Development of a Performance-based Industrial Energy Efficiency Indicator for Glass Manufacturing Plants

Gale A. Boyd, PhD
Research Scholar
Department of Economics, Duke University
Box 90097, Durham, NC 27708

September 30th, 2009

Sponsored by the U.S. Environmental Protection Agency
as part of the ENERGY STAR program.

ACKNOWLEDGMENTS

This work was sponsored by the U.S. EPA Climate Protection Partnerships Division. The research has benefited from comments by participants in various *Energy Star Glass Manufacturing Industry Focus* meetings. The research in this paper was conducted while the author was a Special Sworn Status researcher of the U.S. Census Bureau at the Triangle Census Research Data Center. Research results and conclusions expressed are those of the author and do not necessarily reflect the views of the Census Bureau or the sponsoring agency. This paper has been screened to insure that no confidential data are revealed. Support for research conducted at the Triangle RDC from NSF (awards no. SES-0004335 and ITR-0427889) is also gratefully acknowledged.

Development of a Performance-based Industrial Energy Efficiency Indicator for Glass Manufacturing

Gale A. Boyd

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. One key management opportunity is determining an appropriate level of energy performance for a plant through comparison with similar plants in its industry. Performance-based indicators are one way to enable companies to set energy efficiency targets for manufacturing facilities. The U.S. Environmental Protection Agency (EPA), through its ENERGY STAR program, is developing plant energy performance indicators (EPIs) to encourage a variety of U.S. industries to use energy more efficiently. This report describes work with the glass manufacturing industry to provide a plant-level indicator of energy efficiency for facilities that produce various types of glass products in the United States. 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 glass manufacturing plants. The individual equations are presented, as well as instructions for using those equations as implemented in an associated Microsoft Excel spreadsheet.

1 Introduction

ENERGY STAR was introduced by EPA in 1992 as a voluntary, market-based partnership to reduce air pollution through increased energy efficiency. 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. A key step in improving corporate energy efficiency is to institutionalize strategic energy management. Modeled on the International Organization for Standardization (ISO) quality and environmental standards, the ENERGY STAR Guidelines for Energy Management identify the components of successful energy management (EPA 2003).

These include:

- Commitment from a senior corporate executive to manage energy across all businesses and facilities operated by the company;
- Appointment of a corporate energy director to coordinate and direct the energy program and multi-disciplinary energy team;

- Establishment and promotion of an energy policy;
- Development of 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;
- Conduct of audits to determine areas for improvement;
- Setting of goals at the corporate, facility, and subunit levels;
- Establishment of an action plan across all operations and facilities, as well as monitoring successful implementation and promoting the value to all employees; and
- Provision of rewards for the success of the program.

Of the major steps in energy management program development, benchmarking energy use by comparing current energy performance to that of 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 higher organizational level by gauging the performance of a single manufacturing plant to its industry. Regardless of the application, benchmarking enables companies to determine whether better energy performance could be expected. It empowers them to set goals and evaluate their reasonableness.

Boyd, Dutrow, and Tunnessen (2008) describe the evolution of a statistically based plant energy performance indicator for the purpose of benchmarking manufacturing energy use for ENERGY STAR. Boyd and Tunnessen (2007) describe 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. This report describes the basic concept of benchmarking and the statistical approach employed in developing performance-based energy indicators for flat and container glass, the evolution of the analysis done for these segments of 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 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. 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 nationally represent 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 comparison of those best practices, or best-performing plants, to 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 circumstance and participation.

2.1 Scope of an Indicator — Experience with the Glass Manufacturers

EPA initiated discussions about developing a plant-level benchmark with glass manufacturers. Companies with facilities located within the United States were invited to participate in discussions. At the outset, the term "plant benchmark" was used. Industry engineers routinely develop benchmarks at many levels of plant operation, but they expressed concern that using the word "benchmark" would be confusing and could imply a particular process or tool. For this reason, it was decided that a simple descriptive term would be clearer; thus, ENERGY STAR plant energy performance indicator (EPI) was adopted. The scope for the EPI is a plant-level indicator, not process-specific, and it relates plant inputs in terms of all types of energy use to plant outputs as expressed in a unit of production and/or material processed. Discussion with industry representatives helped to define the energy focus of the model.

The model was designed to account for major, measurable impacts that affect a plant's energy use. The starting point for EPI development was Census data for industrial plants. For the glass industry, these included information on energy use, amount of material input in the form of glass sand and cullet (scrap glass), the total value of shipments, the shares of product types, and production labor person hours. The actual data used for each of the industry segments depended on the information available from Census and on the results of the statistical analysis.

Ideally the approach to developing an EPI identifies those factors that most directly influence energy use and applies them to normalize the energy use. The most basic normalization is for production level, i.e. energy use per unit of product. Other factors may influence the level of energy use per unit of product, including specific product types, quality and choice of materials used in production (e.g., amount of cullet utilized), plant design capacity (reflecting possible economies of scale), and utilization rates. Including these other factors in the statistical model allows one to construct alternative "benchmarks" of the basic concept of energy use per unit of product. This ideal situation may be limited due to the availability of data or simple limits of the capacity of the methodology to incorporate all of the possible options. The options and data under consideration for the analysis of glass industry energy use are as follows.

Production: The industry can be grouped into several basic product segments: flat, container, fiber (insulation), and specialty products. Since there is virtually no plant that produces products in more than one of the first three categories, we constructed separate EPIs for the first two product segments.[1] While separating plants into these groups effectively controls for the broad differences in product type, there remain issues regarding the measurement of production and differences in product type within each market segment. For measurement of production, the Census data provide total value of product shipped for each plant in each segment; however, the Census data do not provide measures of physical production, e.g. tons of glass melted, ft^2 of flat glass, etc. Having a single physical measure for each industry segment would be convenient, but product differences within each industry segment make any measure of production difficult to assign. Having different product types may complicate conversion, and cause problems associated with different energy requirements. One option for production normalization would be to start from energy use per dollar of product, and associate product shares. Any conversion to a normalization based on physical product would require additional sources of data.

Materials: Data on the use of glass sand, soda ash (and some other chemicals), and cullet can be included in the analysis to the extent that they have direct correlation with energy. Glass sand and cullet have been found to be useful proxies for production since they are directly related to physical product flows, and levels of cullet use specifically have a direct impact on energy use relative to production using sand. However, the level of raw material use may not be a good indicator of what types of downstream processing different products may require.

Capacity: Furnaces of different sizes may have different inherent efficiencies. A source of industry-wide data on the number or capacities of furnaces is not available. If trade associations or other industry sources have this type of information, it could be incorporated in a future analysis. The book value of capital is available from the Census, but would be difficult to apply for this function.

Utilization: Without direct measurement of capacity and physical product, a simple measure of utilization is not possible. However, labor hours may provide a proxy of plant utilization. Labor data may also capture differences in downstream product processing, i.e., differences in raw production and fabricated final product. This information is available from Census and is tested during development of the models.

For purposes of the analysis presented below, the approach combines factors from the above elements: it uses materials (sand and cullet) as a proxy for production, and combines them with labor hours (in the case of flat glass) and value of shipments (in the case of container glass) to control for some final product differences. The analysis relies on data from the Census on plants that produce glass from raw materials in a glass furnace in order to manufacture intermediate or final products of a largely standardized

[1] As of this report, the model for fiberglass insulation was still under development and will be included in a future version of this report. The specialty products segment is so diverse that a meaningful analysis does not appear feasible at this time.

nature, specifically flat and container glass. The U.S. Bureau of Census defines flat glass manufacturing plants (NAICS 327211) as establishments primarily engaged in manufacturing glass products using float, sheet, and plate process; and container glass manufacturing plants (NAICS 327213) as establishments primarily engaged in manufacturing glass packaging containers. Product types considered part of the flat glass segment include tempered, fabricated products, and all other. No information on product types was available in the Census data for container, but a wide range of products is also produced in this segment. The factors considered for flat and container glass are shown in Table 1.

Table 1: Glass Manufacturing Plant Characteristics and Products

- Flat Glass
    - Total value of shipments for the following products
        - Float or plate glass
        - Tempered glass and products made from tempered glass
        - Other fabricated products
    - Total glass sand
    - Total purchased cullet
    - Total production worker hours

- Container glass
    - Total value of shipments for the following products
        - Glass containers
    - Total glass sand
    - Total purchased cullet
    - Total production worker hours

The model is based on total source energy, defined as the total Btus of purchased/transferred fuels, steam, and hot or chilled water, plus the total amount of purchased/transferred electricity (or electricity associated with purchased oxygen or compressed air) converted from kWh to Btu at roughly the average rate of conversion efficiency for the entire U.S. electric grid, 10,236 Btu/kWh. Source energy is used to more closely align our energy measure with the underlying goals of the EPA ENERGY STAR program: pollution reduction at the source. For this reason, a kWh of electricity is treated as the equivalent energy consumed to produce that kWh at the generating source.

2.2 Data Sources

This analysis uses confidential plant-level data from two sources: the Longitudinal Research Database (LRD) and the Manufacturing Energy Consumption Survey (MECS) maintained by the Center for Economic Studies (CES), U.S. Bureau of the Census (Census). The LRD includes the non-public, plant-level data that are the basis of government-published statistics on manufacturing. CES has constructed a panel of plant-level data from the Annual Survey of Manufacturers (ASM) and the Census of Manufacturers (CM). The LRD includes economic activity — for example, labor, energy, plant and equipment, materials costs, and total shipment value of output — for a sample of plants during the survey years, and for complete coverage of all plants during the years of the Economic Census. The MECS is also used. MECS is a detailed survey of energy use for a sample of plants in the ASM and CM.

Under Title 13 of the U.S. Code, these data are confidential; however, CES allows academic and government researchers with Special Sworn Status to access these confidential micro-data under its research associate program at one of nine designated Census Research Data Centers. 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, rather than aggregate data, significantly enhances the information that can be obtained about economic performance, particularly when examining the issue of energy efficiency.

Variable Specific Data Sources and Transformations

- Data for total value of shipments and labor (person hours) were taken from the CM for 2002.
- Production of different product types (using 10-digit NAICS product codes) was taken from the 2002 CM product trailer files.
- Material input (using 7-digit NAICS material codes) was taken from the 2002 CM material trailer files. Glass sand and cullet in tons were imputed from the cost of sand or cullet reported in the 2002 CM and the average price of glass sand and cullet adjusted for inflation, estimated from the plant-level data in the 1997 CM material trailer files. Survey questions for the physical amount of sand and cullet were dropped from the 2002 CM questionnaire.
- Electricity use was taken from the 2002 ASM, which was available for every plant in the dataset.
- Fuel use was taken from the 2002 MECS for those plants included in the MECS sample by converting the physical units for every fuel type into Btu content and summing. For all other plants, fuel use was imputed from the cost of fuels as reported in the 2002 ASM using the price of fuels based on the total cost and total Btu for each plant and averaging over all plants in the specific sample.

3 Statistical Approach

The goal of this study was to develop an estimate of the distribution of energy efficiency across the industry. Efficiency is the difference between the actual energy use and "best practice," i.e., the lowest energy use achievable. What is achievable is influenced by operating conditions that vary between plants, so the measure of best practice must take these conditions into account. Statistical models are well-suited for accounting for these types of observable conditions but typically are focused on average practice, not best practice. However, stochastic frontier regression analysis is a tool that can be used to identify "best practice." This section provides the background on the stochastic frontier, a discussion on the review process and evolution of the model's equations, and the final model estimates.

3.1 Stochastic Frontier

The concept of the stochastic frontier analysis that supports the EPI can be easily described in terms of the standard linear regression model, which is reviewed in this section. A more detailed discussion on the evolution of the statistical approaches for estimating efficiency can be found in Greene (1993). Consider at first the simple example of a production process that has a fixed energy component and a variable energy component. A simple linear equation for this can be written as

$$E_i = \alpha + \beta\, y_i \qquad (1)$$

where

E = energy use of plant i and
y = production of plant i.

Given data on energy use and production, the parameters α and β can be fit via a linear regression model. Since the actual data may not be perfectly measured and this simple relationship between energy and production may only be an approximation of the "true" relationship, linear regression estimates of the parameters rely on the proposition that any departures in the plant data from Eq. 1 are "random." This implies that the actual relationship, represented by Eq. 2, includes a random error term ε that follows a normal (bell-shaped) distribution with a mean of 0 and variance of σ^2. In other words, about half of the actual values of energy use are less than what Eq. 1 would predict and half are greater.

$$E_i = \alpha + \beta\, y_i + \varepsilon_i$$
$$\varepsilon \sim N(0,\sigma^2) \qquad (2)$$

The linear regression gives the average relationship between production and energy use. If the departures from the average, particularly those that are above the average, are due to energy inefficiency, we would be interested in a version of Eq. 1 that gives the "best" (lowest) observed energy use. For example, consider that capacity utilization can influence the energy use per unit of production due to the fixed and variable components of plant energy use (see Figure 1). A regression model can find the line that best explains the average response of energy use per unit of production to a change in utilization rates. The relationship between the lowest energy consumption per unit of production relative to changes in utilization can be obtained by shifting the line downward so that all the actual data points are on or above the line. This "corrected" ordinary least squares (COLS) regression is one way to represent the frontier.

While the COLS method has its appeal in terms of simplicity, a more realistic view is that not all the differences between the actual data and the frontier are due to efficiency. 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 v_i in the analysis – but also add a second random component u_i to reflect energy inefficiency.[2] Unlike the statistical noise term, which may be positive or negative, this second error term will follow a one-sided distribution. If we expand the simple example of energy use and production to include a range of potential effects, we can write a version of the stochastic frontier model as energy use per unit of production as a general function of systematic economic decision variables and external factors,

$$E_i = h(Y_i, X_i, Z_i\,;\,\beta) + \varepsilon_i \tag{3}$$

$$\varepsilon_i = u_\mathrm{i} - v_\mathrm{i} \qquad\qquad v \sim N\,[0, \sigma_\mathrm{v}^2]\,,$$

where

E = TSE, total source energy (or other measure of total fuel and electricity);
Y = production, measured by dollar shipments or physical production;
X = systematic economic decision variables (i.e., labor-hours worked, materials processed, plant capacity, or utilization rates);
Z = systematic external factors (e.g., heating and cooling loads); and
β = all the parameters to be estimated.

We assume that energy (in)efficiency u is distributed according to one of several possible one-sided statistical distributions,[3] for example exponential, half normal, or truncated normal. It is then possible to estimate the parameters of Eq. 3, along with the distribution parameters of u.

[2] By random we mean that this effect is not directly measurable by the analyst, but that it can be represented by a probability distribution.

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

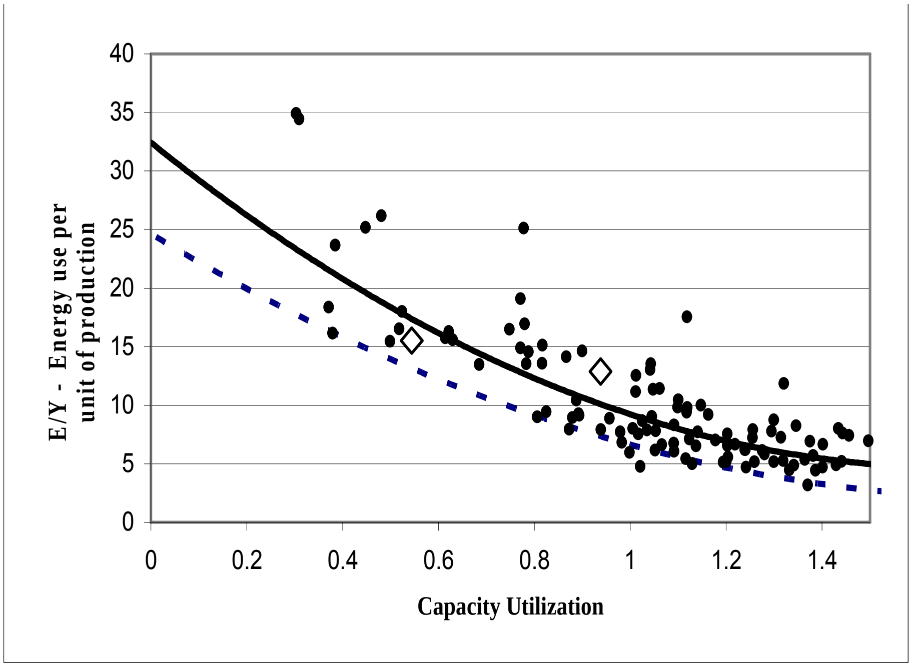


Figure 1 COLS and Frontier Regression of Energy Use per Unit of Production against Capacity Utilization

One advantage of the approach is that the parameters used to normalize for systematic effects and describe the distribution of efficiency are jointly estimated. The standard regression model captures the behavior of the average (see solid line in Figure 1), but the frontier regression (the dotted line in Figure 1) captures the behavior of the best performers. For example, if the best performing plants were less sensitive to capacity utilization because they use better shutdown procedures, then the estimated slope of the frontier capacity utilization curve would not be as steep as the slope for the average plants.

Another advantage of this method is that we can test if the differences in energy use, represented by the terms u and v, are statistically significant. If the estimated variance of u is small, we can conclude that the simpler statistical model in Eq. 2 is valid and base our measurements on those results. Therefore the frontier yields a more general analysis that allows for either a one-sided (skewed) distribution representing efficiency or a more "normal" (bell-shaped) distribution. If the former is the case then we interpret that as meaning the many plants are close to one another in terms of energy use, with a smaller number being "further" from the group of good performers. In the latter case, that of the bell-shaped, normal efficiency distribution, we have a few "good performers," a large number of "average" plants, and a few "poor performers." In either case we have a statistical approach to assign a ranking for the plants.

For simplicity, we assume that the function $h(\,)$ is linear in the parameters, but allow for non-linear transformations of the variables. In particular, production, materials, and labor enter the equation in log form, as does the energy variable. This means that the terms u and v can easily be interpreted as percentage deviations in energy, rather than absolute. This has implications for the model results since we now think of the distributional assumptions in terms of percent, rather than absolute level. When there is wide variation in plant scale, this seems appropriate and may avoid possible heteroscedasticity in either or both error terms.

Given data for any plant, we can rearrange Eq. 3 into Eq. 4 and compute the difference between the actual energy use and the predicted frontier energy use:

$$E_i - \left[h(Y_i, X_i, Z_i\,;\,\beta)\right] = u_{\mathrm{i}} - v_{\mathrm{i}} \tag{4}$$

In the case where the frontier model is appropriate, we have estimated the probability distribution of *u*. Eq. 5 represents the probability that the plant inefficiency is greater than this computed difference:

$$\begin{aligned}\text{Probability}\left[\textit{energy inefficiency} \geq E_i - \left(h(Y_i, X_i, Z_i\,;\,\beta)\right)\right] &= \\ 1 - F(E_i - h(Y_i, X_i, Z_i\,;\,\beta))\end{aligned} \tag{5}$$

F( ) is the cumulative probability density function of the appropriate one-sided density function, i.e., gamma, exponential, truncated normal, etc. The value 1 - *F( )* in Eq. 5 defines the EPI rating and may be interpreted as a *percentile ranking of the energy efficiency* of the plant. In practice, we only can measure $E_i - h(Y_i, X_i, Z_i\,;\,\beta) = u_{\mathrm{i}} - v_{\mathrm{i}}$, so this implies that the EPI rating $1 - F\left(E_i - h(Y_i, X_{\mathrm{i}}, Z_i\,;\,\beta)\right) = 1 - F\left(u_{\mathrm{i}} - v_{\mathrm{i}}\right)$ is affected by the random component of v_i; that is, the rating will reflect the random influences that are not accounted for by the function *h(*).*

In the case where the frontier model is not appropriate, there is no *u* term and corresponding estimate, only *v*.

$$E_i - \left[h(Y_i, X_i, Z_i\,;\,\beta)\right] = v_{\mathrm{i}} \tag{6}$$

We can drop the minus sign for *v* since the normal distribution is two sided. The estimate of the variance $v \sim N\ [0, \sigma_v^2]$ can be used in Eq. 5 where *F( )* is now the cumulative probability density function of a standard normal distribution.

Since this ranking is based on the distribution of inefficiency for the entire industry, but normalized to the specific systematic factors of the given plant, this statistical model allows the user to answer the hypothetical but very practical question, "How does my plant compare to everyone else's plants in my industry, *if all other plants* were similar to mine?"

3.2 Evolution of the Model

The model evolved over a period of time, based on comments from industry reviewers and subsequent analyses. The initial model was based on data from 1997.

When data for 2002 became available, the more recent data were used. Industry participants were given an opportunity to test and comment on each version of the model via the annual focus meetings and quarterly conference calls, and personal communications. Companies were asked to input actual data for all of their plants and then to determine whether the results were consistent with any energy efficiency assessments that may have been made for these plants. The resulting comments improved the EPI. This section summarizes this review process and the actions taken vis-à-vis the EPI analysis. The main areas of discussion included the use of glass sand (materials purchased) as a proxy for production volume, the treatment of purchased cullet (scrap glass) as an input, and possible adjustments for fabrication and tempering of flat glass.

Sand as a proxy for production

There is a strong rationale for using physical measure of production in estimating plant-level energy use. However, available data sources do not provide measure of total glass melted or shipped in physical units like weight or volume. In addition, product pricing is not likely to be uniform across plants, making it difficult to assign a price per ton, square foot, etc. of glass. Since the amount of materials processed are likely to be proportional to product, the EPI initially used glass sand, lime, and soda ash as proxies for production. In initial analysis, the latter two variables were deemed unreliable (i.e., they were statistically insignificant or had signs that were difficult to interpret). Industry comments suggested that there were small differences in the basic formula for making glass, particularly when flat and container were treated separately. Since this implied a high degree of colinearity between the three main inputs, the analysis focused on the largest volume input: glass sand. Subsequent comments from industry revealed that there are furnace losses that occur between the feedstocks (sand, lime, etc.) and the volume of production. An engineering estimate of 18% loss was applied to the amount of sand input to the process. This makes the sand input more comparable to the volume of glass melted, and more closely relates to cullet (see below) which does not have combustion losses.

Cullet measurement

Cullet in the form of broken glass and scrap within a plant is always returned to the furnace for re-melt. Scrap glass purchased from outside sources, usually recycled post-consumer glass, is a major input in container glass manufacturing. Scrap is not used much in flat glass; it is used more in fiber glass, but that use is not reported in our data. Use of scrap in container glass can have a major impact on energy use because it is easier to melt than the raw batch materials, and does not suffer losses due to combustion. The primary issue is whether plants should be compared to "similar plants" using the same amount of cullet, i.e., treat cullet use as a normalization factor, or treat cullet as a form of energy efficiency.

Industry comments suggest that cullet is viewed as an energy efficiency option, where procurement of more and higher quality cullet is weighed against energy costs. On the other hand, if plants consuming higher shares of cullet produce a different type/quality of product, then it should be part of the EPI normalization. There is also some statistical evidence of a relationship between cullet use and product values. The statistical modeling approach used here (and described below) is to treat cullet as an energy efficiency, but also to estimate the impact of cullet, sand, and value of shipments jointly. The amount of cullet in the raw feedstock is set equal to an equivalent amount of sand based on a typical batch of 64% sand and 36% other materials, and subtracting the 18% loss factor; i.e., the volume of cullet is reduced to 64% to represent an equivalent amount of sand after losses. Based on this approach, it is possible to use the estimated statistical relationship to measure the energy efficiency of a plant compared to plants using similar levels of cullet as well as to plants using no cullet or some other reference amount. For purposes of implementing the spreadsheet tool, we choose to measure performance against the average amount of cullet used by the industry in the analysis year.

Test for fabrication, tempering, and labor in flat glass

Flat glass manufacturing plants may produce intermediate products for shipment to be processed elsewhere, or have on-site fabrication. Glass may be tempered or not. Either fabrication or tempering may add energy to the product. Industry representatives were interested in including estimates of these effects in the model. The model controlling for fabrication and tempering (share of product) produced results that either were not significant or had opposite signs from the expected effect. These variables were not included in the final version.

3.3 Model Estimates

This section presents the current model estimates for the container and flat glass segments. Several alternatives for specification of *h( )* and for the distribution of the frontier error term *u* were tried. Only the "preferred" model estimates are presented.

Container:

The final version of the container glass equation for TSE is

$$\ln(E_i) = A + \beta_1 \ln(rawfeed)_i + \beta_2 \ln(TVS)_i + \beta_3 culletshare + \mathrm{v_i} \tag{7}$$

where

E = total source energy (MMBTU);
rawfeed = total tons of sand * (1-0.18) + total tons of purchased cullet * 0.65;
TVS = total value of shipments (thousand 2002 constant $);
culletshare = ratio of purchased cullet to rawfeed;
and
β = vector of parameters to be estimated.

The variable v is distributed as $N(0, \sigma_v^2)$.

The estimated parameters of the model are shown in Table 2. Sample size is 62 plants. All parameters shown are significant at the 99% level. Estimates of the frontier resulted in extremely small variance estimates of u, so the simpler OLS model is used in this segment.

Table 2 Container Glass Energy Model Estimates

Variable	Estimate	Standard Error	t-ratio
Constant	6.206118	.99125	6.26
Rawfeed	.5088837	.14140	3.60
TVS	.5187653	.14404	3.60
Cullet share	-.3872742	.18096	-2.14

Error Distribution Parameters	
σ_v	.03397
R – square	.9898
F(3, 58)	1879.39

Models with any combination of the above three variables resulted in higher mean square error. There is an indication that cullet use has a simultaneous impact on energy use and product quality (as reflected in the ratio of value (TVS) to production inputs (raw feed); therefore, a model that measures production as a geometrically weighted average of raw feed and total value of shipments was selected.

<u>Flat/float:</u>

The final version of the flat/float glass equation for TSE is

$$\begin{aligned}\ln(E_i) = {} & A + \beta_1 \ln(total\ sand)_i + \beta_2 \ln(total\ sand)^2{}_i + \\ & \beta_3 \ln(labor\ hours)_i + \beta_4 \ln(labor\ hours)^2{}_i + \beta_5 fabriction\ share + u_i - \mathrm{v}_\mathrm{i}\end{aligned} \quad (8)$$

where

E	=	total source energy (MMBTU);
Total sand	=	total tons of sand (thousands);
Labor hours	=	total person hours (thousands);
Fabrication share	=	ratio of fabricated product to total value shipped;

and

β = vector of parameters to be estimated.

The variable v is distributed as $N(0, \sigma_v^2)$ and u is truncated normal with variance σ_u^2.

The estimated parameters of the model are shown in Table 3. Sample size is 38 plants. All parameters shown are significant at the 99% level. The small size of σ_v

suggests that the model has very little error attributable to random noise and that most departures are attributable to inefficiency.

Table 3 Flat/Float Glass Energy Model Estimates

Variable	Estimate	Standard Error	t-ratio
Constant	10.26416	0.000139	73755.27
Sand	1.211045	4.63E-05	26150.12
Sand^2	-0.07301	5.56E-06	-1.30E+04
Fabrication share	-0.77706	1.42E-05	-5.50E+04
Labor hours	-0.63967	8.19E-05	-7808.75
Labor hours^2	0.095915	7.42E-06	12929.49

Error Distribution Parameters			
Likelihood-ratio test of sigma_u=0: chibar2(01) = 9.29 Prob>=chibar2 = 0.001			
σ_u	0.723982		
σ_v	2.46E-09		

The coefficient of fabrication share exhibited the wrong sign, despite being statistically significant. Closer examination of the raw data suggested that several plants with high fabrication share and very low energy use were the cause. Since another model that drops those observations may result in problems with Census clearing the results (i.e., sample size potentially too small), it is recommended that this model be used, but that the application be limited to evaluating the energy performance of plants without substantial fabrication share (<50%) in the total value of shipments.

4 Judging Glass Manufacturing Plant Energy Efficiency

4.1 How the EPI Works

The glass manufacturing EPIs rate the energy efficiency of a flat and container glass manufacturing plant based in the United States. To use the tool, the following information must be available for a plant.

- Total energy use
    - Electricity in kWh (converted to Btus by the spreadsheet)
    - Fuel use for all fuel types in physical units or Btu
- Container glass
    - Total value of shipments for the following products
        - Glass containers
    - Total glass sand
    - Total purchased cullet
- Flat glass
    - Percent of total value of shipments for the following products

- Fabricated products
- Total glass sand
- Total production worker hours

Based on these data inputs, the glass manufacturing EPIs will report a rating for the plant in the current time period that reflects the relative energy efficiency of the plant compared to that of its industry segment. It is a percentile rating on a scale of 0–100. Plants that rate 75 or better are classified as efficient. (ENERGY STAR defines the 75th percentile as efficient.) A rating of 75 means a particular plant is performing better than 75% of the plants in the industry. The model also reports on the average plant in the industry (defined as the 50th percentile). While the underlying model was developed from data for U.S.-based plants, it does not contain or reveal any confidential information.

4.2 Spreadsheet Tool

To facilitate the review and use by industry energy managers, a spreadsheet was constructed to display the results of the EPI for an arbitrary[4] set of plant-level inputs. The spreadsheet accepts the raw plant-level inputs described above, computes the values for *h( ),* and then displays the results from the appropriate distribution functions for the models presented in Eqs. 7, 8, and 9. The energy managers were encouraged to input data for their own plants and then provide comments. A version of these spreadsheets, dated 9/30/2009 (corresponding to the results described in this report), is available from the EPA ENERGY STAR web site.[5] Examples of the input section of each spreadsheet are shown in Figures 2 and 3. The results section examples are shown in Figures 4 and 5.

Computing a constant dollar value of shipments using BLS Producer Price Deflators

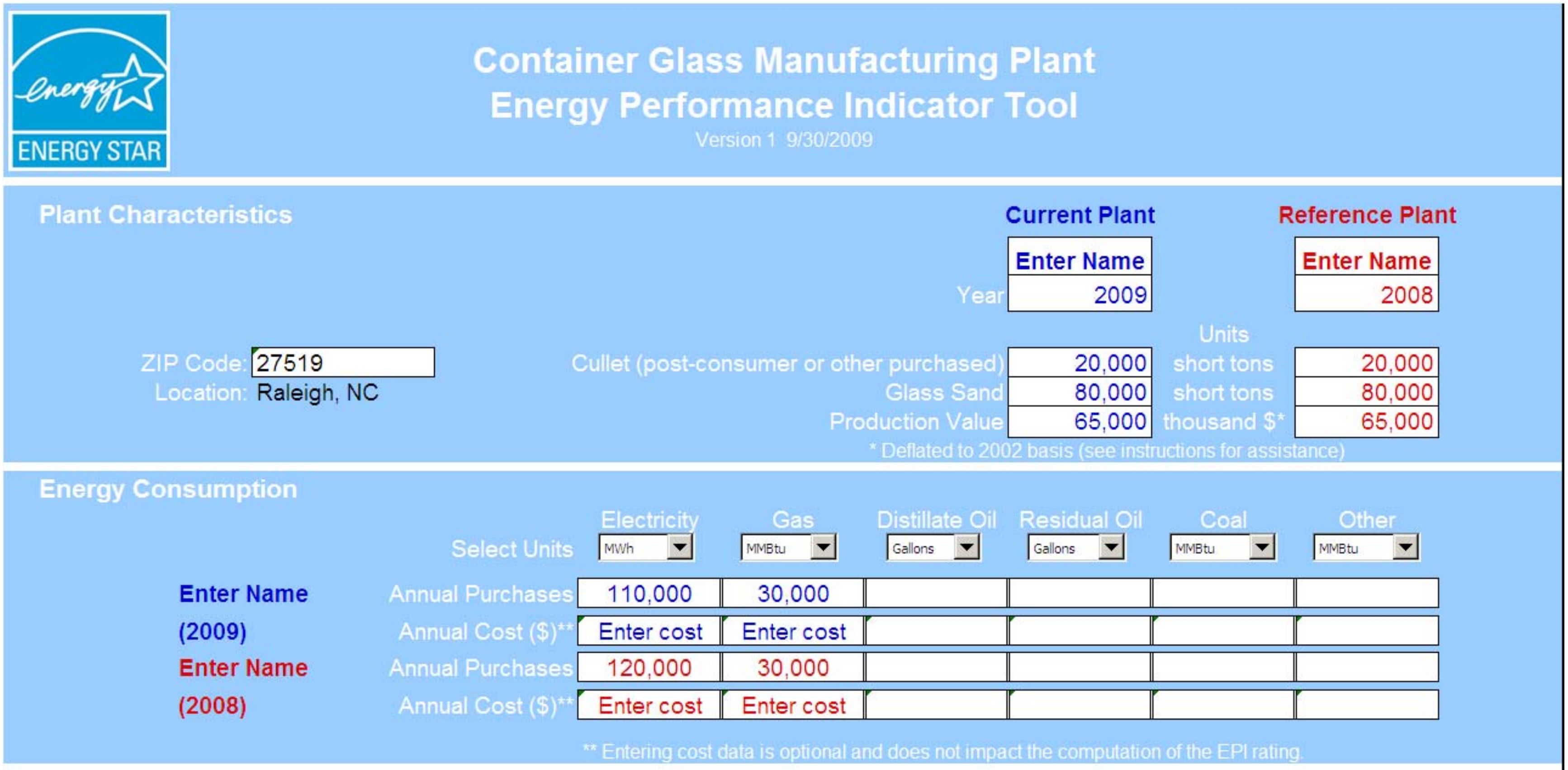
The data for production value must be inflation-adjusted to correspond to prices in the year the data were reported to Census, i.e., 2002 "constant dollars." To calculate this value, users will multiply the production value from the data year (i.e., "current" and "reference" year in the EPI Tool) by the price deflator for the data year. The price deflator is the ratio of the 2002 Producer Price Index to the data year Producer Price Index (represented as 2002PPI/YYYYPPI, where YYYY is the year of the production data). For example, assume that the year of the production data was 2006. Using data from the Bureau of Labor Statistics Producer Price Index web site (see Figure 7), users would multiply the 2006 production data by 0.888 (2002PPI of 133.8 divided by 2006PPI of 150.7). Stated in other words, $1000 of production value in 2006 would have been the equivalent of $888 in 2002, due to inflation.

To find the most current Producer Price Index for this (or another) industry, users will go to the BLS PPI web site http://data.bls.gov/PDQ/outside.jsp?survey=pc, search for the appropriate industry (in this case 327213), select the product (in this case

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

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

327213327213P), and click the “Get Data” button (see Figure 6). The results are displayed in a new window (see Figure 7). The last column shows annual data for each year, appropriate for computing the deflator. Otherwise, you may calculate a number that matches your data set by calculating a simple average of the monthly PPIs that correspond to your current year data. For example, if the twelve-month period you will use as your current year is September 2008 through August 2009, calculate the simple average of the monthly PPIs for that same period, and divide that average by the 2002 annual PPI to compute your custom deflator.



ENERGY STAR

Container Glass Manufacturing Plant
Energy Performance Indicator Tool

Version 1 9/30/2009

Plant Characteristics

ZIP Code: 27519
Location: Raleigh, NC

	Current Plant	Units	Reference Plant
	Enter Name		Enter Name
Year	2009		2008
Cullet (post-consumer or other purchased)	20,000	short tons	20,000
Glass Sand	80,000	short tons	80,000
Production Value	65,000	thousand $*	65,000

* Deflated to 2002 basis (see instructions for assistance)

Energy Consumption

		Electricity	Gas	Distillate Oil	Residual Oil	Coal	Other
	Select Units	MWh	MMBtu	Gallons	Gallons	MMBtu	MMBtu
Enter Name	Annual Purchases	110,000	30,000				
(2009)	Annual Cost ($)**	Enter cost	Enter cost				
Enter Name	Annual Purchases	120,000	30,000				
(2008)	Annual Cost ($)**	Enter cost	Enter cost				

** Entering cost data is optional and does not impact the computation of the EPI rating.

Figure 2 Input Section of the Container Glass EPI Spreadsheet Tool

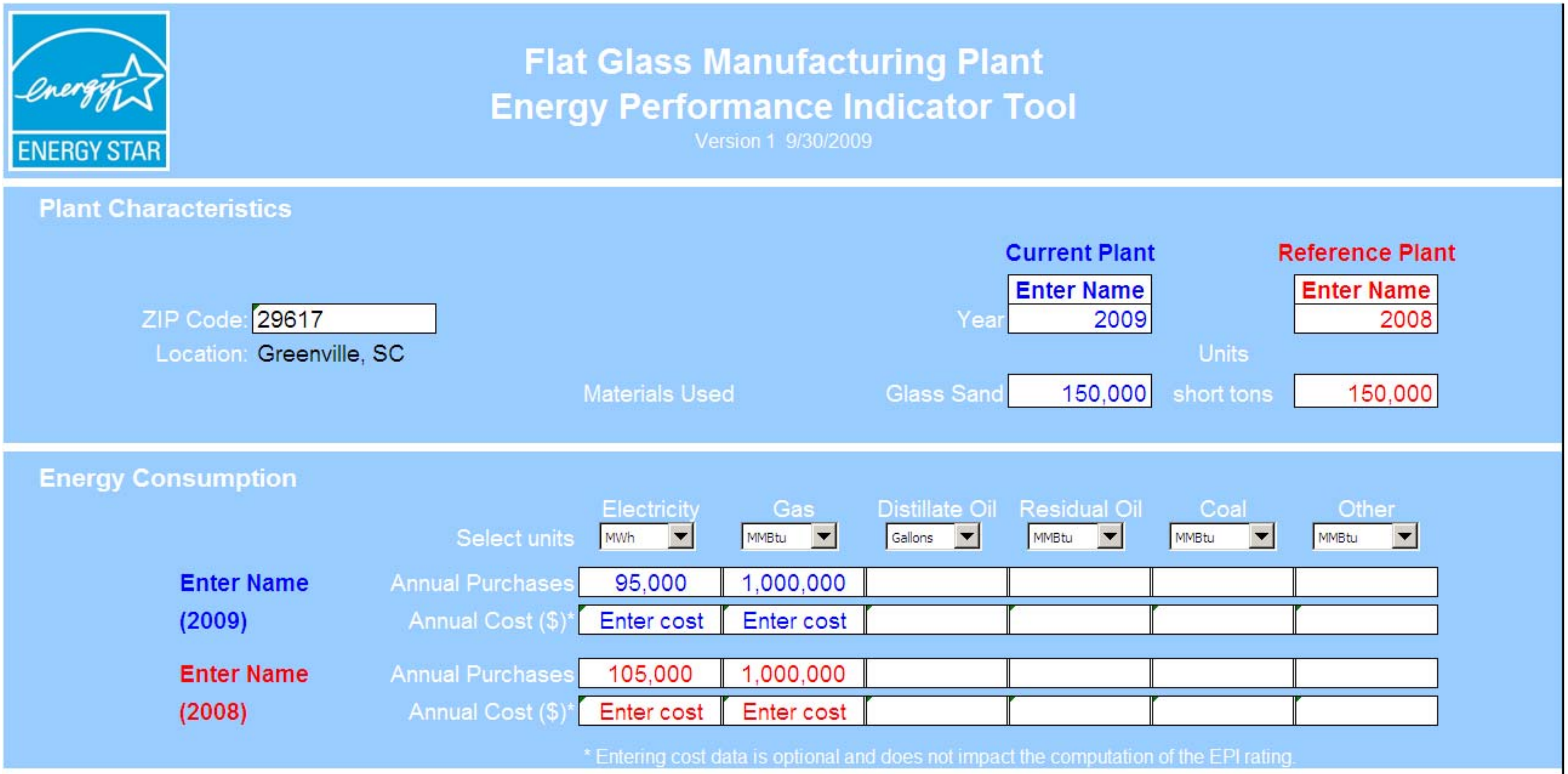


Figure 3 Input Section of the Flat Glass EPI Spreadsheet Tool

Results	Your Current Plant Enter Name 2009	Your Reference Plant Enter Name 2008	Average Plant Enter Name 2009	Efficient Plant Enter Name 2009
Energy Performance Rating	83	69	50	75
Annual Energy Cost ($/year)				
Total Source Energy (MMBtu)	1,159,568	1,262,256	1,387,050	1,223,647
Total Site Energy (MMBtu)	405,320	439,440	484,835	427,718

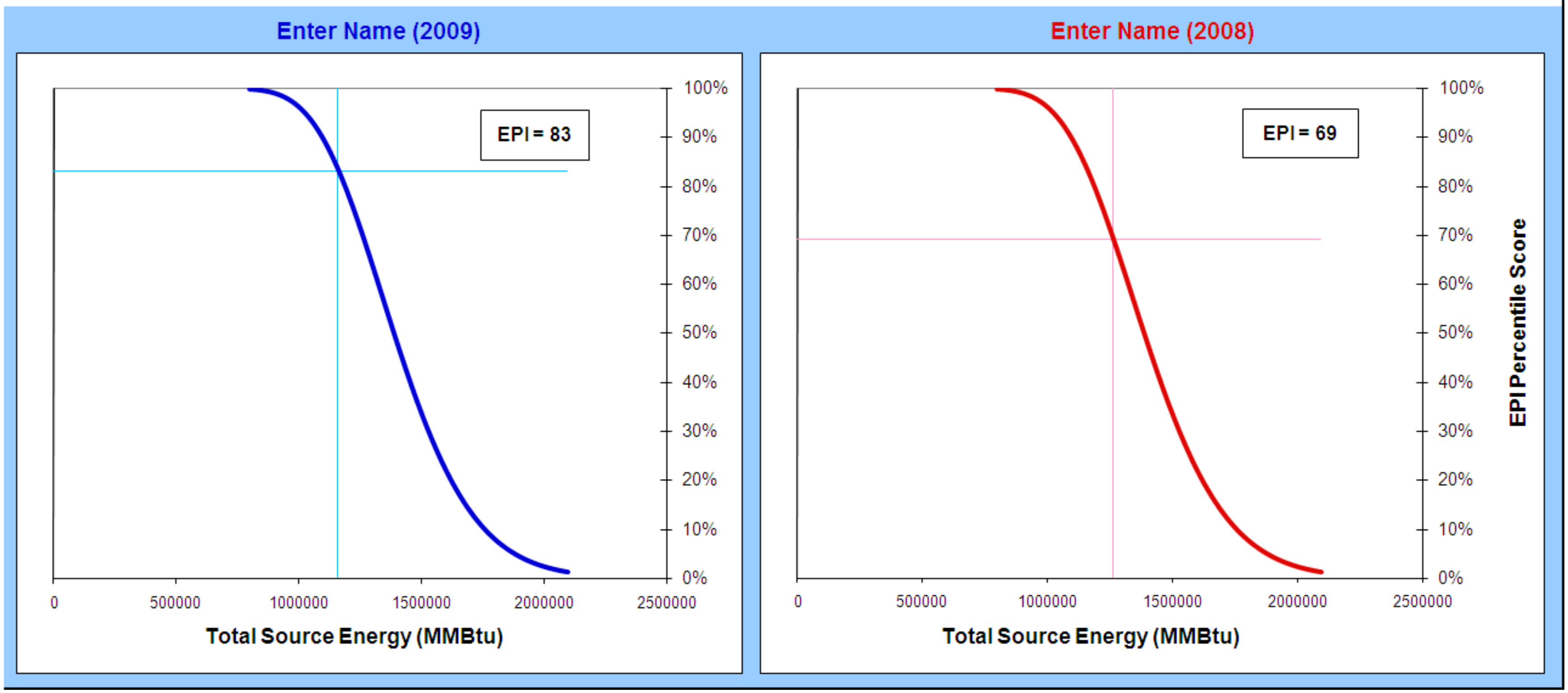


Figure 4 Output Section of the Container Glass EPI Spreadsheet Tool

Results	Your Current Plant Enter Name 2009	Your Reference Plant Enter Name 2008	Average Plant Enter Name 2009	Efficient Plant Enter Name 2009
Energy Performance Rating	79	71	50	75
Annual Energy Cost ($/year)				
Total Source Energy (MMBtu)	1,975,536	2,078,224	2,433,999	2,038,135
Total Site Energy (MMBtu)	1,324,140	1,358,260	1,631,433	1,366,098

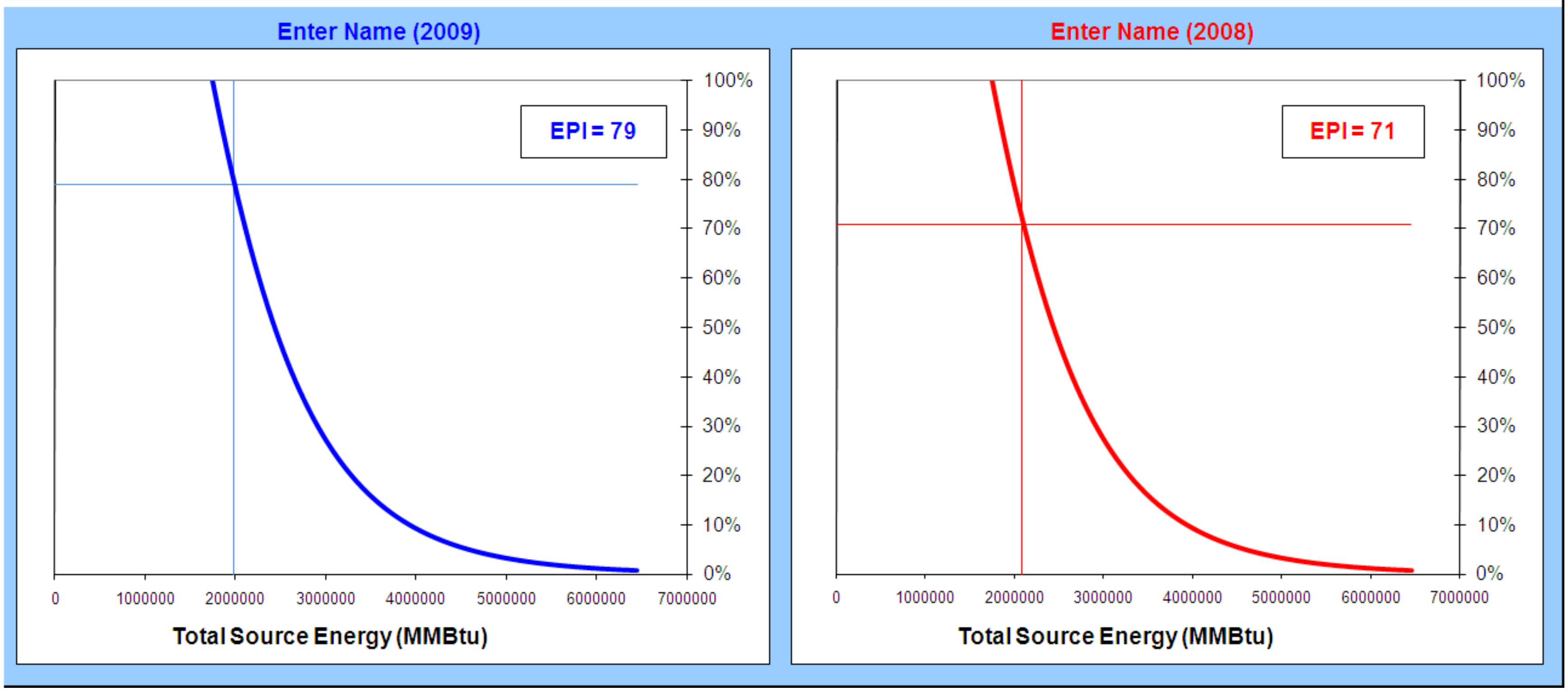


Figure 5 Output Section of the Flat Glass EPI Spreadsheet Tool

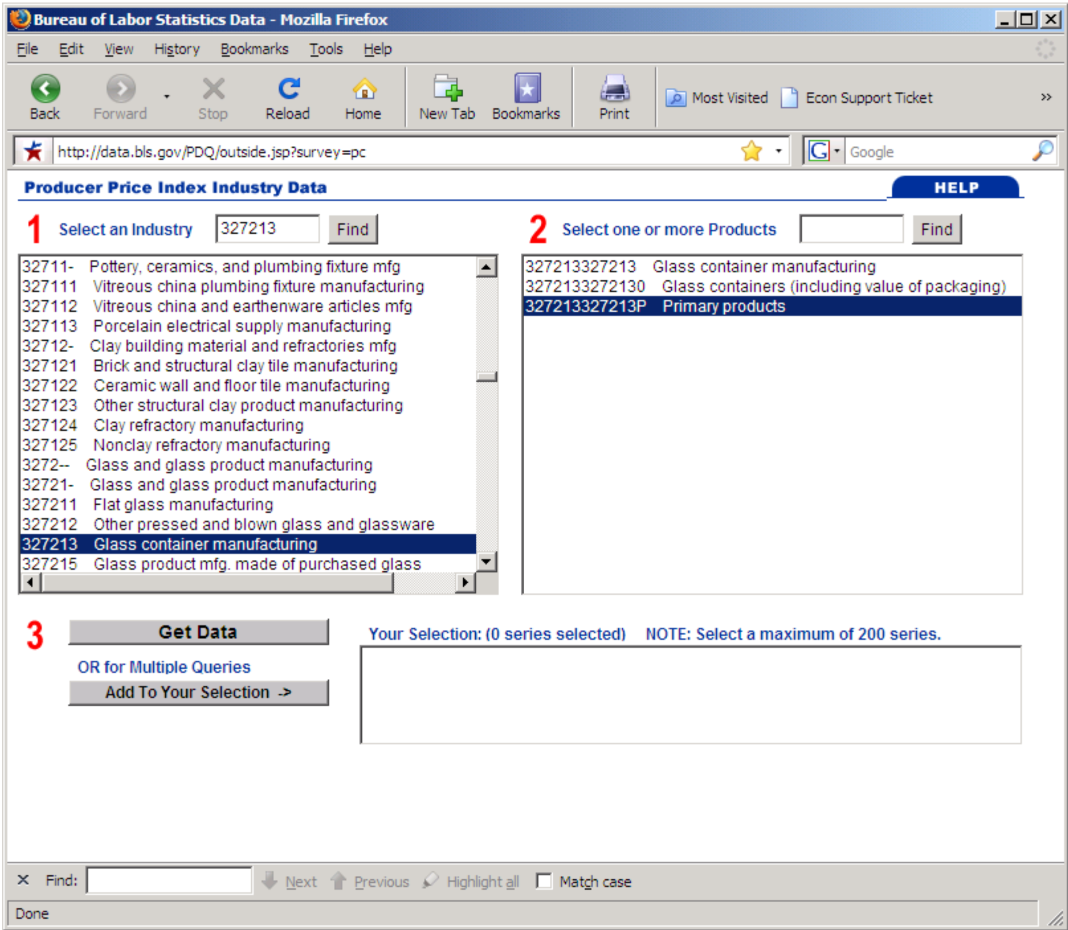
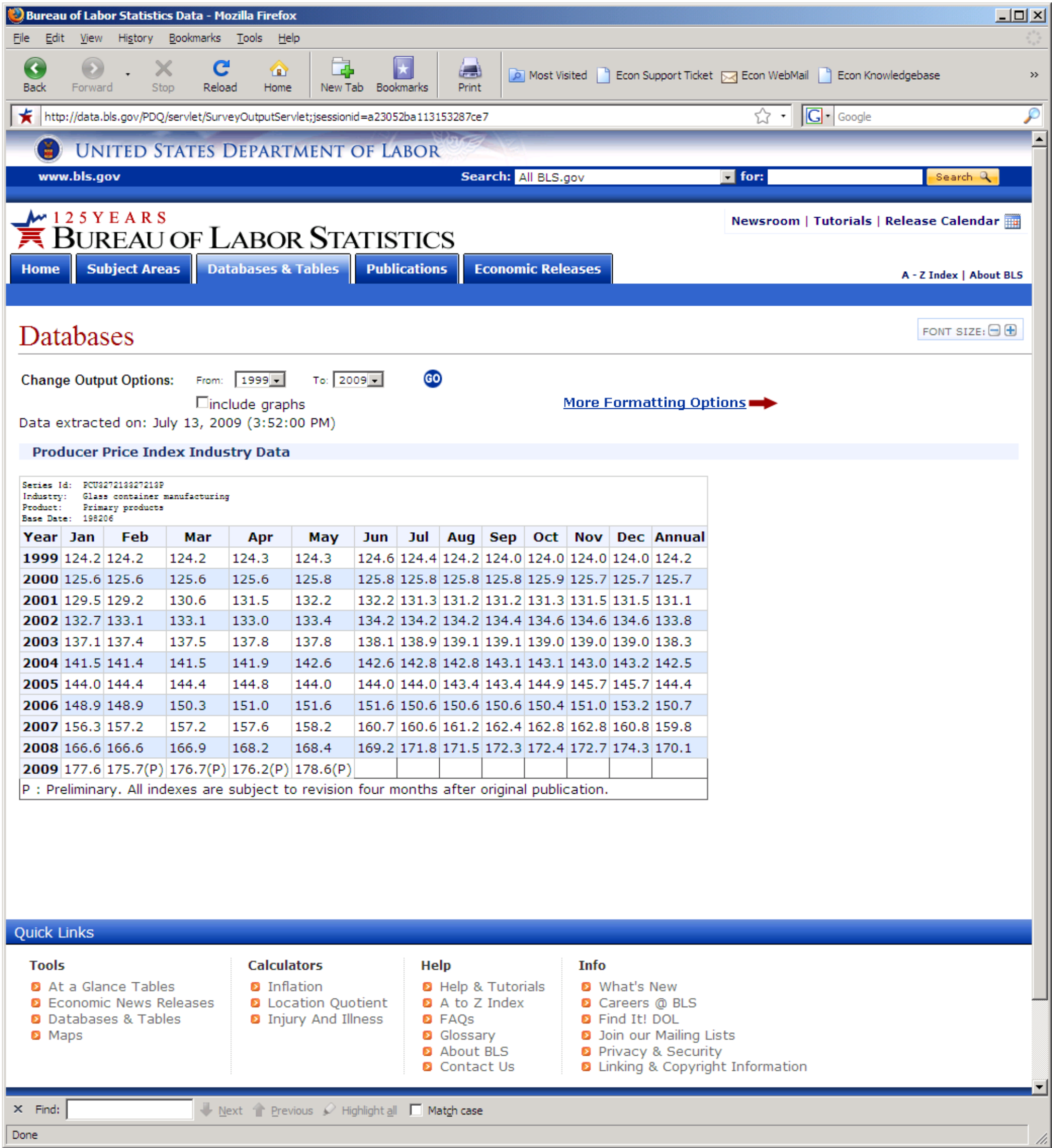


Figure 6 Step One: Extracting PPI from the BLS web site



Bureau of Labor Statistics Data - Mozilla Firefox

http://data.bls.gov/PDQ/servlet/SurveyOutputServlet;jsessionid=a23052ba113153287ce7

UNITED STATES DEPARTMENT OF LABOR

www.bls.gov

125 YEARS BUREAU OF LABOR STATISTICS

Newsroom | Tutorials | Release Calendar

Home | Subject Areas | Databases & Tables | Publications | Economic Releases

A - Z Index | About BLS

Databases

Change Output Options: From: 1999 To: 2009

include graphs

More Formatting Options

Data extracted on: July 13, 2009 (3:52:00 PM)

Producer Price Index Industry Data

Series Id: PCU327213327213P
Industry: Glass container manufacturing
Product: Primary products
Base Date: 198206

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1999	124.2	124.2	124.2	124.3	124.3	124.6	124.4	124.2	124.0	124.0	124.0	124.0	124.2
2000	125.6	125.6	125.6	125.6	125.8	125.8	125.8	125.8	125.8	125.9	125.7	125.7	125.7
2001	129.5	129.2	130.6	131.5	132.2	132.2	131.3	131.2	131.2	131.3	131.5	131.5	131.1
2002	132.7	133.1	133.1	133.0	133.4	134.2	134.2	134.2	134.4	134.6	134.6	134.6	133.8
2003	137.1	137.4	137.5	137.8	137.8	138.1	138.9	139.1	139.1	139.0	139.0	139.0	138.3
2004	141.5	141.4	141.5	141.9	142.6	142.6	142.8	142.8	143.1	143.1	143.0	143.2	142.5
2005	144.0	144.4	144.4	144.8	144.0	144.0	144.0	143.4	143.4	144.9	145.7	145.7	144.4
2006	148.9	148.9	150.3	151.0	151.6	151.6	150.6	150.6	150.6	150.4	151.0	153.2	150.7
2007	156.3	157.2	157.2	157.6	158.2	160.7	160.6	161.2	162.4	162.8	162.8	160.8	159.8
2008	166.6	166.6	166.9	168.2	168.4	169.2	171.8	171.5	172.3	172.4	172.7	174.3	170.1
2009	177.6	175.7(P)	176.7(P)	176.2(P)	178.6(P)								

P : Preliminary. All indexes are subject to revision four months after original publication.

Quick Links

Tools: At a Glance Tables; Economic News Releases; Databases & Tables; Maps

Calculators: Inflation; Location Quotient; Injury And Illness

Help: Help & Tutorials; A to Z Index; FAQs; Glossary; About BLS; Contact Us

Info: What's New; Careers @ BLS; Find It! DOL; Join our Mailing Lists; Privacy & Security; Linking & Copyright Information

Figure 7 Step Two: Example Table of PPI Results from the BLS web site

4.3 Use of the ENERGY STAR Glass Manufacturing EPI

The ENERGY STAR glass manufacturing EPIs are now complete, as are spreadsheet tools for calculating EPI ratings. EPA intends to use the EPIs to motivate improvement in energy use in U.S.-based glass manufacturing. EPA works closely with the manufacturers, through an ENERGY STAR Industrial Focus on energy efficiency in glass manufacturing, to promote strategic energy management among the companies in this industry. The glass manufacturing EPIs are important tools that enable companies to determine how efficiently each of the plants in the industry is using energy and whether better energy performance could be expected.

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 (or monthly) use for every plant in a company on a rolling 12-month basis. EPA suggests that the EPI rating be used to set energy efficiency improvement goals at both the plant and corporate levels.

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.

4.4 Steps to Compute a Rating

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 EPI rating 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 Use*
    - TSE is computed from the metered energy data.
    - The total site consumption for each energy type entered by the user is converted into source energy using the source to site 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 "Best Practice"*[6] *TSE*
    - Predicted "Best 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 minimum energy use for the building, given its specific operational constraints.
4. *EPI compares Actual TSE to Predicted "Best Practice" TSE*
    - A lookup table maps all possible values of TSE that are lower than the Predicted "Best Practice" TSE to a cumulative percent in the population.
    - The table identifies how far the energy use for a plant is from best practice.

---

[6] The model computes the "best practice" for frontier models and "average practice" for ordinary least squares. Steps 3 and 4 are similar for the OLS models, except that the prediction is for the average energy use and the percentiles are relative to the average (i.e. 50th percentile).

- The lookup table returns a rating 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 rating 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.

5 References

Boyd, G., E. Dutrow, et al. (2008). "The Evolution of the Energy Star Industrial Energy Performance Indicator for Benchmarking Plant Level Manufacturing Energy Use." *Journal of Cleaner Production Volume* 16 (Issue 6): 709-715.

Boyd, G. A. and W. Tunnessen (2007). “Motivating Industrial Energy Efficiency through Performance-based Indicators.” *ACEEE Summer Study On Energy Efficiency In Industry Improving Industrial Competitiveness: Adapting To Volatile Energy Markets, Globalization, And Environmental Constraints*, White Plains, New York, ACEEE.

EPA, 2003, *Guidelines for Energy Management*, U.S. Environmental Protection Agency, Washington, DC; available online at http://www.energystar.gov/index.cfm?c=guidelines. guidelines_index.

Greene, W.H., 1993, “The Econometric Approach to Efficiency Analysis,” pp. 68–119 in *The Measurement of Productive Efficiency: Techniques and Applications*, H. Fried, et al., (editors), Oxford University Press, NY.