished engine or transmission, and are instead shipped as component parts. Most companies had different ways of tracking equivalent units, or did not track them at all. After discussion, utilizing a metric based on the total labor hours per unit was the most commonly used definition. Under this method, if a plant produces a fully assembled transmission in 4.0 hours per unit (HPU), and produces a specific transmission component in 1.0 HPU, the equivalent unit factor for that specific component would be 0.25 (1.0 HPU / 4.0 HPU). Every four units of this specific component would count as one equivalent unit and would be added to the total production amount of the plant. Inversely, a plant that imports components could have a negative value for equivalent units that would be subtracted from the total production amounts.

3.2 Model Drafts

The first drafts of both the engine and transmission EPIs were produced using a split electricity and fuels model that incorporated all the variables listed above that were applicable to engines or transmissions. With few preconceived expectations for what would be the major energy drivers for each product, a "kitchen sink" approach was taken and all variables were included in the statistical model. Statistical tests were used to assess the impact of individual variables on energy use. Further models were refined based on industry comments and statistical significance.

Engines

Industry-collected information resulted in 68 observations with data across three years from 23 plants.[2] Compared to company information from the US EPA ECHO database, the industry-supplied sample includes all engine manufacturing plants within the United States. Early statistical results showed that two variables that heavily influenced EPI scores were the engine block material type (iron or aluminum) and outside air into the facility. Since the process is basically the same regardless of whether iron or aluminum are used, this large impact was unexpected by the industry and hinted that there were some confounding factors influencing predicted energy. Minimum outside air was also large, but was considered to be a variable that was difficult to measure at the plant level. In addition, reducing outside air to the plant (or specific process) would be viewed as an energy efficiency management approach, and should not be treated as an external factor in the EPI normalization. The energy impacts of other variables were of the expected direction and aligned with the correct energy source. For example, production only affected electricity usage and did not have a statistical impact on fuel consumption, which was expected given the production processes. Ultimately, the first model needed revision, and a simpler approach was taken for the second draft that limited the number of variables and removed outside air.

During the second draft phase, variables concerning product type such as number of cylinders, block material, and the number of lines for each engine component piece were removed. A streamlined electricity model remained that included production, jobs per hour, and a weather variable that only affected electricity use when the plant had air tempering. The fuel model was similarly streamlined to include only plant area, weather, and a dummy variable for the production of four-cylinder engines. While conducting the analysis, the plant area variable continuously appeared to be significant in the electricity model, but the coefficient was much larger than industry reviewers had expected. To better account for the energy related to the size of a plant, a fixed effects model was used for electricity. A portion of the fixed effect is related to plant area since plant area generally stays constant over time. A separate regression model was run with plant area regressed against the fixed effect value to show the amount that is related to the size of the plant. This value was then reinserted into the model to account for plant area. Industry comments were more positive regarding the new approach to plant area, but

[2] One plant only provided two years of data.

the significance of the four-cylinder variable in the fuel model was still puzzling to industry participants since they saw no reason for energy to differ across the production of engines with different numbers of cylinders. These results led to a deeper investigation into what plant differences could be the cause. Further examination showed key differences in older and newer plants in both size, location and number of engine cylinders. Newer plants were smaller and more likely to be located in the southern United States. Presuming that newer plants are more efficient, this could cause a bias in the results and would need further analysis.

Based on industry feedback during testing, it was determined that calculating equivalent unit values of engine plants was problematic. An additional data collection effort was conducted for the total amounts of the following component parts:

- Crankshafts
- Engine Blocks
- Engine Heads
- Camshafts
- Rods
- Pistons
- Pumps

This meant that calculating equivalent units was no longer needed and allowed for a comparison between labor weights and energy weights for each component piece. Component numbers greater than the total finished engines reported indicate that additional components were produced and sold. Conversely, component numbers less than the total finished engines indicate that parts are transferred into the plant after being produced elsewhere. Following initial analysis, crankshafts, blocks, heads, camshafts, and rods joined the previously mentioned variables in the electricity model. They were not significant in the fuels model, as expected, since fuel usage is not directly related to production in this industry. For this reason, the dummy variable for the production of four cylinder engines was removed from the fuel model as well, even though it was statistically significant.

Transmissions

Industry-collected information resulted in 38 observations with data across three years from 13 plants.[3] Compared to company information from the US EPA ECHO database, the industry-supplied sample includes nearly all transmission manufacturing plants within the United States. Similar to the first model of engines, all provided variables were included and most were statistically significant with larger than expected impacts. For example, there were large statistical differences concerning whether the plant produced a 4-, 5-, 6-, or 8-speed transmission, but the actual process is very similar and would not be expected to result in substantial variations in energy consumption. Additionally, there was a statistically significant fuel impact between automatic and manual transmissions when fuel is not directly used in the production process. Overall, initial reviews determined a simpler approach was needed that aligned more closely with the production processes and industry expectations.

[3] One plant only provided two years of data.

Subsequent analysis focused on removing extra variables and presenting a model that only focused on the energy differences identified by industry partners. The revised electricity model included production, weather, plant area, and whether a four-speed transmission was produced. Although there was thought to be little energy differences between transmission number of speeds, the four speed consistently showed lower energy usage than those with more speeds, and thus remained in the model. The fuel model consisted of weather and plant area. Plant area coefficients in both the electricity and fuels models were having a much larger impact than anticipated. A 10% increase in plant area would have resulted in an 11.6% and 14.3% increase to electricity and fuel consumption, respectively. The impact on total energy usage attributed to an increase in plant area, while holding all other factors constant, appeared to be larger than industry reviewers had expected. The same size and location disparity observed between newer and older engine plants was discovered with transmission plants as well, with the effects being even more pronounced given the smaller sample.

Analysis and discussions about the transmission model centered around equivalent units and plant area. Although component parts were being included in the engine model, transmissions have many smaller components that would contribute negligible energy amounts or their production is not tracked. Therefore, the existing equivalent unit definition was kept. This was one of the major distinctions between the final powertrain models.

In order to address the plant area bias introduced into the analysis, the HVAC ventilation rate (referred to as HVAC) and outside air variables were revisited. Energy usage associated with each of these variables would be directly correlated with the size of the plant, but we assumed that it would be difficult to adjust. For testing purposes, two models were created: one that treated HVAC and outside air as an efficiency, and another that treated them as variables to be normalized, in both the electricity and fuels models. Including these variables drastically reduced the energy impact associated with plant area to more reasonable estimates. The normalized model allowed for each plant to input their outside air and HVAC values, and treated them as something that could be actively managed at the plant level; industry participants quickly dismissed the idea that these variables could be changed regularly for energy savings, so it was determined that they would be treated as an internal efficiency built into the model. To avoid an omitted variable bias in the other parameters of the model, these two variables were included in the regression, but the EPI model used the industry average values for HVAC and outside air to assign expected energy usage. Plants lower than the industry average would be expected to use less energy, and that would appear in their inputs and final scores; i.e., these two variables are treated as energy management strategies, not as factors to be normalized.[4]

During the third phase of testing of both models, it was discovered that less than 25% of the plants within the United States and Canada were eligible for certification. Inclusion of less energy intensive plants located in Mexico were skewing the upper quartile of the distribution for both the engine and transmission models. Mexican plants were included in the original analysis to add to the sample size and allow for the model to be more applicable to other plants around the world. Since ENERGY STAR certification is not offered in Mexico and it was not clear how similar the operating

[4] This differs from how a similar issue was handled for engines, where air-handling variables were simply dropped. This is due to the fixed effects approach which mitigated the omitted variable issue, since air-handling was largely a constant, plant-specific effect.

conditions of these plants where to U.S. and Canadian plants, they were removed from the final Energy Performance Score (EPS) distribution but remained in the underlying regression model.

The inclusion of plant area in the electricity model also continued to raise concerns. Since many plants do not have air conditioning, the size of a plant has little to do with electricity. The strong effect of plant area was determined to be due to the bias introduced by newer plants being smaller than the older plants, and was therefore removed from the model. This saw final scores for smaller plants increase and larger plants decrease, which lined up more with industry expectations given the knowledge of their own plants.

After viewing the large distribution of consumed electricity and fuels in both powertrain sectors, a kernel density approach was used to calculate electric and thermal scores. This non-parametric approach was more accurate than a standard ordinary least squares model since neither energy variable was normally distributed. Kernel density estimation is expanded upon in section 3.4.

3.3 Final Models

Summary statistics for the final variables utilized in both models are detailed in Tables 1 and 2 below:

Table 1 Engine Summary Statistics

Variable	Mean	Standard Deviation
Electricity (MWh)	81,542	45,120
Total Fuels (MMBtu)	128,619	152,622
Plant Area (square ft.)	1,385,868	741,338
Jobs Per Hour	130	61
Total Finished Engines	384,951	202,626
Crankshaft machining (produced)	346,882	195,488
Engine Block machining (produced)	364,579	195,094
Engine Head machining (produced)	374,829	218,098
Camshaft machining (produced)	203,919	265,500
Rod machining (produced)	196,447	311,841
Annual HDD	4,589	1,650
Annual CDD	1,324	547

Table 2 Transmission Summary Statistics

Variable	Mean	Standard Deviation
Electricity (MWh)	101,868	64,216
Total Fuels (MMBtu)	238,572	226,132
Plant Area (square ft.)	1,590,685	994,133
Total Finished Transmissions	601,006	326,616
Total Equivalent Transmissions	2,098	7,827
Annual HDD	4,511	1,597
Annual CDD	1,475	515

3.4 Modeling Electricity and Fuel Use Separately

There are instances in which modeling total energy use is the most appropriate approach, particularly when there are substantial opportunities to meet production energy requirements by using fuels instead of electricity, or when there is onsite electricity generation from combined heat and power (CHP) where typically more fuel is used and less electricity purchased. This would result in a plant appearing very fuel inefficient and very electric efficient; examples of the converse are possible. However, when certain products are inherently more (or less) electric or fuel intensive, then it may be appropriate to represent the electricity and fuel use separately since those production differences can more readily be accounted for in the analysis. Separating the energy forms may also improve the ability to measure weather effects, since higher cooling degree days (CDD) will be associated with higher cooling loads and electricity use; conversely, heating degree days (HDD) will be associated with heating loads and fuel use.[5]

Similar to previous analysis of the automobile assembly industry, there are distinct uses for electricity and fuels when manufacturing engines and transmissions. Separate analyses for electricity and fuels were included in the earliest drafts of each model. Electricity is used for machining and assembling products and providing cooling to the plant space. Fuels are used almost exclusively to heat the manufacturing space, meaning production factors are not relevant to fuel consumption. Modeling these energy inputs separately allows for a more accurate analysis of the energy required for different production components and removes some of the variation that would be present in a total energy model. Additionally, at the time of data collection, there were few applications of CHP for powertrain manufacturing. However, other areas of the automotive industry have seen increases in installed or planned CHP projects. Future drafts of these models will need to review the prevalence of CHP throughout powertrain plants to determine if a total energy model would be more accurate.

The analysis of each energy form follows the same general approach as would be taken for a total energy analysis, resulting in an individual measure of energy efficiency performance. Since the percentile rankings of these individual measures of efficiency are based on a probability distribution, each with its own variance, the EPS of the total energy use would also be derived from these separate variances. If electric efficiency was independent of (unrelated to) fuel efficiency, then the relevant variance for the sum of electricity use and fuel use would be the sum of the underlying variances, but this is unlikely to be the case. The energy management of the firm (plant) might make a particular location more (or less) efficient in both cases, making the efficiencies correlated. Either the joint distribution would need to be explicitly modeled, or another way to obtain the efficiency distribution for total energy would be necessary. In the case of both powertrain EPIs, the latter was chosen.

The general form of the underlying EPI equation is

$$E = f(Y, X;\ \theta) + \varepsilon \qquad (1)$$

[5] There are exceptions to this pattern, e.g., electricity used in the heating system, fuels driving adsorption chillers, etc.

or in this case

$$\ln(E) = a + \sum_{j=1}^{n} b_j\, ln(y_j) + \sum_{j=1}^{m} c_j\, x_j + \varepsilon \qquad (2)$$

Where Y includes measure of activities, X is plant characteristics like weather and product mix, and the vector of parameters to be estimated is $\theta = (a, b_*, c_*, \sigma^2)$.

We compute the estimate of efficiency as $\hat{\epsilon}_{i,t}$, for every plant, i, and year, t, from the parameter estimates, which are denoted by a $\widehat{\ }$, from

$$\ln(E) - \hat{a} + \sum_{j=1}^{n} \widehat{b_j} \ln(y_j) + \sum_{j=1}^{m} \widehat{c_j}\, x_j = \hat{\epsilon}_{i,t} \qquad (3)$$

For models using ordinary least squares (OLS) estimates, such as is the case for this industry, we have estimated the variance of the error term of equation (1), and we can compute the probability that the difference between actual energy use and predicted average energy use is no greater than this computed difference under the assumption that the efficiency, ε, is normally distributed with zero mean and variance σ^2, i.e., $\varepsilon \sim N(0, \sigma^2)$

$$\text{EPS} = (1 - \Pr(\varepsilon \le \hat{\epsilon}_{i,t})) \cdot 100 \qquad (4)$$

One minus this probability, multiplied by 100, is the *Energy Performance Score* (EPS), and is the *percentile ranking of the energy efficiency of the plant.*[6]

However, the EPI has two types of energy, so it is necessary to have $\hat{\epsilon}_{i,t,e}$ and $\hat{\epsilon}_{i,t,f}$, where e and f represent electricity and fuels. The sum of two normally distributed variables is not necessarily normal, unless they are uncorrelated. It would be preferable to compute the analog of $\hat{\epsilon}_{i,t,e}$ and $\hat{\epsilon}_{i,t,f}$, but for the sum of electricity and fuels. To do this, we need to account for the fact that the equations are estimated in log form, convert the predicted values for the energy use into levels, convert them to common units so they can be added together, and have a method to compute the probability in equation (4) that is the basis for the EPS.

While it is true that the predicted value of the natural log of energy use, $\widehat{\ln(E)}$, is

$$\widehat{\ln(E)} = \hat{a} + \sum_{j=1}^{n} \widehat{b_j} \ln(y_j) + \sum_{j=1}^{m} \widehat{c_j}\, x_j \qquad (5)$$

we need the predicted *level of energy use* in order to add electricity and fuel together. For an OLS, the estimate of the predicted level of energy use – i.e., the expected value of E – is not the exponential of $\widehat{\ln(E)}$, but is

$$\hat{E} = e^{\left(\widehat{\ln(E)} + \frac{\sigma^2}{2}\right)} \qquad (6)$$

σ^2 is the OLS error variance estimated from (2).

For notational simplicity, we denote $E_{i,t}$, $\widehat{E_{i,t}}$, $F_{i,t}$, and $\widehat{F_{i,t}}$ to be the actual and predicted pairs for electricity use and fuel use, respectively, for each plant and year. We can compute the estimates of

[6] By ENERGY STAR convention, the EPS is 100 for the lowest value of energy intensity, representing efficiency. In statistics, the lowest (left-most value of the density and distribution) is zero and the largest (right-most value) is 100%. To create the EPS, we use the simple transformation.

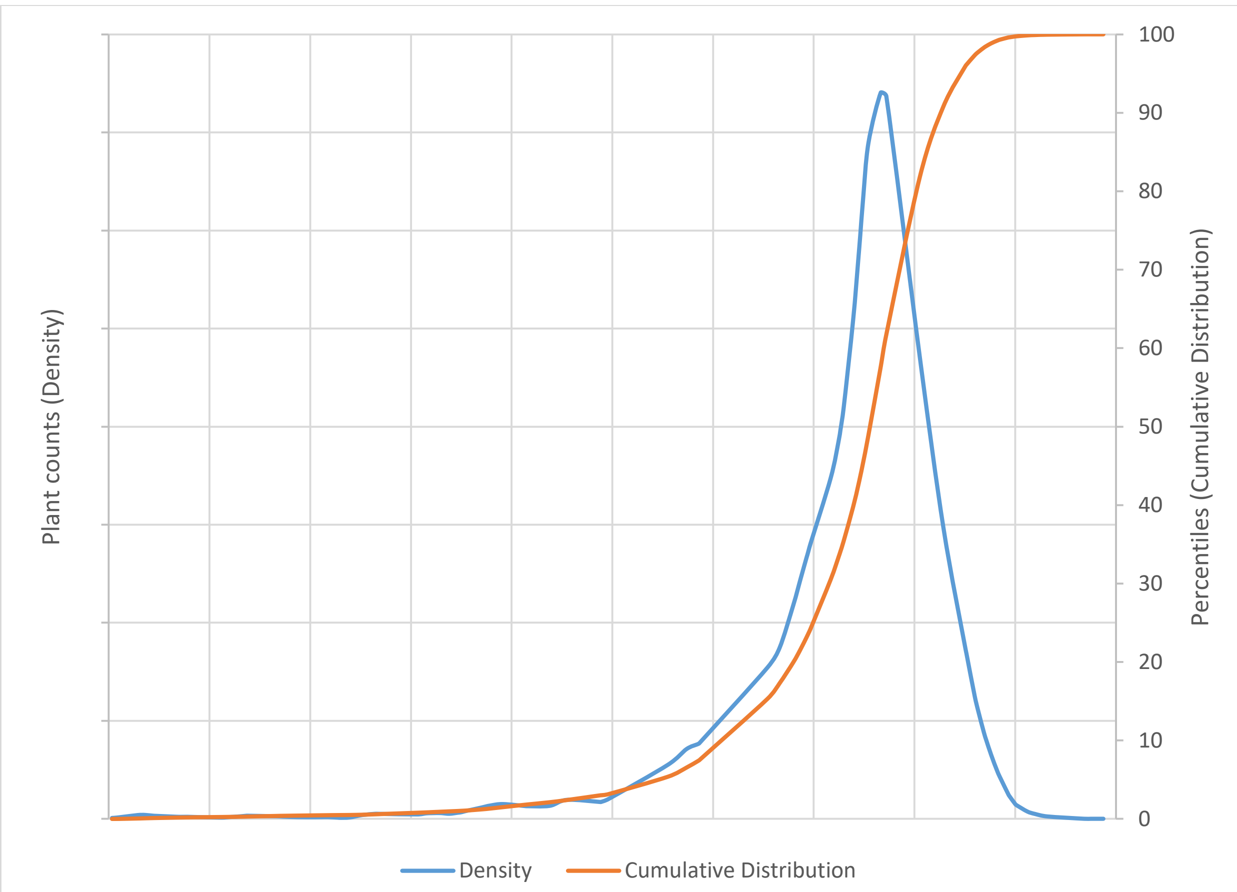
plant level total energy efficiency by adding actual electricity and fuel use and subtracting the predicted levels from equation (6) above.

$$\left(E_{i,t} \cdot C + F_{i,t}\right) - \left(\widehat{E_{i,t}} \cdot C + \widehat{F_{i,t}}\right) = \widehat{\epsilon_{i,t}} \quad (7)$$

C is the unit conversion of electricity to source MMBtu, since the model estimate for electric efficiency is in units other than source MMBtu.

To allow for the possibility that the distribution of $\epsilon_{i,t}$ from equation (7) is not a simple normal distribution, we estimate the distribution non-parametrically via a kernel density. Kernel density estimation is a flexible approach to computing the density function, similar in concept to a "smoothed histogram." The support points for the non-parametric estimate for the density of the plant level efficiencies, $\epsilon_{i,t}$, are then used to compute the cumulative distribution function via numerical integration over the support points. An example is shown in Figure 1 (Boyd and Lee 2016). The kernel density (blue) and associated distribution (orange) of a set of actual efficiency estimates is obviously not a normal distribution. The cumulative distribution can be converted to a lookup table for the percentile corresponding to any value of $\epsilon_{i,t}$.

Figure 1 Example of a Kernel Density and Associated Cumulative Distribution Estimate for Energy Efficiency in Metal Based Durables (Boyd and Lee 2016)



4 FINAL MODEL ESTIMATES

This section presents the final equations used for the engine and transmission EPIs, based on the methods and evolution described above. Stylized results that provide additional interpretation are also given.

4.1 Statistical Estimates and Elasticities

The final equations for electricity and fuels are shown in equations 8-11 and final results are shown in Table 3 below. In the engine model, the largest electricity drivers are shown to be production and jobs per hour, with plant size and weather being the only drivers for fuel consumption. In the transmission model, the largest electricity drivers are plant area and production, and fuel drivers include weather and plant area characteristics. Elasticities are reported along with coefficients to more easily understand the impact each variable has on energy usage. Using elasticity values, a 1% increase in each variable would lead to an electricity/fuels increase equal to the given elasticity. For example, a 10% increase in the production of finished engines would increase predicted electricity by 6.5%. For the engine component ratio variables, the same applies, but any increases are for additional components produced above the number of finished engines. For example, a plant that produces 100 total engines and 110 crankshafts would be expected to use 3.1% more electricity than a plant that does not produce additional crankshafts. Weather normalization is treated differently in each model. In the engine electricity model, weather only impacts energy usage when the plant has air tempering. For transmission plants, a 10% increase in HDD and CDD above the industry average would result in a 10.8% and 9.9% increase to fuels and electricity, respectively. Finally, the HVAC and outside air variables are treated the same way, with expected energy increases applying to plants above or below the industry-wide average. These results are consistent with industry expectations regarding the different energy types needed for plant processes. Table 3 provides a summary of the variables and their impacts on electricity and fuel EPI models.

Engine Plants

$$\ln(electricity) = \alpha + \beta_1 \ln(finished\ engines) + \beta_2 \ln(jobs\ per\ hour) + \beta_3(Air\ Tempered * CDD) + \beta_4 \left(crankshafts/_{finished\ engines}\right) + \beta_5 \left(blocks/_{finished\ engines}\right) + \beta_6 \left(heads/_{finished\ engines}\right) + \beta_7 \left(camshafts/_{finished\ engines}\right) + \beta_8 \left(rods/_{finished\ engines}\right) + \varepsilon \quad (8)$$

$$\ln(fuels) = \alpha + \beta_1 \ln(plantarea) + \beta_2 HDD + \varepsilon \quad (9)$$

Transmission Plants

$$\ln(electricity) = \alpha + \beta_1 \ln(finished \ \& \ equivalent \ transmissions) + \beta_2 \left({CDD}/{Industry \ Avg \ CDD} \right) + \beta_3 \ln(plantarea) + \beta_4 (Industry \ Avg \ CFM) + \beta_5 (Industry \ Avg \ Min \ Outside \ Air) + \varepsilon \quad (10)$$

$$\ln(fuels) = \alpha + \beta_1 \left({HDD}/{Industry \ Avg \ HDD} \right) + \beta_2 \ln(plantarea) + \beta_3 (Industry \ Avg \ CFM) + \beta_4 (Industry \ Avg \ Min \ Outside \ Air) + \varepsilon \quad (11)$$

Table 3 Model Results and Variable Impacts

	Engine Electricity Model			**Engine Fuels Model**		
Variables	**Coefficient**	**Standard Error**	**Elasticity**	**Coefficient**	**Standard Error**	**Elasticity**
Log Finished Engines	0.645**	0.074	0.645	-	-	-
Log Jobs Per Hour	0.428**	0.123	0.428	-	-	-
Crankshaft Ratio	0.321*	0.185	0.31	-	-	-
Blocks Ratio	0.243	0.149	0.24	-	-	-
Head Ratios	0.115	0.09	0.11	-	-	-
Camshaft Ratio	0.046	0.06	0.03	-	-	-
Rod Ratio	0.136	0.181	0.09	-	-	-
Log Plant Area	-	-	-	0.241	0.323	0.241
Annual CDD (Dependent on Air Tempering)	0.000108	0.000103	0.11	-	-	-
Annual HDD	-	-	-	0.000458**	0.000123	2.10
R-Squared	0.777			0.342		

	Transmission Electricity Model			**Transmission Fuels Model**		
Variables	**Coefficient**	**Standard Error**	**Elasticity**	**Coefficient**	**Standard Error**	**Elasticity**
Log Finished & Equivalent Transmissions	0.368*	0.153	0.368	-	-	-
Log Plant Area	0.740**	0.163	0.740	0.816**	0.177	0.816
Industry Average CFM (HVAC)	0.411**	0.135	0.79	0.890**	0.50	1.71
Industry Average Minimum Outside Air	0.789	0.668	0.20	1.32*	0.723	0.34
Annual CDD (Over Industry Average)	0.995**	0.280	0.99	-	-	-
Annual HDD (Over Industry Average)	-	-	-	1.077**	0.319	1.08
R-Squared	0.747			0.898		

** Significant at the 99% level; * Significant at the 90% level

4.2 Stylized Results

When only examining the raw data on energy intensity (energy/total product) for both engine and transmission manufacturing that only normalizes for production, the range of performance is quite wide. The small sample size and diversity of these plants in size, age, location, etc. are major contributors to this large distribution in intensity. The EPI analysis shows that this observation taken by itself is actually misleading; after normalizing for additional factors, the range of performance is narrower, especially in the total energy models. The red lines in Figures 2-7 take the raw energy intensity data and transform it into the kernel density distribution of plants that lie above or below the average energy electricity, fuel, and total intensity, and are represented on a log scale. Average engine intensities are 2.68 MMBtu/finished engine (electric), 0.45 MMBtu/finished engine (thermal), and 3.12 MMBtu/finished engine (total), and average transmission intensities are 2.28 MMBtu/total production (electric), 0.51 MMBtu/total production (thermal), and 2.79 MMBtu/total production (total). The blue lines representing the kernel density from the EPI analysis tell a different story. Most of those differences come from differences that are accounted for in the analysis, production amounts, importing or exporting components, different climates, plant size, etc. The normalized range of actual efficiency, after these differences are accounted for, is narrower. This is consistent with the results of a meta-analysis of EPI studies for other industries (Boyd 2016). The difference in total energy consumption between an "average" plant (score of 50) and an "efficient" plant (score of 75) is roughly 27% for engine manufacturing and 24% for transmission manufacturing. As expected, this matches closely with the automobile assembly EPI (22%) that is mostly comprised of facilities of the same companies, hinting that energy efficiency is industry wide and is implemented across all facilities regardless of process.

Figure 2 Engines: Comparing the Distribution of Electricity Intensity to Efficiency

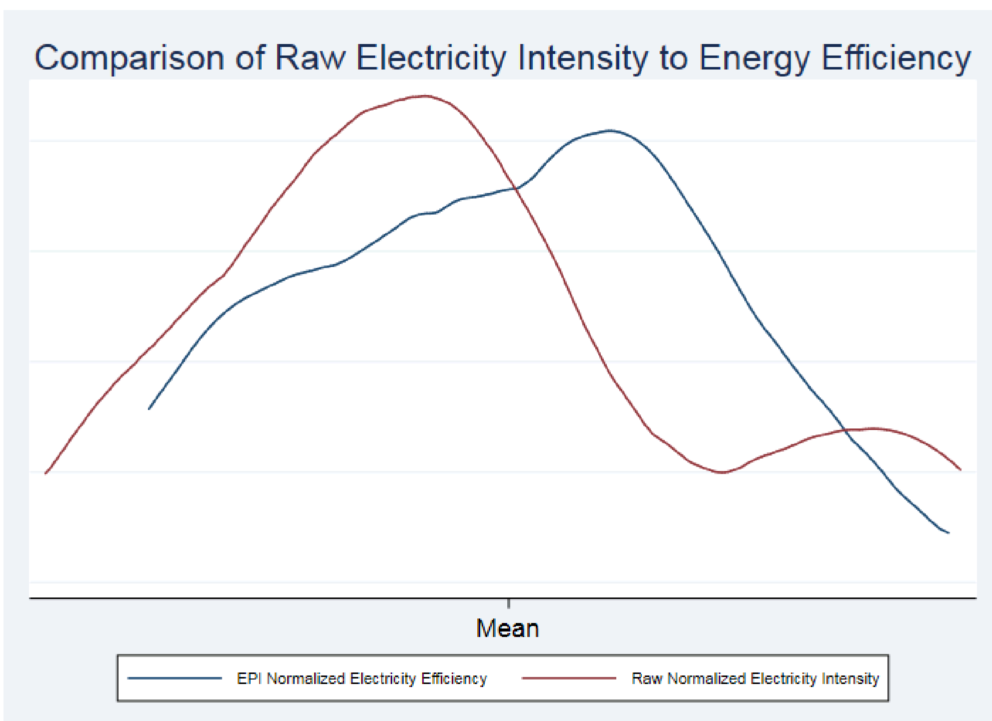


Figure 3 Engines: Comparing the Distribution of Fuels Intensity to Efficiency

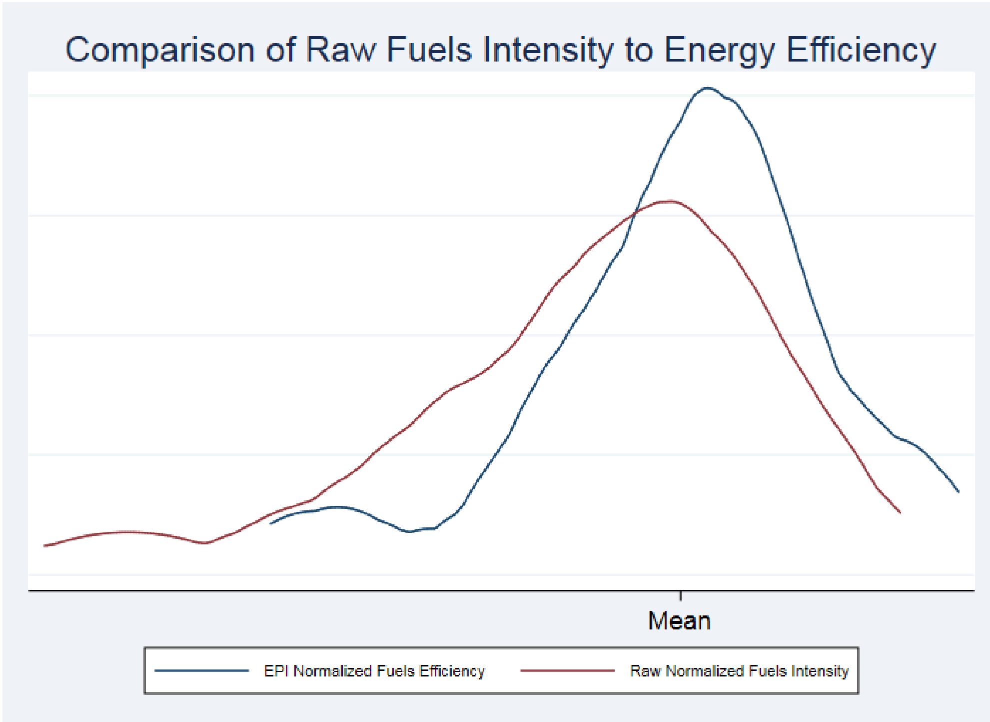


Figure 4 Engines: Comparing the Distribution of Total Energy Intensity to Efficiency

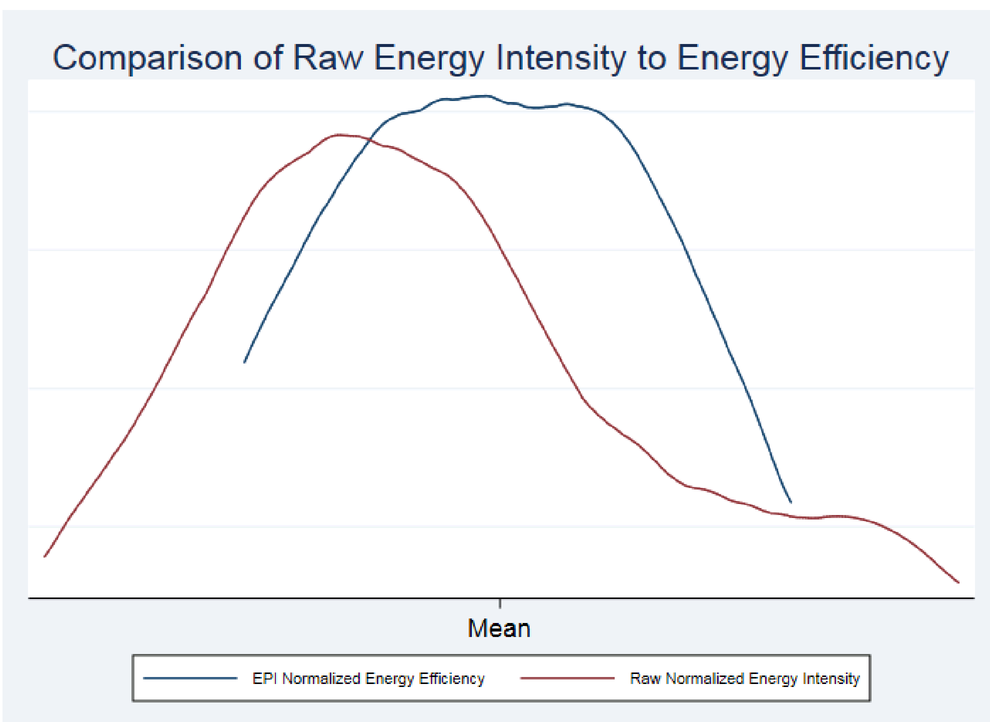


Figure 5 Transmissions: Comparing the Distribution of Electricity Intensity to Efficiency

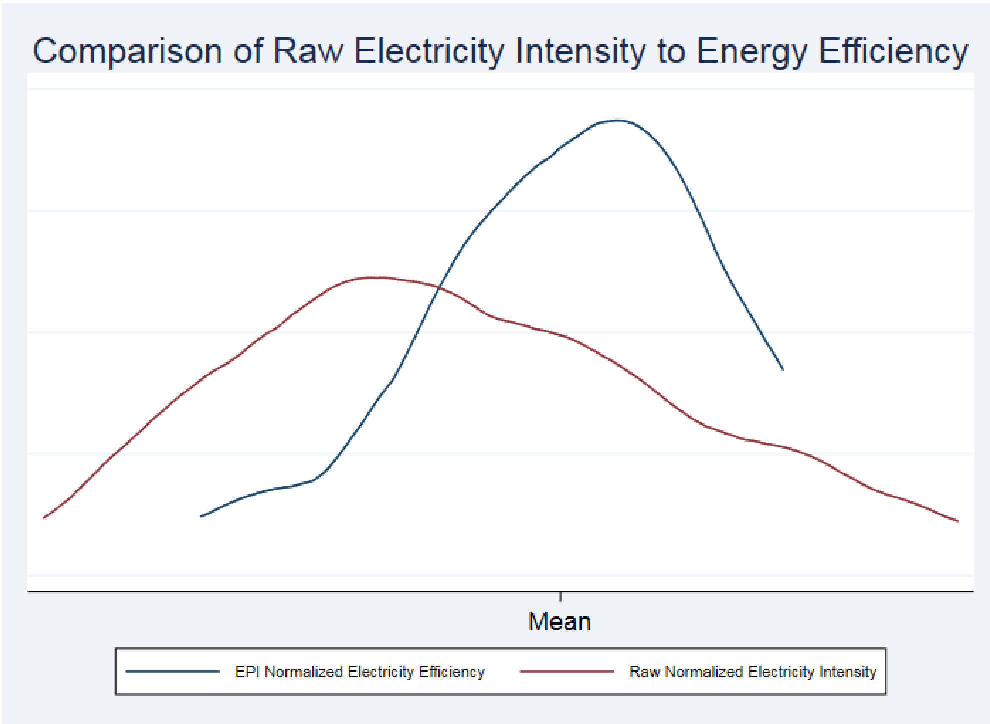


Figure 6 Transmissions: Comparing the Distribution of Fuels Intensity to Efficiency

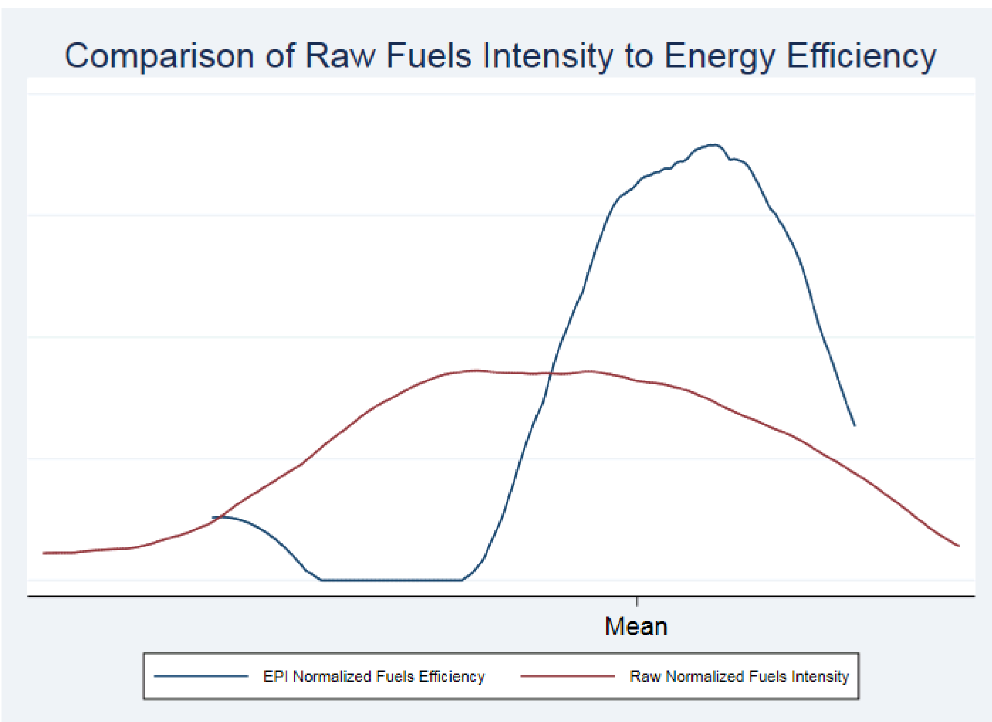
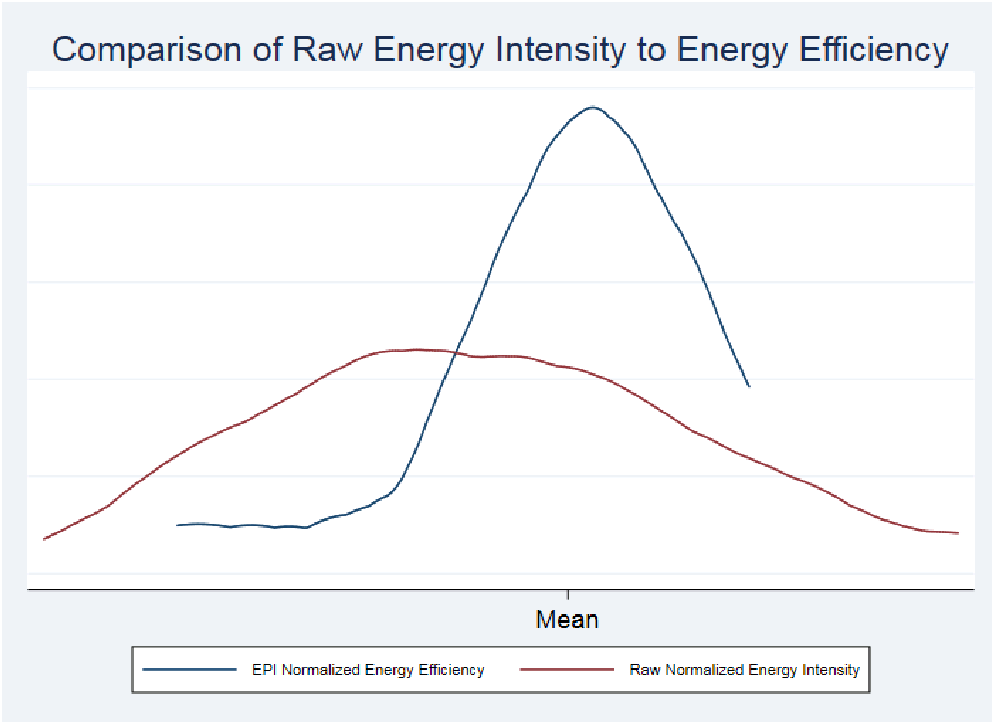


Figure 7 Transmissions: Comparing the Distribution of Total Energy Intensity to Efficiency



5 SCORING POWERTRAIN MANUFACTURING PLANT EFFICIENCY

This section describes the spreadsheet tools that are created based on the above analysis. Suggestions for how to use the tools and interpret the results are also shown below.

5.1 How the Powertrain EPIs Work

The engine powertrain plant EPI scores the energy efficiency of engine manufacturers across the United States and Canada. To use the tool, the following information must be available for a plant.

- Total energy use
  - Electricity (converted to source MMBtus by the spreadsheet tool)
  - Fuel use for all fuel types in physical units or MMBtu (converted to source MMBtus by the spreadsheet tool)
- Production Numbers
  - Finished Engines produced
  - Crankshaft machining (produced)
  - Engine Block machining (produced)
  - Engine Head machining (produced)
  - Camshaft machining (produced)
  - Rod machining (produced)
- Weather
  - Heating degree days (HDD)
  - Cooling degree days (CDD)
- Plant Operations and Characteristics
  - Is the plant air-tempered?
  - Designed Jobs per Hour (JPH) total line rate
  - Total plant area

The transmission powertrain plant EPI scores the energy efficiency of transmission manufacturers across the United States and Canada. To use the tool, the following information must be available for a plant.

- Total energy use
  - Electricity (converted to source MMBtus by the spreadsheet tool)
  - Fuel use for all fuel types in physical units or MMBtu (converted to source MMBtus by the spreadsheet tool)
- Production Numbers
  - Finished Transmissions produced
  - Equivalent Transmission Units produced
- Weather
  - Heating degree days (HDD)
  - Cooling degree days (CDD)

- Plant Characteristics
    - Total plant area

Based on these data inputs, the EPI will report an Energy Performance Score (EPS) for the plant in the current time period that reflects the relative energy efficiency of the plant compared to that of the industry. The EPS is a percentile score on a scale of 1–100. An EPS of 75 means a particular plant is performing better than 75% of the plants in the industry, on a normalized basis. ENERGY STAR defines the 75th percentile as the benchmark for efficiency, so plants that score 75 or better are classified as efficient. The model also estimates what the energy use would be for an "average" plant (defined as the 50th percentile) with the same production characteristics. This overall score is complemented with similar efficiency scores for electricity and fuels consumption. While the underlying model was developed from industry-supplied data, it does not contain or reveal any confidential information.

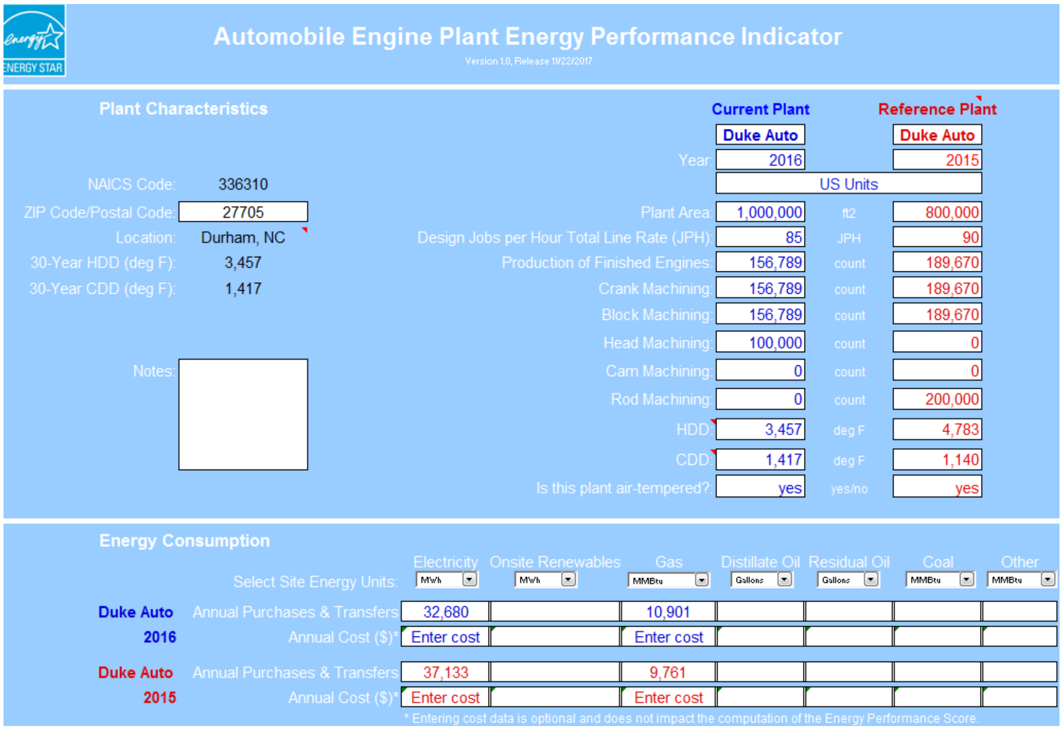
5.2 Spreadsheet Tools

To facilitate the review and use by industry energy managers, spreadsheets were constructed to display the results of both the engine and transmission EPIs for an arbitrary[7] set of plant-level inputs. Energy managers were encouraged to input data for their own plants and then provide comments. Versions of these spreadsheets corresponding to the results described in this report are available from the EPA ENERGY STAR web site.[8] Example inputs and outputs of the spreadsheet tools are shown in Figures 8-15.

[7] In other words, for plant data that may not originally have been in the data set used to estimate the model equations.

[8] http://www.energystar.gov/epis

Figure 8 Input Section of the Engine Manufacturing EPI Spreadsheet Tool



Automobile Engine Plant Energy Performance Indicator

Version 1.0, Release 11/22/2017

Plant Characteristics

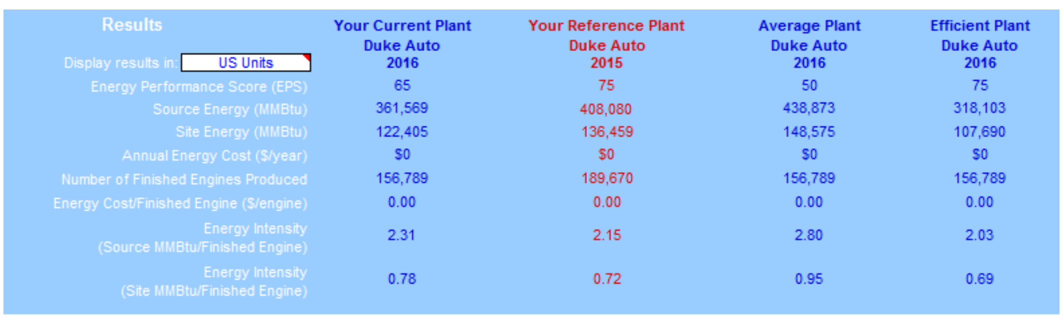
			Current Plant		Reference Plant
			Duke Auto		Duke Auto
		Year	2016		2015
NAICS Code:	336310		US Units		
ZIP Code/Postal Code:	27705	Plant Area	1,000,000	ft2	800,000
Location:	Durham, NC	Design Jobs per Hour Total Line Rate (JPH)	85	JPH	90
30-Year HDD (deg F):	3,457	Production of Finished Engines	156,789	count	189,670
30-Year CDD (deg F):	1,417	Crank Machining	156,789	count	189,670
		Block Machining	156,789	count	189,670
		Head Machining	100,000	count	0
Notes:		Cam Machining	0	count	0
		Rod Machining	0	count	200,000
		HDD	3,457	deg F	4,783
		CDD	1,417	deg F	1,140
		Is this plant air-tempered?	yes	yes/no	yes

Energy Consumption

		Electricity	Onsite Renewables	Gas	Distillate Oil	Residual Oil	Coal	Other
	Select Site Energy Units:	MWh	MWh	MMBtu	Gallons	Gallons	MMBtu	MMBtu
Duke Auto	Annual Purchases & Transfers	32,680		10,901				
2016	Annual Cost ($)*	Enter cost		Enter cost				
Duke Auto	Annual Purchases & Transfers	37,133		9,761				
2015	Annual Cost ($)*	Enter cost		Enter cost				

* Entering cost data is optional and does not impact the computation of the Energy Performance Score.

Figure 9 Output Section of the Engine Manufacturing EPI Spreadsheet Tool



Results	Your Current Plant	Your Reference Plant	Average Plant	Efficient Plant
Display results in: US Units	Duke Auto 2016	Duke Auto 2015	Duke Auto 2016	Duke Auto 2016
Energy Performance Score (EPS)	65	75	50	75
Source Energy (MMBtu)	361,569	408,080	438,873	318,103
Site Energy (MMBtu)	122,405	136,459	148,575	107,690
Annual Energy Cost ($/year)	$0	$0	$0	$0
Number of Finished Engines Produced	156,789	189,670	156,789	156,789
Energy Cost/Finished Engine ($/engine)	0.00	0.00	0.00	0.00
Energy Intensity (Source MMBtu/Finished Engine)	2.31	2.15	2.80	2.03
Energy Intensity (Site MMBtu/Finished Engine)	0.78	0.72	0.95	0.69

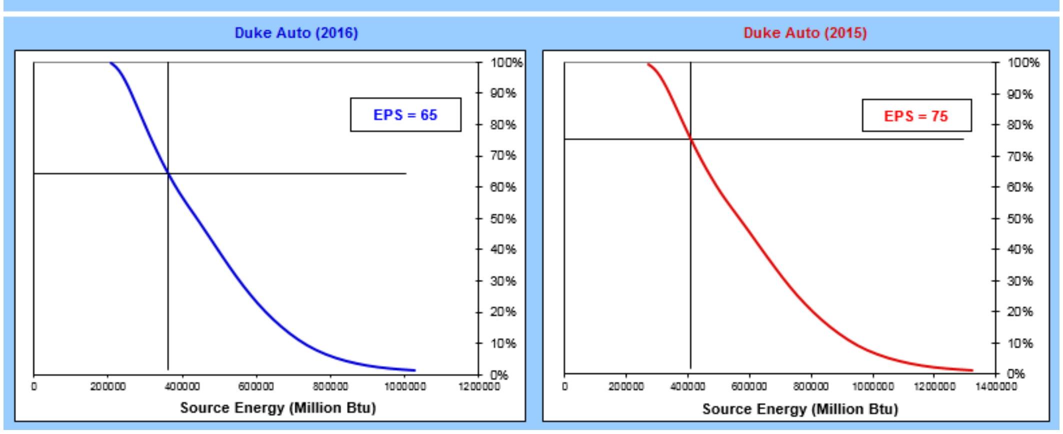


Figure 10 Electricity Output Section of the Engine Manufacturing EPI Spreadsheet Tool

Electricity Results	Your Current Plant Duke Auto 2016	Your Reference Plant Duke Auto 2015	Average Plant Duke Auto 2016	Efficient Plant Duke Auto 2016
Electric Rating (ER)	62	66	50	75
Annual Electricity Cost ($/year)	$0	$0	$0	$0
umber of Finished Engines Produced	156,789	189,670	156,789	156,789
Electricity Cost/Finished Engine ($/engine)	0.00	0.00	0.00	0.00
Electricity (Source MMBtu)	350,123	397,831	412,065	283,425
Electricity (Site MMBtu)	111,504	126,698	131,231	90,263
Electricity (kWh)	32,680,000	37,133,000	38,461,583	26,454,497
Electric Energy Intensity (Source MMBtu/Finished Engine)	2.23	2.10	2.63	1.81
Electric Energy Intensity (kWh/Finished Engine)	208.43	195.78	245.31	168.73

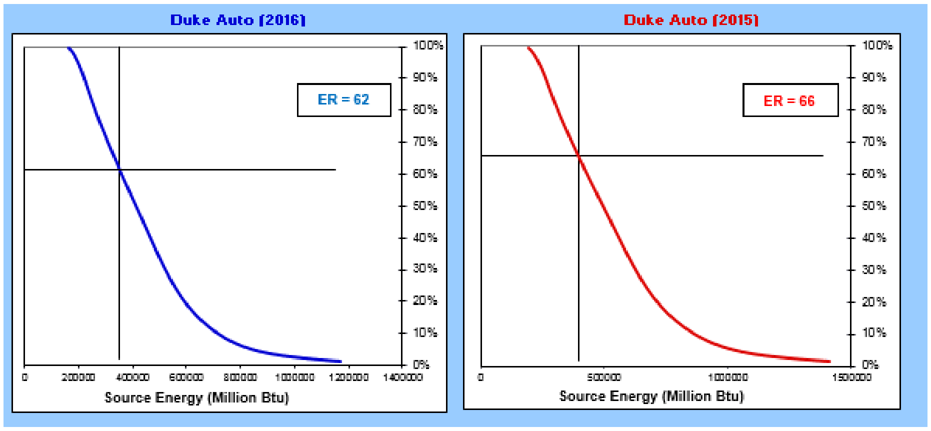


Figure 11 Thermal Output Section of the Engine Manufacturing EPI Spreadsheet Tool

Thermal (Fuels) Results	Your Current Plant Duke Auto 2016	Your Reference Plant Duke Auto 2015	Average Plant Duke Auto 2016	Efficient Plant Duke Auto 2016
Thermal Rating (TR)	85	92	50	75
nnual Thermal Energy Cost ($/year)	$0	$0	$0	$0
mber of Finished Engines Produced	156,789	189,670	156,789	156,789
Thermal Energy Cost/Finished Engine ($/engine)	0.00	0.00	0.00	0.00
Thermal Energy (Source MMBtu)	11,446	10,249	40,411	18,490
Thermal Energy (Site MMBtu)	10,901	9,761	38,486	17,609
Thermal Energy Intensity (Source MMBtu/Finished Engine)	0.07	0.05	0.26	0.12

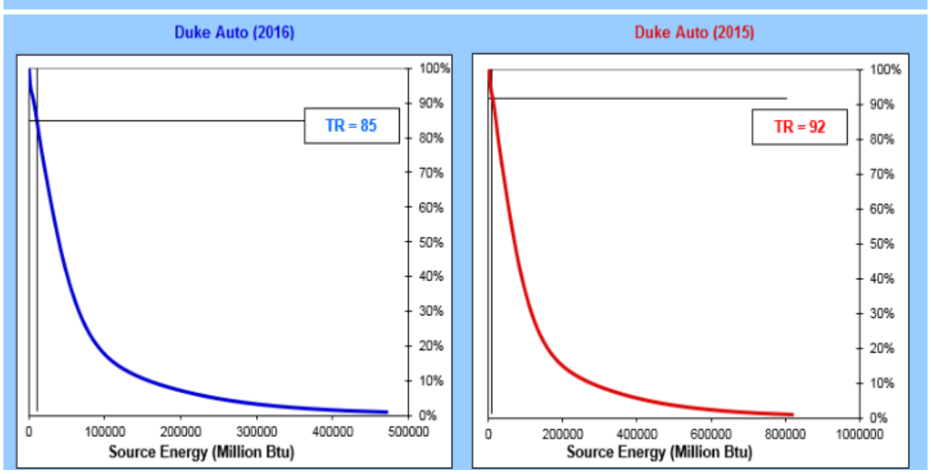


Figure 12 Input Section of the Transmission Manufacturing EPI Spreadsheet Tool

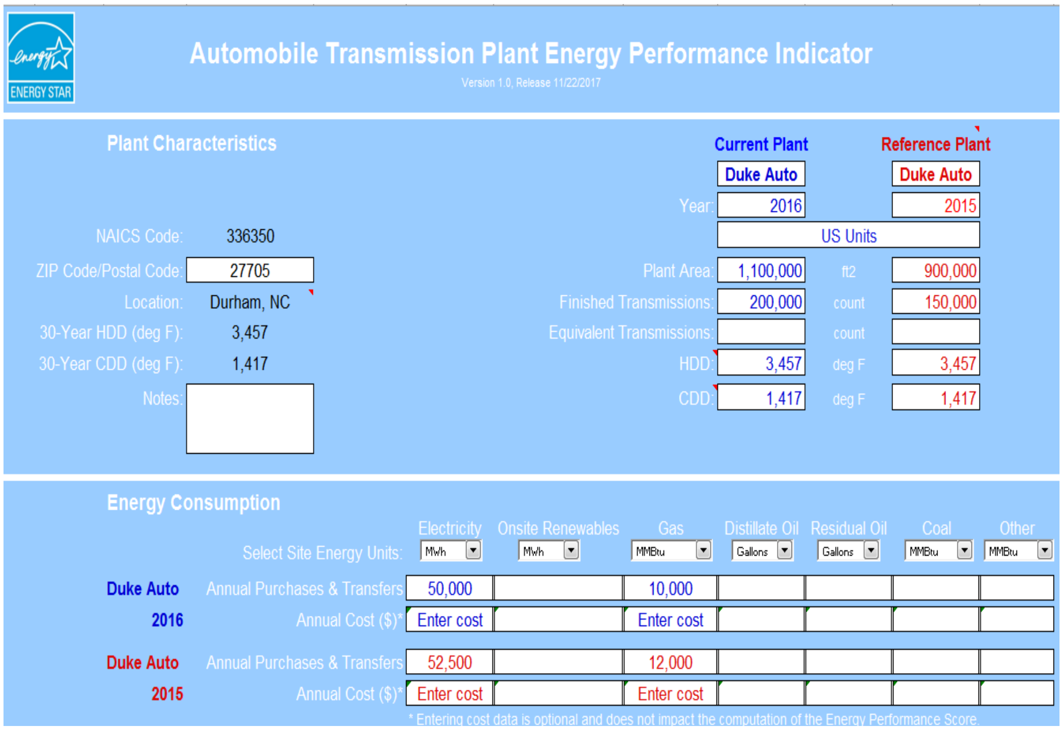


Figure 13 Output Section of the Transmission Manufacturing EPI Spreadsheet Tool

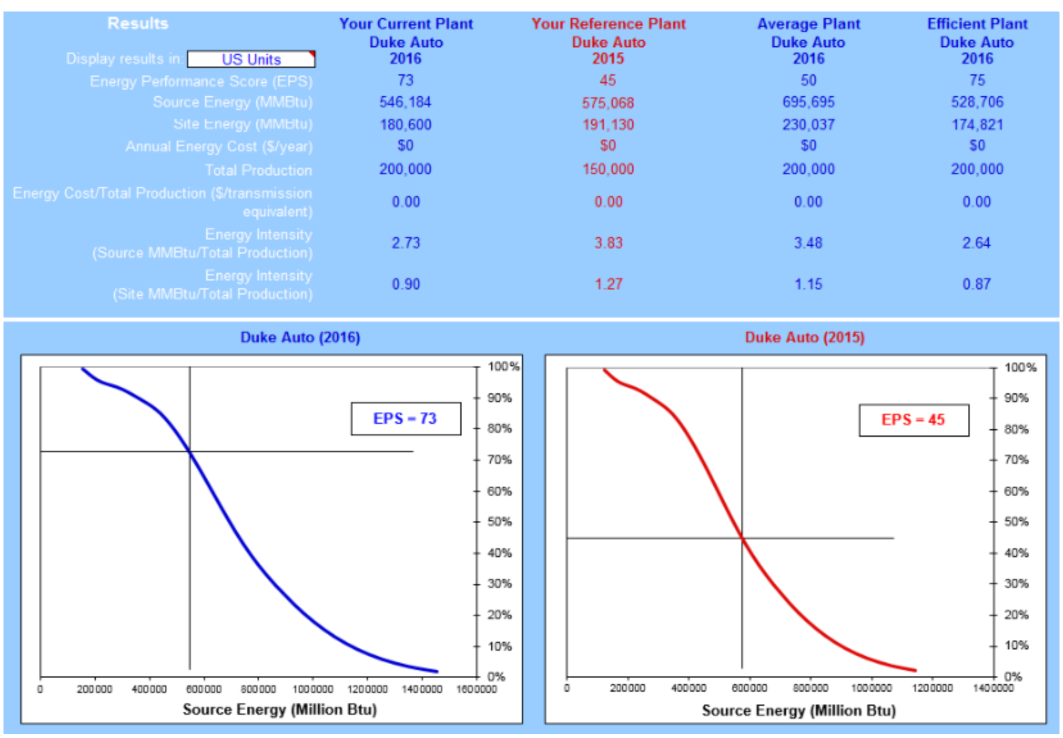


Figure 14 Electricity Output Section of the Transmission Manufacturing EPI Spreadsheet Tool

Electricity Results	Your Current Plant Duke Auto 2016	Your Reference Plant Duke Auto 2015	Average Plant Duke Auto 2016	Efficient Plant Duke Auto 2016
Electric Rating (ER)	55	31	50	75
Annual Electricity Cost ($/year)	$0	$0	$0	$0
Total Production	200,000	150,000	200,000	200,000
Electricity Cost/Total Production ($/transmission equivalent)	0.00	0.00	0.00	0.00
Electricity (Source MMBtu)	535,684	562,468	567,467	416,723
Electricity (Site MMBtu)	170,600	179,130	180,722	132,714
Electricity (kWh)	50,000,000	52,500,000	52,966,583	38,896,382
Electric Energy Intensity (Source MMBtu/Total Production)	2.68	3.75	2.84	2.08
Electric Energy Intensity (kWh/Total Production)	250.00	350.00	264.83	194.48

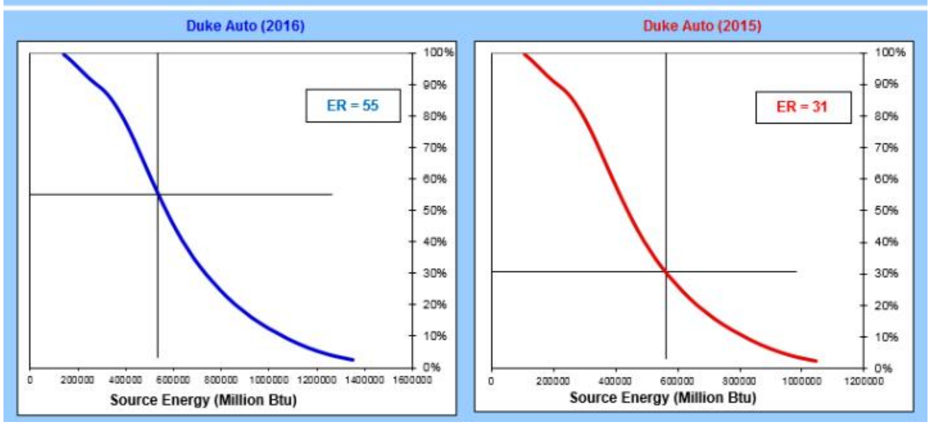
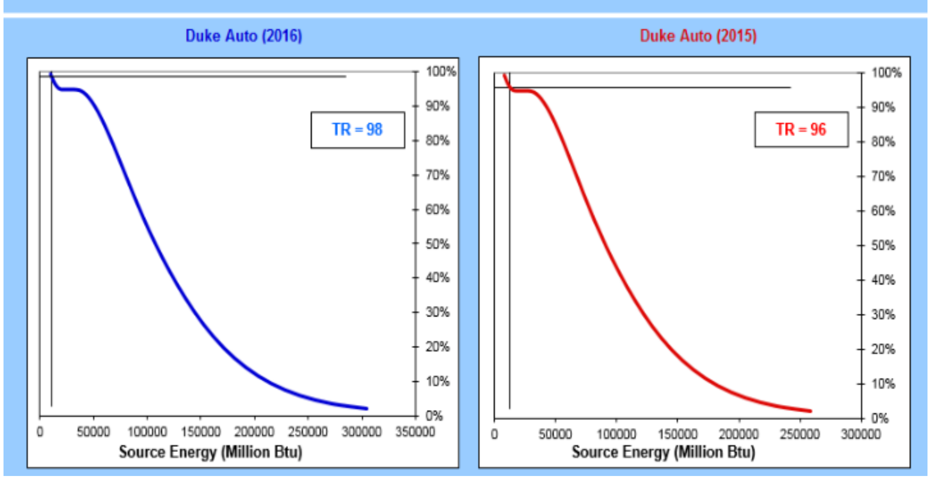


Figure 15 Thermal Output Section of the Transmission Manufacturing EPI Spreadsheet Tool

Thermal (Fuels) Results	Your Current Plant Duke Auto 2016	Your Reference Plant Duke Auto 2015	Average Plant Duke Auto 2016	Efficient Plant Duke Auto 2016
Thermal Rating (TR)	98	96	50	75
Annual Thermal Energy Cost ($/year)	$0	$0	$0	$0
Total Production	200,000	150,000	200,000	200,000
Thermal Energy Cost/Total Production ($/transmission equivalent)	0.00	0.00	0.00	0.00
Thermal Energy (Source MMBtu)	10,500	12,600	107,038	72,603
Thermal Energy (Site MMBtu)	10,000	12,000	101,941	69,145
Thermal Energy Intensity (Source MMBtu/Total Production)	0.05	0.08	0.54	0.36



5.3 Use of the ENERGY STAR Powertrain EPIs

EPIs are developed to provide industry with a unique metric for evaluating energy performance that will lead plants to take new steps to improve their energy performance. To promote the use of EPIs, EPA works closely with the manufacturers through an ENERGY STAR Industrial Focus on energy efficiency in manufacturing to promote strategic energy management among the companies in this industry. The EPI is an important tool that enables companies to determine how efficiently each of the plants in the industry is using energy and whether better energy performance could be expected. The EPI and the Energy Performance Score also serve as the basis for ENERGY STAR recognition. Plants that score a 75 or higher become eligible for ENERGY STAR certification.

EPA recommends that companies use the EPIs on a regular basis. At a minimum, it is suggested that corporate energy managers benchmark each plant on an annual basis. A more proactive plan would provide for quarterly use (rolling annual basis) for every plant in a company. EPA suggests that the EPI score be used to set energy efficiency improvement goals at both the plant and corporate levels. The EPIs also can be used to inform new plant designs by establishing energy intensity targets.

The models described in this report are based on the performance of the industry for a specific period of time. One may expect that energy efficiency overall will change as technology and business practices change, so the models will need to be updated. EPA plans to update these models every few years, contingent on newer data being made available and industry use and support of the EPI tools.

5.4 Steps to Compute a Score

All of the technical information described herein is built into spreadsheets available from EPA (http://www.energystar.gov/epis). Anyone can download, open the EPI spreadsheets, and enter, update, and manage data as they choose. The following details each step involved in computing an EPS for a plant.

1. User enters plant data into the EPI spreadsheet

- Complete energy information includes all energy purchases (or transfers) at the plant for a continuous 12-month period. The data do not need to correspond to a single calendar year.
- The user must enter specific operational characteristic data. These characteristics are those included as independent variables in the analysis described above.

2. EPI computes the Total Source Energy (TSE) Use

- TSE is computed from the metered energy data.
- The total site energy consumption for each energy type entered by the user is converted into source energy using the site-to-source conversion factors.
- TSE is the sum of source energy across all energy types in the plant.
- TSE per relevant unit of production is also computed.

3. EPI computes the Predicted "Average Practice"[9] TSE

- Predicted "Average Practice" TSE is computed using the methods above for the specific plant.
- The terms in the regression equation are summed to yield a predicted TSE.
- The prediction reflects the expected average energy use for the plant, given its specific operational characteristics.

4. EPI compares Actual TSE to Predicted "Average Practice" TSE

- A lookup table maps all possible values of TSE that are higher or lower than the Predicted "Average Practice" TSE to a cumulative percent in the population.
- The table identifies how far above or below the energy use for a plant is from average practice.
- The lookup table returns a score on a scale of 1-to-100.
- The Predicted TSE for a median and 75th percentile plant is computed based on the plant-specific characteristics.
- A score of 75 indicates that the building performs better than 75% of its peers.
- Plants that earn a 75 or higher may be eligible to earn the ENERGY STAR.

[9] The model computes the "best practice" for frontier models and "average practice" for ordinary least squares. Steps 3 and 4 are similar for the frontier models, except that the prediction is for the best practice energy use and the percentiles are relative to the best (i.e., 100th percentile).

6 REFERENCES

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