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# The evolution of the ENERGY STAR® energy performance indicator for benchmarking industrial plant manufacturing energy use ☆

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**Abstract**

ENERGY STAR® is a voluntary government/industry partnership that offers information to businesses and consumers on energy-efficient solutions, making it easier to save money and protect the environment for future generations. Introduced in 1992 by the US Environmental Protection Agency (EPA), this voluntary labeling program was designed to identify and promote energy-efficient products as basic pollution prevention opportunities. The ENERGY STAR label can now be found on appliances, office equipment, lighting, buildings, and more. In 2002, ENERGY STAR was extended beyond its role in identifying *energy efficient products* to identifying *energy-efficient production*. The ENERGY STAR industry program focuses on encouraging and enabling sustainable corporate energy management. One of the three information tools EPA developed under ENERGY STAR, which also includes energy management networking and industry specific energy guides, is the energy performance indicator (EPI). The EPI is a statistical benchmarking tool that provides a ‘‘birds-eye’’ view of sector-specific plant-level energy use via a functional relationship between the level of energy use and the level and type of various production activities, material input’s quality, and external factors, e.g. climate and material quality. The EPI uses stochastic frontier regression to estimate the lowest observed plant energy use, given these factors. This statistical model also provides a distribution of energy efficiency across the industry, which allows the user to answer the hypothetical but very practical question, ‘‘How would my plant compare to everyone else in my industry, *if all other plants* were similar to mine?’’ The result is a tool that can be used by corporate and plant energy managers to estimate the energy efficiency of their portfolio of plants. This paper describes the role of the EPI within the context of the overall goals of ENERGY STAR and gives examples of how this information tool was developed and is being used.



*Keywords:* Energy savings; ENERGY STAR; Energy efficient products; Energy efficient production processes; Energy performance indicator

## 1. Introduction

The US Environmental Protection Agency (EPA) introduced ENERGY STAR in 1992 as a voluntary government program that reduces air pollution through increased energy efficiency. EPA designed ENERGY STAR to inform businesses and consumers about energy-efficient solutions and make it easier to save money and protect the environment for future generations. To aid decision-making that reduces energy use, EPA designed the ENERGY STAR certification mark as a label

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for products, homes, and facilities that meet or exceed performance guidelines.[1] The ENERGY STAR mark is a nationally-recognized symbol of energy efficiency. It can be found on many products including, appliances, office equipment, and lighting as well as on homes, and buildings. Currently, the ENERGY STAR symbol is recognized by more than 60% of all US households.

EPA identifies the best in energy performance through energy performance benchmarks for existing buildings and selected industrial facilities. Based on this work, EPA recognized that the practice of benchmarking is necessary for identifying potential energy performance, but is also part of managing energy across a corporation. EPA worked with its partners to identify a holistic system for achieving superior energy performance and enhanced its energy management guidance. Businesses and other organizations now learn through ENERGY STAR to manage energy at a strategic, corporate level.[2] EPA focuses ENERGY STAR on identifying the management practices that result in superior corporate energy performance and provides the management tools that enable energy efficiency. Through this partnership, businesses and other organizations can thereby improve energy efficiency and gain recognition for superior performance through the ENERGY STAR label and partner awards.

In its work with industrial companies, the EPA offers a suite of energy management tools. One of these is a benchmark of manufacturing plant energy performance called the energy performance indicator (EPI). The EPI is a statistical tool that provides a "birds-eye" view of industrial, sector-specific, plant-level energy use via a functional relationship between the level of energy use and the level and types of production activities, quality of material inputs, and external factors. The EPI uses stochastic frontier regression to estimate the lowest observed plant energy use, given these factors. This statistical model also provides a distribution of energy efficiency across the industry, and permits corporate and plant managers to answer the question, "How would the energy performance of my plant compare to that of others in my industry, *if all other plants* were similar to mine?" The result is a tool that can be used by managers to estimate the energy efficiency of their manufacturing plants. This paper describes the role of the EPI within the context of the overall goals of ENERGY STAR and gives examples of how this information tool was developed and is used.

## 2. Encouraging energy efficiency − from products and beyond

In the market of energy-efficient products and practices, ENERGY STAR promotes informed decision-making on energy efficiency. Consumers and businesses sometimes conduct their affairs in a manner that does not result in an energy-efficient outcome. EPA has observed that decisions improve when information is provided on energy-efficient products and practices along with the financial and environmental impacts. Thus, EPA designed the ENERGY STAR program to enhance the market "for energy efficiency by reducing the transaction costs and lowering the investment risks to the point that many more projects become attractive".[3] With better information, businesses and individuals are empowered to make informed decisions that affect energy efficiency.

EPA offers ENERGY STAR to aid in the identification of energy-efficient products, homes, buildings and facilities. In the areas of products and homes, EPA coordinates with the Department of Energy and a number of manufacturers "to determine the energy performance levels that must be met for a product to earn the ENERGY STAR".[3] Products earning the ENERGY STAR are awarded a label that identifies them as offering energy performance and a reasonable payback of initial purchase price.

Selected buildings and facilities can earn the ENERGY STAR if actual energy performance scores in the 75th percentile or higher on the EPA's national energy performance rating system. This rating system enables specific space types to be benchmarked to determine their energy efficiency as compared to a normalized population of actual US facilities. In addition to providing the market with a way to identify energy-efficient facilities, EPA's energy benchmarking system provides a valuable management tool for promoting greater energy efficiency.

Benchmarking energy use is a critical energy management activity. It enables organizations to determine whether better energy performance should be expected for a facility, process or piece of equipment and aids them in achieving their energy reduction goal setting and in providing them a way to evaluate the reasonableness of such goals.

EPA recognizes benchmarking is one of several critical steps in managing energy usage more effectively and that additional resources are necessary for driving greater energy efficiency. EPA, therefore, worked with its partners to identify the strategic steps of organizational energy management and included these in the ENERGY STAR resources. The strategic steps are incorporated in the ENERGY STAR Guidelines for Energy Management,[4] a framework for controlling energy use across an organization.

By offering a roadmap for centrally managing energy, EPA helps an organization take action on benchmarking facility energy performance. The combination of management strategies and benchmarks enables an organization to improve its level of energy performance, to save money and to reduce its greenhouse gas emissions.

## 3. Benchmarking plant energy use with the energy performance indicator

The concept of energy efficiency in manufacturing is complex. Efficiency must be defined relative to some benchmark

[1] US EPA. Using the ENERGY STAR identity to maintain and build value. EPA 430-B-03-003.

[2] In this paper, the term "corporate" is not intended to refer to the legal organization of a company, but rather it is used to refer to the upper levels of the business organization.

[3] US EPA [4].

[4] US EPA. Guidelines for Energy Management. www.energystar.gov.

of performance, i.e. a notion of the "best practice" or lowest achievable energy use. However, this concept must also take into account factors that influence the amount of energy required to produce the particular goods or services. Engineering estimates have often been employed to estimate industrial benchmarks. ENERGY STAR has developed an approach based on best observable performance. The ENERGY STAR energy performance indicator (EPI) is a statistical benchmarking tool that provides a "birds-eye" view of sector-specific plant-level energy use via a functional relationship between the level of energy use and the level and type of various production activities, quality of material inputs, and external factors, e.g. climate and material quality. The EPI uses stochastic frontier analysis (SFA). This data analysis technique provides an estimate of the lowest observed plant energy use, given these various factors. The SFA statistical model also provides a distribution of energy efficiency across the industry, which allows the user to answer the hypothetical but very practical question, "How would the energy performance of my plant compare to that of others in my industry, *if all other plants* were similar to mine?" The result is a tool that can be used by corporate and plant energy managers to estimate the energy efficiency of a portfolio of plants.

A plan was developed to create a model for manufacturing plants within a particular industry that could be used to benchmark a particular plants performance in relation to those plants within the industry that perform the best in regard to energy usage. This required a source of data to be identified that could be utilized to nationally represent all manufacturing plants within a particular industry, as well as other available information sources that could add to the manufacturing and energy picture for the industry. The primary data sources chosen for use were data collected by the US Bureau of the Census (Census), including the Census of Manufacturing and the Manufacturing Energy Consumption Survey. These data include economic activity – for example, labor, energy, materials costs, and output – for a sample of plants during survey years and complete coverage during the years of the economic census.

For different industries different types of Census data may be used to support the analysis, depending on what data are available and what aspects of production are the most important drivers of energy consumption. By using data from the Census on the energy use of the plants (both electricity and fuels) and the economic activities, whether it is the amount of materials processed or the level and mix of production of different goods, an industry specific analysis of energy can be obtained.

Under Title 13 of the US Code, these data are non-public; however, a research program maintained by the Center for Economic Studies (CES) allows academic and government researchers with *Special Sworn Status* to access these micro-data at one of several secure Research data centers.[5] The confidentiality restrictions prevent the disclosure of any information that would allow for the identification of a specific plant's or firm's activities. Aggregate figures or statistical coefficients that do not reveal the identity of individual establishments or firms can be released publicly. The ability to use plant-level data significantly enhances the information that can be obtained about performance, particularly when examining the issue of energy efficiency.

Since ENERGY STAR assigns a percentile ranking to any given plant, it was necessary to estimate the distribution of the energy efficiency for a given industrial sector. The use of confidential data from Census prevents the release of individual plant results. But, Census permits the clearance of statistical models, therefore SFA was used to estimate the observed "best practice" for energy use in various industries. The SFA approach simultaneously quantifies the relationship between resource use and production activities while measuring inefficiency in that relationship. The analysis that was conducted to develop the EPI uses plant-level data to assess the impact of various activities on energy use. The types of activities that are included in the EPI are highly industry specific, but may include output and input mix, plant capacity and utilization, and external factors like weather, etc.

The concept of the statistical frontier analysis that supports the EPI can be easily explained in terms of the standard linear regression model. This section provides a brief overview of this motivation. A much more detailed discussion of the evolution of the statistical approaches for estimating efficiency can be found in Green [2]. Consider at first, the simple example of a production process that has a fixed energy component represented by $\alpha$ and a variable energy component (i.e. energy use per unit of production represented by $\beta_y$). Given facility level data on energy use and production, these parameters representing the fixed and variable energy use can be estimated via a simple linear regression model.

$$E_i = \alpha + \beta y_i + \varepsilon_i, \ \ \varepsilon \sim N\left(0, \sigma^2\right) \tag{1}$$

where $i$ is the $i$th plant, $E$ is a measure of energy use, and $y$ is production.

Since we recognize that there may still be errors in data collection/reporting, effects that are unaccounted for in the analysis, and that a linear equation is an approximation of the complex factors that determine manufacturing energy use we still wish to include the statistical noise, or "random error" term, in the analysis, $v_i$, but also add a second random component, $u_i$, which follows a one-sided distribution, to reflect energy inefficiency. If we expand the simple example of energy use and production to include a range of potential effects we can write the more general version of the stochastic frontier model as

$$E_i = f(Y_i, X_i, Z_i; \beta) + \varepsilon_i \quad \varepsilon_i = u_i - v_i \quad v \sim N\left[0, \sigma_v^2\right] \tag{2}$$

where $E$ is energy use, either electricity, non-electric energy, or total primary energy, $Y$ is production, measured by either physical production or total value $X$ includes systematic economic decision variables (i.e. non-energy production inputs),

[5] For more information see http://webserver01.ces.census.gov/index.php/ces/1.00/researchprogram.

$Z$ includes systematic external factors, and $\beta$ includes the parameters to be estimated.

We assume that energy inefficiency, $u$, is distributed according to some one-sided statistical distribution,[6] for example gamma, exponential and truncated normal. Since actual energy use will be higher than the "best practice" energy use, the addition of the one-sided $u_i$ captures the additional energy use of any particular plant. It is then possible to estimate the parameters of Eq. (2), along with the distribution parameters of $u$. The estimated distribution of $u_i$ represents the range of inefficiency in the industry. The approach that is used to estimate these parameters depends on the type of distribution that is used to represent inefficiency.[7] The estimates of $\beta$ represent the factors that determine the level of energy use. This may include some fixed components as well as the energy use that it might take to process a unit of materials, or the incremental energy use it takes to make a specialized product compared to a "standard product." The later sections gives an example for corn refining.

Given data for any plant, we can compute the difference between the actual energy use and the predicted frontier energy use, that is, the most efficient plant energy use

$$E_i - f(Y_i, X_i, Z_i; \beta) + v_i = u_i \tag{3}$$

Since we have estimated the distribution of $u$, we can compute the probability that the plant inefficiency[8] is greater than this computed difference

$$\Pr(\text{inefficiency} \geq E_i - f(Y_i, X_i, Z_i; \beta) + v_i) \tag{4}$$

This is the EPI score and is the same as a *percentile ranking of the energy efficiency* of the plant. In practice we only can measure $E_i - f(Y_i, X_i, Z_i; \beta) = u_i - v_i$, so this implies that the EPI score is affected by the random component of $v_i$, i.e. the score will reflect the random influences that are not accounted for by the function $f(*)$. This is different from the use of SFA to estimate $u_i$ conditional on the sample observation of $E_i - f(Y_i, X_i, Z_i; \beta) = u_i - v_i$. It is done, in part, because of the inability to release plant-level census data used in the estimation process and in part because of the context in which the model will be used.

The role of the function, $f(*)$ in the EPI is to normalize for exogenous effects, i.e. it controls for factors that influence energy use but are not decided on the basis of energy use alone. As was noted above, the types of production activities and structural factors that are included in the function $f(*)$, used to derive the EPI, are industry specific. However, there are a number of common factors that any industry analysis will likely consider. For simplicity we continue to assume that the function, $f(*)$, is a linear function of the parameters, $\beta$, but it may include non-linear forms for the $Y$, $X$, and $Z$. This means that $f(*)$ may be log linear or include second order (quadratic) terms.

The variables to include (or exclude) for a given industry is driven by some prior knowledge and expectations about what factors will have significant influence on energy use in that sector. This choice, driven by $Y$, may be the value of total plant production, a physical production measure, or several physical production measures (if an industry produces different products). $X$ may include quantity and types of materials purchased, labor, or plant capacity. $Z$ may include a variety of external factors like weather variables (such as heating and cooling degree days), capacity utilization, regulatory factors, etc. Since the statistical formulation allows us to estimate the standard error of the estimated parameters, the decision to include any of these variables can be driven by the data and model estimates. Conventional statistical tests can determine which factors to include in the normalization and provide confidence intervals for these effects.

## 4. Examples from specific industry sectors

To facilitate the review of and use by automobile industry energy managers, a spreadsheet (Fig. 1) was constructed to display the results of the EPI analysis for an arbitrary[9] set of plant-level inputs. The user inserts plant-level inputs into the spreadsheet and it computes the EPI scores and other summary information. In the example of Fig. 1, the production level has increased by 40% (i.e. from two shifts to three) but energy use has only increased by 10%. We see that the plant has made an efficiency improvement in terms of energy use per vehicle, but how does this compare to the industry performance? The EPI shows that the plant has gone from slightly below average (40th percentile) to slightly above (53rd percentile).

The energy managers were encouraged to input data for their own plants and then provide comments. A version of this spreadsheet which corresponds to the results described in this paper is available from the EPA ENERGY STAR web site.[10] The example of the spreadsheet and results section is for total site energy (TSE). The spreadsheet has additional tabs that display the fossil fuel and electricity results separately. The results for the electricity and fuels models are based directly on the parameter estimates and the corresponding formulae documented by Boyd [1].[11]

Although the automobile assembly EPI is intended to produce plant-specific analysis of energy efficiency, some broad inferences about efficiency in automobile assembly can be made based on the models and the underlying data. The data set used to create the model includes 35 plants for 3 years each (1998–2000) provided by 5 companies, resulting in 105 plant-years of

[6] We also assume that the two types of errors are uncorrelated, $\sigma_{u,v} = 0$.

[7] Gamma is a very flexible distribution, but also generates a model that is very difficult to estimate. Exponential and truncated normal frontier models can be estimated using relatively conventional maximum likelihood techniques available in many modern statistical packages. A wide range of additional distributional assumptions regarding the heteroscedasticity of either $u$ or $v$ are also possible. Green Greene [3] presents an overview of SFA treatments.

[8] The terms efficiency and inefficiency are used loosely here. They reflect two sides of the coin, either how close or how far you are from the best.

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

[10] http://www.energystar.gov/index.cfm?c=industry.bus_industry.

[11] Also available on the ENERGY STAR web site.

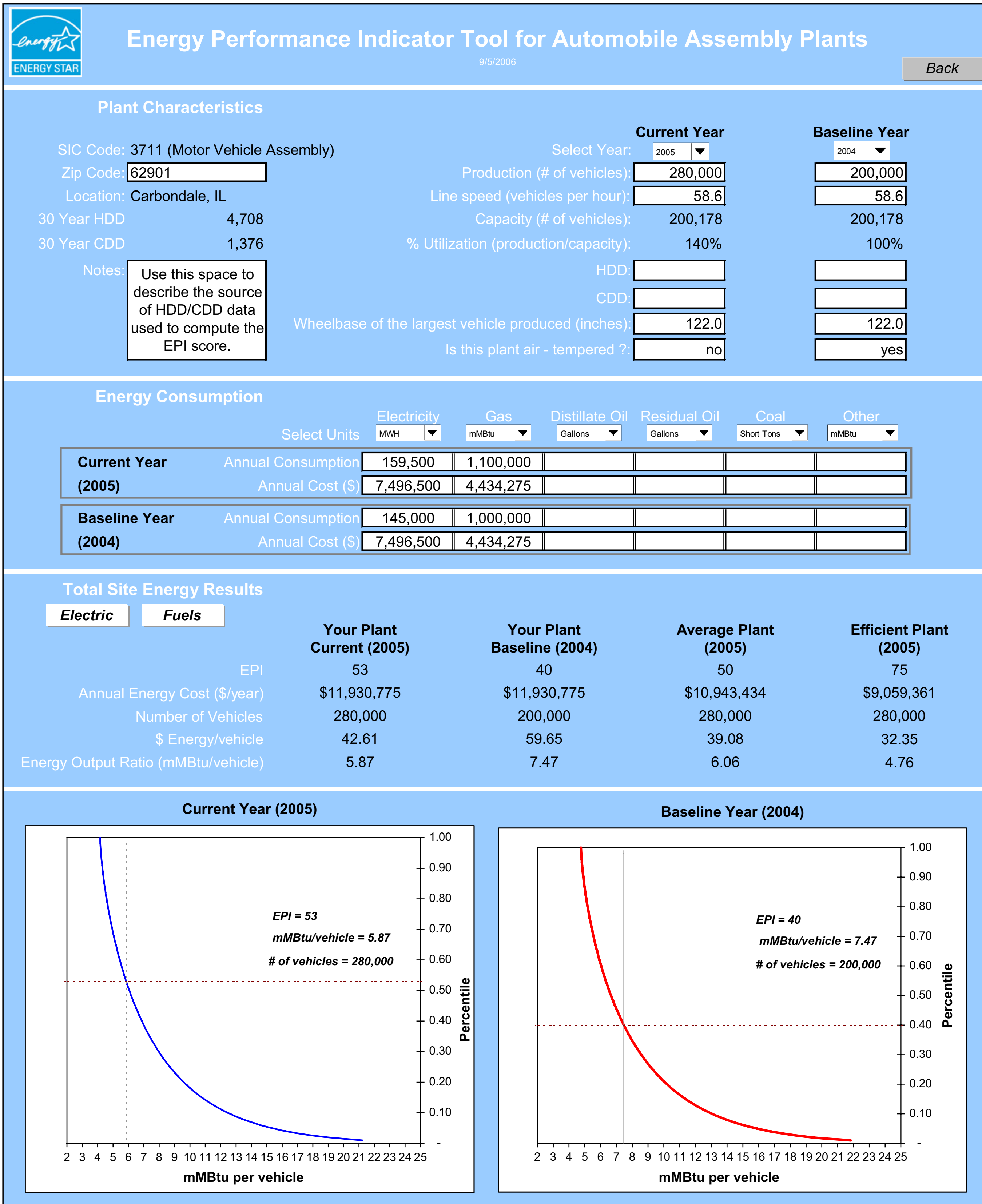


Fig. 1. Screenshot of the EPI spreadsheet for motor vehicle assembly.

data. Therefore, the results presented below represent the performance of the industry averaged over a 3-year period.

The average energy consumed per vehicle manufactured was 8.1 million Btu and the median 6.9 million Btu per vehicle. The difference between the average and the median is due to the nature of the one-tailed distribution that characterizes energy efficiency. If we compute the EPI model's "best practice" estimates for every plant in the data set and aggregate the electricity and fossil fuels to TSE, we find that the average "best practice" consumption per vehicle would be 4.8 million Btu and the median "best practice" would be 4.6 million Btu.

If we overlay the actual TSE per vehicle distribution with the "best practice" energy predicted by the model, we see how different the actual performance is from the potentially best performance. Because of inherent differences in plant location, vehicle size, etc. there is no single number that can be called "best practice." Instead we see a range of performance. However, this range is far smaller and less widely distributed than the actual performance. These differences point the way for substantial improvements in energy use in auto assembly. If every plant were able to achieve its corresponding predicted best practice, the annual energy use in the industry would have been 37%, or 21 trillion Btu lower.

Some plants may produce a variety of products, making it challenging to construct a meaningful measure of energy efficiency. The approach used by ENERGY STAR solves that challenge and can normalize for these effects. A good example of this is the corn refining industry. The most important outputs of wet corn milling are corn starch, corn sweeteners, and ethanol. Both corn sweeteners and ethanol are made from the starch in the corn. Sweeteners fall into three major categories: corn syrup, dextrose and fructose, often called glucose syrup. Ethanol is an increasingly important component of the US fuel supply. Corn starch is another important corn refining product, with both food and industrial applications, such as the paper industry. Corn oil, produced from the germ component, is another product. Corn refining also produces many byproducts that are used in animal feed. Plants in the industry may produce a wide range of these products, depending on their process configuration and on market conditions for production.

To illustrate how the product mix affects the best practice and a plant's relative efficiency, a hypothetical plant is constructed. The product mix shown in Table 1 is not a specific plant, but is consistent on a mass balance basis with the amount

Table 1
Example product mix and comparison case inputs

| | Baseline | Comparison |
|---|---|---|
| Total grind ($10^6$ lbs) | 2644 | 2644 |
| Average grind rate (bushels/day) | 131,176 | 131,176 |
| Maximum grind rate (bushels/day) | 131,176 | 131,176 |
| Capacity utilization (%) | 100 | 100 |
| HFCS sweeteners ($10^6$ lbs) | 300 | 300 |
| Crystalline and anhydrous glucose ($10^6$ lbs) | 0 | 0 |
| Other non-HFCS sweeteners ($10^6$ lbs) | 500 | 500 |
| Modified starch ($10^6$ lbs) | 743.8 | 943.8 |
| Non-modified starch ($10^6$ lbs) | 200 | 0 |
| Total alcohol ($10^6$ gals) | 0 | 0 |

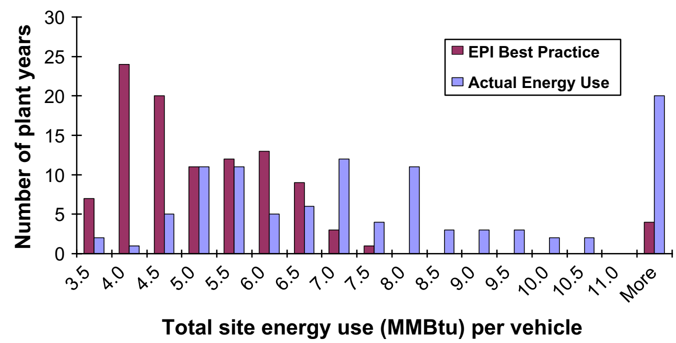


Fig. 2. Comparison of actual and best practice energy use in motor vehicle assembly.

of corn processed. In this comparison case some of the non-modified starch production is shifted to modified starch production. This shifts the frontier. A plant with the same level of energy use would have lower levels of inefficiency and a higher percentile ranking based on the estimated variance of the truncated normal efficiency term. The distribution of energy efficiency is plotted relative to the predicted best practice for the two hypothetical plants in Fig. 2. If these two plants were using the same amount of energy, the baseline plant would be about average for the industry, but the comparison plant would be a top performer (Fig. 3).

## 5. Energy management decisions enabled by the EPI

EPA released its first EPI in 2005 for the automobile manufacturing industry. The auto assembly EPI benchmarks auto assembly plants in the US. Through its work with the auto industry as part of ENERGY STAR, EPA suggested that the companies incorporate the EPI into their corporate energy management program and develop a schedule for regularly evaluating their plant EPI scores.

While actual plant scores are the property of the companies, several have shared their experiences in using the tool. For example,

> "*Toyota North America uses the EPI to gauge our progress against the competition. An external measure is necessary to gain better understanding of where we stand in the industry. We also compare the EPI against our internal metrics as a verification step.*"[12]

> "*The EPI benchmarking program gives California Portland Cement Company valuable insight into how our facilities are performing against the rest of the cement industry. Developers of the EPI emphasized the need to compare facilities against those of similar configurations, technology levels and personnel loading. Having participated in the review and refinement of the tool gives us added confidence that many of the unique aspects of the cement process were carefully considered and integrated into the final package.*"[13]

[12] Bradley J. Reed, Toyota Manufacturing North America, personal communication.

[13] Steve Coppinger, P.E., California Portland Cement Company, personal communication.

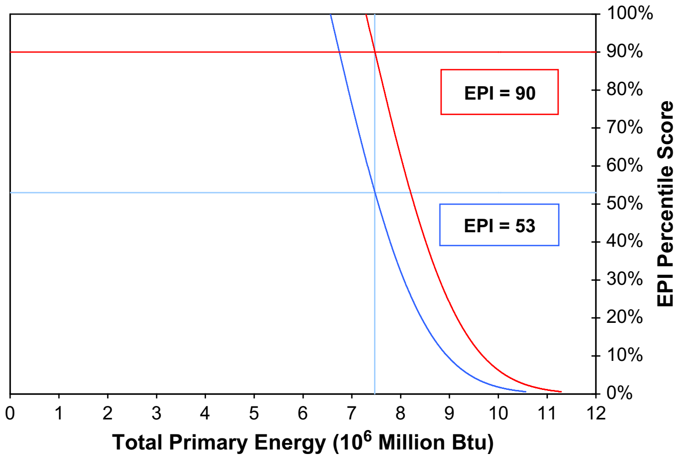


Fig. 3. Comparison of hypothetical corn refineries with the same energy consumption.

Another manufacturer's corporate energy manager described the company's plans to rank all plants, report plant scores to plant managers and discuss opportunities for improving energy performance in low-scoring plants. As expected, the manufacturer reported a spread of scores across its plants and even expressed surprise at which plants scored higher than others. This energy manager has taken the steps necessary to understand the plant scores and as a result, better understands why plants are performing as they are and what activities need to be taken to ensure continual improvement in energy performance in these plants.

One interesting outcome of enhancing the energy management system for this manufacturer is the interest that has been expressed by certain "shops" within the company. In particular, one group had refrained from fully supporting the corporate energy program prior to the use of the ENERGY STAR plant energy benchmark. The corporate energy manager now reports that the national benchmark has brought greater respect for the energy program and legitimacy to its efforts to score energy performance across the corporation's facilities. Further, there is a sense of belonging to a greater cause based on the company's association with the ENERGY STAR partnership.

## 6. Use of EPI for plant recognition

EPA has now established procedures for companies whose plants have an EPI score of the 75th percentile or greater for the most recent year to apply for ENERGY STAR recognition. On September 13, 2006, EPA officially announced the first 17 plants to receive ENERGY STAR recognition for superior energy efficiency in their respective industry. At that time, seven companies from three industries, automobile assembly, wet corn refining, and cement manufacturing received awards. Several more companies were either in the application process or stated their intent to apply in the near future. For just those 17 plants, the difference between the actual energy use and the energy use of a similar plant performing at the 50th percentile in terms of energy efficiency amounts to 3 billion lbs. of annual $CO_2$ emissions that would have otherwise been produced. As additional industry specific analyses are completed, ENERGY STAR recognition will be extended to those industries as well. Studies of pharmaceutical, glass, food processing, paper, and petrochemicals are now underway or being planned.

## 7. Summary

Providing consumers and businesses tools to make better informed decisions about energy use has an important indirect impact on the environment, since lower energy use results in reduced emissions from energy consumption activities. EPA has a 13-year history providing information about superior energy performance for consumer goods and buildings through the use of the ENERGY STAR label. In order to provide this recognition, EPA has developed methods to measure the range of energy performance and identify those that are the most efficient. Most recently this approach has been extended to provide companies with information about the range of energy performance of manufacturing plants within a variety of industries. EPA has developed the procedures for companies that wish to apply for recognition of energy efficiency, in the form of a manufacturing plant ENERGY STAR, based on the methods described in this paper. ENERGY STAR recognition will eventually be available for a range of manufacturing plants, including auto assembly, corn refining, cement, pharmaceuticals, food processing, and glass manufacturing. Other industries are being added to this list as the ENERGY STAR manufacturing program evolves.

Through the process of developing benchmarks of plant energy use there is recognition that this type of measurement and performance evaluation is a fundamental part of corporate energy management. While industry wide evaluations may exist selectively within some trade associations or private consulting firms, most companies do not have access to this valuable information. EPA is providing such evaluations in a voluntary public–private endeavor to motivate lower energy use and cleaner production throughout the manufacturing sector. The ENERGY STAR label for plants offers an additional incentive for corporate energy management.

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