Plant Energy Benchmarking: A Ten Year Retrospective of the ENERGY STAR Energy Performance Indicators (ES-EPI) [1]

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ABSTRACT

Over the past several years, there has been growing interest among policy makers and others in the role that benchmarking industrial energy efficiency can play in climate, air, and other potential regulatory actives. For over ten years, the U.S. Environmental Protection Agency (EPA) has supported the development of sector specific industrial energy efficiency benchmarks, known as ENERGY STAR® Energy Performance Indicators (ES-EPI). To date there are ES-EPIs that are either completed or under development for fourteen broad industries. Within these industries, ES-EPIs account for over two dozen sub-sectors and many more detailed product types. Newer versions, or "updates" for three of the industries' ES-EPI have been developed in recent years. Through the process of updating these ES-EPIs, the program has been able to observe changes in the energy performance of the sector as well as the range in performance found in the sector. This paper reviews approaches for developing energy efficiency benchmarks in the context of providing an overview of the approach that has been used in this research to develop this ES-EPI, summarizing the industry specific and general findings regarding the range of performance within and across industries. Observations about industrial plant benchmarking and lessons learned are explored. Over the 10 years of preparing ES-EPI we find that there are few sectors that are best represented by a simple "energy per widget" benchmark; that less energy intensive sectors tend to exhibit a wider range of performance than energy intensive ones; and that changes over time in the level and range of energy performance, i.e. "industry curve shift", for ES-EPI that have been updated do not reveal any single pattern.

Introduction

ENERGY STAR is a voluntary program launched by the EPA in 1992 to identify and promote energy efficient products, buildings, homes, and manufacturing facilities.[2] The program was established to find cost-effective ways to reduce greenhouse gas emissions associated with energy use. Initially focused on consumer products, the program expanded into the commercial building market in 1995 and released its first energy-efficiency benchmark for office buildings in

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[2] See EPA (2011) for more information.

1998. In 2000, the EPA expanded the program to include manufacturing plants. The goal of ENERGY STAR for Industry is to identify and promote best practices that help improve the energy efficiency of industrial plants. To that end, ENERGY STAR focuses on providing tools that encourage better corporate energy management. A key and unique aspect of the program's strategy to improve energy management practice is the development of sector specific energy performance benchmarks.

Starting in 2002 EPA has supported the development of a suite of sector specific, intra-industry benchmarking tools called ENERGY STAR Energy Performance Indicators (ES-EPI). These ES-EPIs compute an Energy Performance Score (EPS) or "ENERGY STAR score" that compares plant's performance against its peers to ranks a specific plant on a percentile scale (1-100) based in individual product, material, and location characteristics that impact energy use.

The goal of the ES-EPI is to provide companies within a manufacturing sector with an objective measure of how their plant compares to the rest of the industry. EPA had observed that most companies lack sufficient information on the relative efficiency of their plants. Consequently, many companies did not know if their companies where operating efficiently or where the frontier for improved efficiency lies. By creating a benchmarking for energy efficiency within a sector, EPA believed it could provide valuable information that would motivate companies to take action to improve the performance of their plants. EPA reasoned that companies would be motivated to improve their efficiency in order to reduce costs and improve operating margins. In the process of improving their energy efficiency, the sector's greenhouse gas emissions associated with fossil fuel consumption could also be reduced in a cost effective manner.

The second objective of developing ES-EPI was to establish criteria for determining which plants would qualify for recognition. Through its product labeling program and commercial building program, EPA was able to observe the positive impact that providing recognition to top performers on overall sector efficiency. In order to provide recognition for energy efficient manufacturing plants, EPA needed an objective and transparent means to determine which plants are best-in-class. The establishment of an ES-EPI would provide that means and by involving the industry in its development, the process for which the ES-EPI is developed would ensure transparency as well as confidence by the industry that the tool and method are accurate.

To develop an ES-EPI, ENERGY STAR needed to address a variety of key issues:

- How to define energy efficiency?
- What metrics should be used to measure efficiency?
- How do you adjust or normalize for differences between plants?

Defining Energy Efficiency[3]

Efficiency is a measure of relative performance; but relative to what? Defining energy efficiency requires a choice of a reference point or benchmark against which to compare energy use. Energy efficiency benchmarks can be developed through a variety of means, such as

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[3] This section draws from Boyd, G. (2012). A Statistical Approach to Plant-Level Energy Benchmarks and Baselines: The Energy Star Manufacturing-Plant Energy Performance Indicator. Carbon Management Technology Conference. Orlando, Florida USA.

engineering and theoretical estimates of performance or through observing the range of actual levels of performance. The choice of method used to define efficiency depends on the need to define a reference point for energy efficiency. One of the challenges with using energy efficiency benchmarks based on engineering or theoretical estimates is that they are often dismissed by industry as being economically infeasible.

Consequently, ENERGY STAR for Industry program has focused on developing benchmarks based on actual or observed operational performance rather than theoretical estimates of potential efficiency levels. Additionally, EPA need to identify a benchmarking method that would be perceived by end users as being economically feasible is important for the adoption of the benchmarking system and ultimately its impact on driving change.

The reference point for economic potential (observed practice) depends, in part, on the reason for measuring efficiency as well as the available information to create a reference. Generally, the *Ceteris Paribus* principle ("all other things being equal or held constant") is usually desired in creating the reference point, or benchmark. From a practical perspective there is a hierarchy of measures and methods by which one can "hold constant" things that influence *energy use* that are not part of *energy efficiency.* The first is some measure of production activity, either production itself or alternatively a ubiquitous input into the production process. This is most commonly done by computing the ratio of energy use to activity, a measure of energy intensity. Energy intensity is a common metric that controls for changes in production and is commonly confused with energy efficiency, as in the statement "*the industry or plant's energy efficiency has improved based on the fact that the corresponding energy intensity has declined over time.*" This type of statement brings us to the second way that one may approach the ceteris paribus principle for measuring efficiency, comparing energy intensity a particular plant, firm, or industry to itself over time. This approach is a plant (firm, etc.)[4] specific *baseline* comparison, or *intra-plant* efficiency benchmark. The baseline approach has the advantage of controlling for some plant specific conditions that do not change during the comparison period.

The next level of this ceteris paribus principle is an *inter-plant* comparison that may include a variety of factors that influence energy use, but may not be viewed as efficiency. Factors may include difference in the types of product and materials used, as well as location specific conditions. Intra-plant comparisons within an industry also get us closer to the notion of an observed best-practice benchmark of economic energy efficiency, since by definition there is some group of plants that are the best performers. This was the notion introduced by (Farrell 1957) and has been the basis for measuring production efficiency in economics. A modified approach has been adopted by ENERGY STAR (Boyd 2005) and its evolution is discussed by (Boyd, Dutrow et al. 2008).

Intensity Metric Selection

Intensity ratios provide a basic metric for measuring energy efficiency and performance compared to a baseline. To measure intensity you need a measure of energy and something for the denominator. For the numerator in ENERGY STAR uses total source energy, defined as the net Btu total of the fuels (Btu) and electricity (Kwh) with electricity converted to Btu based on the level of efficiency of the U.S. grid for delivered energy, i.e. including generation and

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[4] Throughout the paper we will refer to the plant level as the unit of observation, but the concept may also apply to more aggregate levels like firms and industries, an sometimes to less aggregate levels like process units.

transmission losses. A net measure is needed for when energy is transferred off site, most commonly in the form of steam or electricity.

The choice of the denominator is a major issue for measuring intensity. Ideally the denominator should capture some measure production. (Freeman, Niefer et al. 1997) show that industry level trends in energy intensity based on value, both total and value added, can differ dramatically from those based on physical quantities. As Freeman et all have observed, there are many challenges with creating efficiency benchmarks based on price indexes, cost and other value measurements.[5]

Given issues with linking energy use with price indexes, ENERGY STAR focused on using metrics based on physical quantities. For physical production to be meaningful it needs to be at a high level of industry specificity. For example, the "Dairy" industry produces many products that cannot be aggregated, but "Fluid Milk" can. Therefore, within industries, it is necessary to differentiate between specific types for plants and manufacturing operations.

Similarly, ENERGY STAR has avoided using physical size (sq ft) as the main denominator for energy intensity benchmarks for most industrial facilities.[6] While commonly used for commercial buildings where energy use is primarily tied to plug loads, lighting and HVAC systems, energy intensity based on size (sq. ft) does not correspond well with production energy use. While ENERGY STAR ES-EPIs provide energy intensity rations for users, their value for developing intra-plant comparisons is limited. For intra-plant comparison, there are multiple factors that must be considered.

Multi-Factor Benchmarks

When making intra-plant comparisons, it necessary consider a variety of factors that do not neatly fit neatly under the denominator of an energy intensity ratio. While all plants may make a common product, other differences can significantly affect energy intensity. The difficulty with applying an industry level inter-plant benchmark is controlling for inter-plant difference other than production volume. While the things that differ between plants are numerous, we have found that the primary difference that have the most impact on energy fall into the following categories:

- Product mix
- Process inputs
- Size - Physical or productive capacity and utilization rates
- Climate (and other location specific factors)

The choice of factors to include in the analysis depends upon the nature of the production process, the configuration of the industry (e.g. is upstream integration common or rare), the

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[5] As Freeman et all (2007) note, *"For an industry producing a single, well-defined, homogeneous good, it is relatively easy to construct an accurate price index. Most industries, however, produce many poorly-defined, heterogeneous goods. For a variety of reasons, the more diverse the slate of products produced by an industry, the more difficult it becomes to construct an accurate price index. ...the accuracy of industrial price indexes is of extreme importance to industrial energy analysts and policy makers who use value-based indicators of energy intensity."*

[6] The one exception is Pharmaceutical manufacturing where energy intensity is expressed as MMBTU/SQ FT. This metric was chosen largely because of the huge impact of HVAC systems in pharmaceutical manufacturing.

availability of data to represent these factor, and ultimately the outcome of the statistical tests for significance. In order to address these types of factors, the ES-EPI uses a multivariate approach to normalization where multiple effects are simultaneously considered (Boyd and Tunnessen 2007). The next sections discussed the four basic categories of effects that are commonly considered. There is further elaboration on the way this is implemented the section on industry specific comparisons.

Product mix. Not all plants produce exactly the same product. In fact, many plants themselves produce multiple products. The diversity between plants gives rise to a mix of derived demands for specific processes and energy services. To the extent that the final product is the results of a series of energy using steps the energy use of the plant will depend on the level and mix of products produced. Rather than specifying each process step individually, the approach used here is to identify those products that use significantly more (or less) energy and measure those energy requirements with a statistical comparison.

One approach to controlling for product mix is to segment the industry into cohorts based on product categories. This works best when there is no overlap between plants that produce the various basic products and there are sufficient numbers of plants to conduct the statistical comparison between those resulting groups. This means each sub-group is effectively treated as a separate industry for evaluation proposes. A good example is the glass industry where containers and flat glass are distinct industry segments.

When such natural sub sectors do not exist and multiple products are produced within a plant, additional approaches are needed. The statistical approach used by ENERGY STAR is well suited to testing if a particular grouping of products is appropriate for benchmarking differences in energy. When industries produce a mix of products that differs across plants then the product mix (share of activity) of distinct products is needed. This approach was first used in the ES_EPI for wet corn mills and was later applied to mane other sectors (see below). Other industries like pharmaceuticals or autos that also have a diverse range of products may be treated differently for benchmarking. In the case of Pharmaceuticals where final production of the product occurs in a clean room environment, product mix was less important for benchmarking "fill and finish" facilities.

Physical size. Size and utilization rates may directly impact energy use. Size may impact specific engineering and managerial advantages to energy use. If there is a substantial "fixed" level of energy use in the short run, the utilization rates may have a non-linear impact on energy intensity. In order to include size (and utilization) as a normalizing factor in the EPI a meaningful measure of size or capacity is needed. It may be measured on an input basis, output basis, or physical size. In some cases there may be advantages to larger scale of production. If it is the case that a larger production capacity or larger physical plant size has less than proportionate requirements for energy consumption then there are economies of scale with respect to energy use. In the cement industry the scale is quite important. The larger size of the kiln (rather than several smaller kilns) has advantages in terms of energy use. The ES-EPI for this sector accounts for this.

Process inputs. There are three ways that process inputs are important for benchmarking. The first is that inputs like materials, labor, or production hours may be good proxy measures of overall production activity when measures of production output are not available or have specific shortcomings[7]. The second is in the identification for upstream (vertical) integration, i.e. whether a plant makes an intermediate product or purchases some pre-processed input. This is an important "boundary" issue for the energy footprint of a plant, even when two plants produce identical outputs. The third way is a variation of the second, relating to material "quality." If there are alternative input choices that differ qualitatively and also with respect to energy use then input quality measures can be introduced into the benchmark.

The first way process inputs can be helpful in developing a statistical benchmark of energy use is that inputs like materials, labor, or production hours may be good proxy measures of overall production activity when measures of production output are not available or have specific shortcomings. If a physical measure of output is not readily available and pricing makes the value of shipments a questionable measure of production then physical inputs can be a useful proxy. For some industries the basic material input is so ubiquitous that it makes sense to view energy use per unit of basic input rather than (diverse) outputs. Process inputs may also be useful in measuring utilization, either directly or indirectly. Corn refining is a good example of this approach. The former uses a ubiquitous inputs, corn. Sometimes physical production data is lacking in some way but material flows can be used instead. For example, sand, lime, soda ash, and cullet (scrap glass) are the primary inputs to glass manufacturing.

The second way that process inputs are important for inter-plant benchmarking is when vertical integration is common in a sector. Industries are categorized by the products they produce, but some sectors may face a "make or buy" decision in the way they organize production. A plant may purchase an intermediate product or produce it at the plant as part of a vertically integrated plant. For example, an auto assembly plant may stamp body panels or ship them in from a separate facility. The energy use of these two facilities is not directly comparable. The inter-plant benchmarking approach must account for those "make or buy" decisions in the specific plant configurations. Examples range from food processing, where plant may make juice from concentrate or fresh fruit or paper mills which may purchase (some) market pulp or recycled fibers.

The third way that process inputs are important for inter-plant benchmarking is when differences in material quality may also be related to energy use. For example, if the materials mix to produce a product directly impacts energy uses, then the statistical model can apply different weights to the materials mix in the same manner that it does with product mix. In other words, product/process level differences in energy use can be inferred from the volume and types of materials used in production. To be considered in the statistical normalization, they must be measured on a consistent plant-level basis across the industry. For cement plants the hardness and moisture content of the limestone is hypothesized to influence energy use, but no consistent data is available for this, leaving it the subject of future analysis if data can be collected.

Climate. There are many things under the control of a plant or energy manager, but one they cannot control is "the weather." In most manufacturing plants heating, ventilation and cooling (HVAC) contributes to energy demand and weather determines how much is required to maintain comfort. Since the benchmarking approach used here is annual, seasonal variation does not enter into the analysis, but differences due to the location of a plant and annual variation from the locations norm will play a role. The approach that has been taken for all sectors under

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[7] As discuss in Freeman, et al (1997)

study is to include heating and cooling degree days (HDD and CDD) into the analysis to determine how much these location driven differences in "weather" impact energy use**.**

In principle all plant have some part of energy use that is HVAC related, but when the HVAC component of energy use is small relative to total plant consumption the statistical approach may not be able to measure the effect accurately enough to meet tests for reliability. For some sectors weather is a factor in the process, like auto assembly. It a factor because of paint booths and climate control technology need for those systems. Pharmaceuticals manufacturing, where "clean room" production environment is common, is another good example. The climate impact in this sector is only applicable to the "finish and fill" production stage. The more energy intensive chemical preparation stage is not sensitive to climate. Even in industries where the HVAC component is not an obvious (large) part of energy use there may be effects that the ES-EPI analysis needs to test for. Chillers may be sensitive to CDD (summer) loading.

Detailed Overview of the ES-EPI Tools

Drawing from the general approach above, Table 1 summarizes the factors that have been included in each EPI to explain difference in inter-plant energy use. It is clear that each industry is unique in the characteristics that "matter" for benchmarking. About half of the sectors have been finalized by EPA and the rest are under review. Twenty use some type of physical units for activity; of those, 18 have 2 to 5 different sub-product types or use some other information to further characterize product differences, i.e. price or size. Some measure of plant size and utilization is included in 5, but the small number is due more to data limitations, i.e. available plant level capacity information. Person or operation hours are included in 8 industries. In some cases the labor hours *may* be playing a similar role to utilization, i.e. capturing non-production activity that uses energy. About half of the sectors include process inputs, either as a ubiquitous measure of input, e.g. corn in corn refining or scrap in minimills, or in the form of raw vs. preprocessed inputs, e.g. fresh fruit vs concentrate in Juice production or virgin vs. recycled fiber in paper production. The selection of inputs is based in part on data availability, but then only included when the estimated effect is of reasonable size and statistically significant.

Table 2 further describes the statistical form of the models. Seven sectors exhibit a skewed distribution of energy intensity and are modeled as stochastic frontiers; the rest are best approximated as log normal, i.e. the percentage difference from average performance are "bell shaped." The earliest benchmark year is 2002. This is largely driven by the data available when the analysis was conducted. 2007 is the most recently available data from Census. Sectors that use industry or trade association provided data tend to have more recent benchmark years. For the less energy intensive industries using Census of Manufacturing (CM) data, the energy content of the fuels is imputed using cost data and state level energy prices. This is done since the sample sizes in the Manufacturing Energy Consumption Survey (MECS) are too small. For industries with larger MECS samples the more detailed energy information is used directly.

Sample sized vary depending on the industry, although these sample sizes should be viewed as a complete count of all the plants. Some data is dropped due to incomplete reporting or other "data quality screens" such as for extreme outliers.

Table 1. ES-EPI Benchmarks Inputs, by Industry and Sub-Sector

Focus industries	Product mix	Units	Inputs	Size or capacity	External	Other
Cement (V 2.0)	3 product types	Tons	-	Capacity & # of Kilns	Utilization	Person hours
Corn Refining (V 2.0)	5 product types	Bushels	Corn	Capacity	Utilization	Feed moisture
Dairy - Fluid Milk *	6 product types	Gallons	Whole milk	-	Weather TBD	Person hours
Dairy - Ice cream *	4 product types	Gallons	2 types	-	Weather TBD	Person hours
Ethyl Alcohol **	Single	Gallons	-	-	-	-
Food - Juice (Canned)	4 x 2 product types	Gallons	2 types	-	-	-
Food - Frozen Fried Potatoes	Single	lbs	-	-	-	Warehouse (frozen)
Food - Tomato products **	1 sub-product type		2 types	-	-	Person hours
Baking - Cookies & Crackers	3 product types	lbs	-	-	-	-
Baking - Bread & rolls *	5 Product types	tonss	Raw dough	-	Weather TBD	Freezers
Glass - Flat	-	lbs	Sand	-	-	-
Glass - Container	Price	lbs	Sand, Cullet	-	-	-
Iron and Steel - Integrated *	5 product/activities	tons	-	Furnace capacity	Utilization	-
Iron and Steel – Minimills *	Price	tons	Scrap	Furnace capacity	Utilization	-
Metal casting - Iron *	4 product types	Tons, other	-	-	Weather TBD	Person hours
Metal casting - Investment steel *	-	hours	-	-	Weather TBD	Person hours
Metal casting - "Other" steel *	3 product types	$	-	-	Weather TBD	-
Motor Vehicle V2.0	vehicle size	#	-	-	Weather, Utilization	Air Tempering
Pharmaceuticals	3 activity types *	%	-	Facility size (ft2)	Weather, Utilization	Operation hours
Printing - Lithograph *	6 product types	$	2x3 types	-	Weather TBD	-
Pulp Mills	3 product types *	tons	2 types	-	-	Water treatment
Paper & Board Integrated Mills	3 product types *	tons	3 types	-	-	Water treatment, bleaching chemicals
Ready Mix Concrete *	2 activities	Tons,miles	-	-	-	-

* Under Industry Review, ** Preliminary

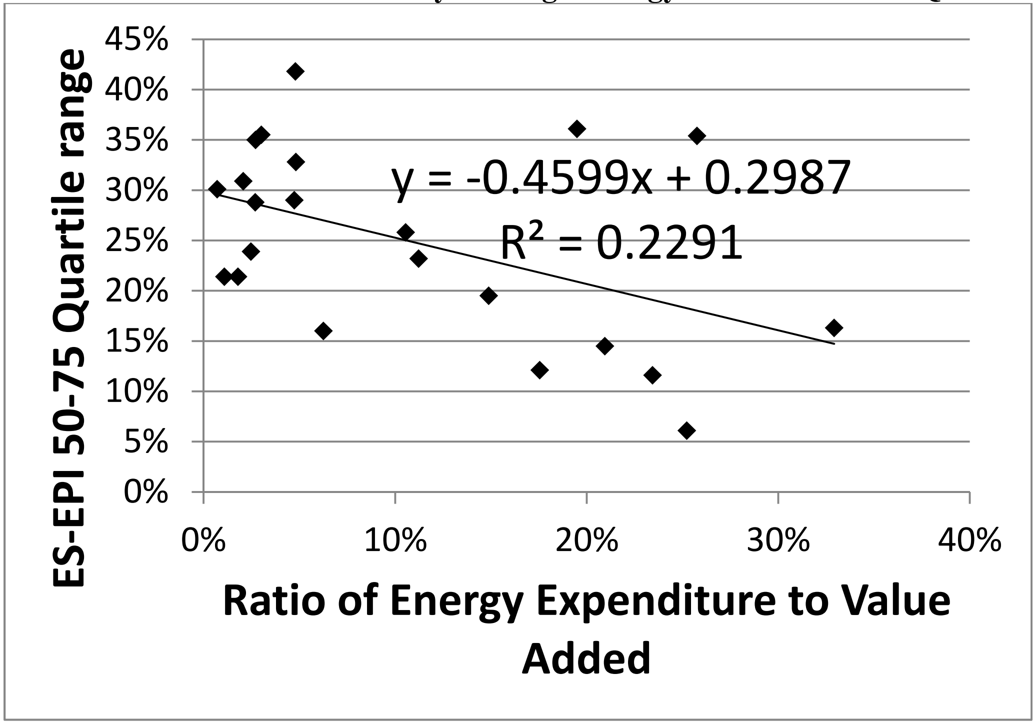
Table 2. ES-EPI Benchmarks Model Details, by Industry and Sub-Sector

Focus industries	Model	Year	# of plants	Data source	75 to 50th
Cement (V 2.0)	log normal	2000-2008	96	PCA	-6.1%
Corn Refining (V 2.0)	half normal frontier	2004-2009	37	Industry	-14.5%
Dairy - Fluid Milk *	log normal	2002	258	CM	-29.0%
Dairy - Ice cream *	log normal	2002	89	CM	-23.9%
Ethyl Alcohol **	log normal	2007	111	CM	-35.4
Food - Juice (Canned)	log normal	2002	44	CM	-41.8%
Food - Frozen Fried Potatoes	log normal	2002	27	CM	-16.0%
Food - Tomato products **	log normal	2002	40	CM	-43.7%
Baking - Cookies & Crackers	log normal	2002	64	CM	-30.9%
Baking - Bread & rolls *	log normal	2007	207	CM	-28.8%
Glass – Flat	log half normal frontier	2002	38	CM, MECS	-16.3%
Glass - Container	log normal	2002	62	MECS	-11.6%
Iron and Steel - Integrated *	log half normal frontier	2005-2009	12	Industry	TBD
Iron and Steel – Minimills *	log normal	2002	39	CM, MECS	-12.1%
Metal casting - Iron *	log normal	2006	83	CM, MECS	-23.2%
Metal casting - Investment steel *	Exponential frontier	2007	51	CM	-32.8%
Metal casting - “Other” steel *	log normal	2007	59	CM	-25.8%
Motor Vehicle (V2.0)	Gamma frontier	2003-2005	33	Industry	-21.4%
Pharmaceuticals	log half normal frontier	2004-2006	61	Industry	-30.1%
Printing - Lithograph *	Log half normal	2007	775	CM	-35.0%
Pulp Mills	log normal	2002	28	CM, MECS	-36.1%
Paper & Board Integrated Mills	log normal	2002	99	CM, MECS	-19.5%
Ready Mix Concrete *	log normal	2008-2009	62	NRMCA	-35.5%

* Under Industry Review, ** Preliminary

The last column labeled 75 to 50th represents the third quartile range, i.e. percent difference of the 75th percentile, i.e. the ENERGY STAR certified plant level, and the average or median performance, the 50th percentile. This ranges from as low as 6% to nearly 44%. Figure 1 compares this third quartile range to the industry average share of energy cost to value added. This cost share reflects how "important" energy is in the sector. We see a clear correlation between high cost shares and the range of performance. This makes sense since industries with higher relative energy costs would put more effort into management of those costs. There are outliers in this relationship, however. They include pulp mills and ethanol (dry mill) plants. The latter is a preliminary estimate. The result for pulp mills may suggest the need for additional scrutiny. However, the EPI uses net purchased energy and pulp mills provide a large amount of internally generated power from black liquor and CHP. There may actually be a wide range of practices in terms of net purchased energy in this sector than for other energy intensive ones.

Figure 1. Correlation between Industry Average Energy Share and 50-75 Quartile Range

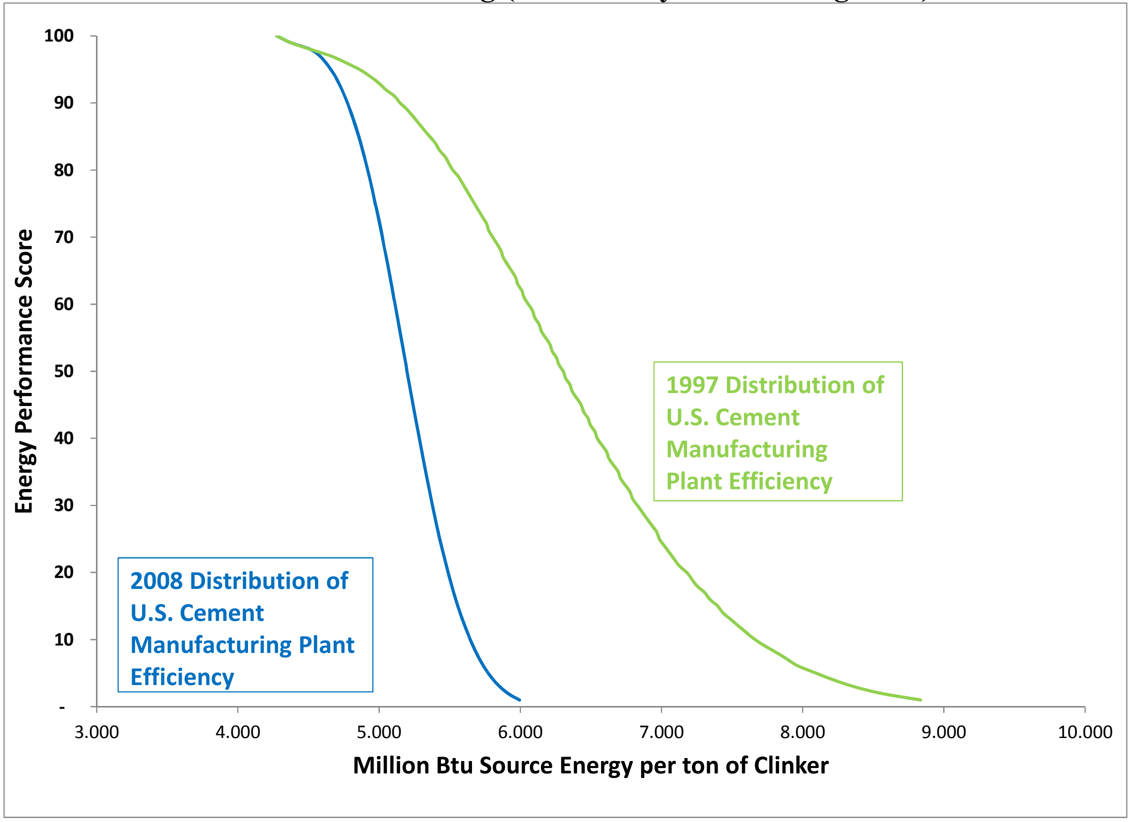


Updates for benchmark year for three ES-EPI

In the 2010, EPA began a process of updating the benchmark year data for the first three ES-EPIs that were officially released; Auto assembly, Cement, and Corn refining (see (Boyd 2005; Boyd 2006; Boyd 2008) for detailed descriptions of the earlier models). Comparing the old benchmark with the new benchmark reveals information about how these three, very different industries have changed over time. Since the ES-EPI analysis reveals both the general level and range of energy performance the comparison focuses on how much the change in the "best practice" and the change in the range of performance contribute to the overall reduction in energy use in the sector (see (Boyd and Zhang 2012), (Boyd and Delgado 2012), and (Boyd 2010) for the details of the updates).

For the cement industry, if one computes the ratio of total energy costs to total value of shipments (adjusted for inflation) in 1997 and 2007 from data collected in the Economic Census, one would conclude that this measure of energy intensity has fallen ~16%, from 0.184 to 0.158. Aggregate data may also give the impression that all plants have made the same steady improvements. The picture that emerges from our plant level statistical analysis is somewhat different and more subtle (figure 2); poorer-performing plants from the late 1990s have made efficiency gains, reducing the gap between themselves and the top performers, whom have changed only slightly. The results from this study focus on energy efficiency and controls for other structural changes in the industry, e.g., increases in average plant size, which also tend to lower energy use. Our estimate of the overall energy efficiency improvement in the 96 plants in our database represents a 13% percent change in total source energy and the source of these changes is clearly not uniform.

Figure 2. Comparison of Two Benchmark Distributions of Energy Efficiency in Cement Manufacturing (source: Boyd and Zhang 2012)



Results for the auto assembly industry are similar, but less dramatic (figure 3). There are two sources of improvement, the changes in the industry energy frontier, i.e. "Best Practices" and technology, and the changes in efficiency, i.e. whether plants are catching up or falling behind. The results suggest that slightly more than half of the improvement is changes in efficiency, which have slightly outpaced changes in the frontier. The combined effect when evaluated against the over 7 million vehicles produced in 2005 by the plants in our study implies in a reduction of 11.6%, or 1462 million lbs of CO_2, attributable to changes in observed industry energy efficiency practices.

Figure 3. Comparison of Two Benchmark Distributions of Energy Efficiency in Auto Assembly (Source: Boyd 2010)

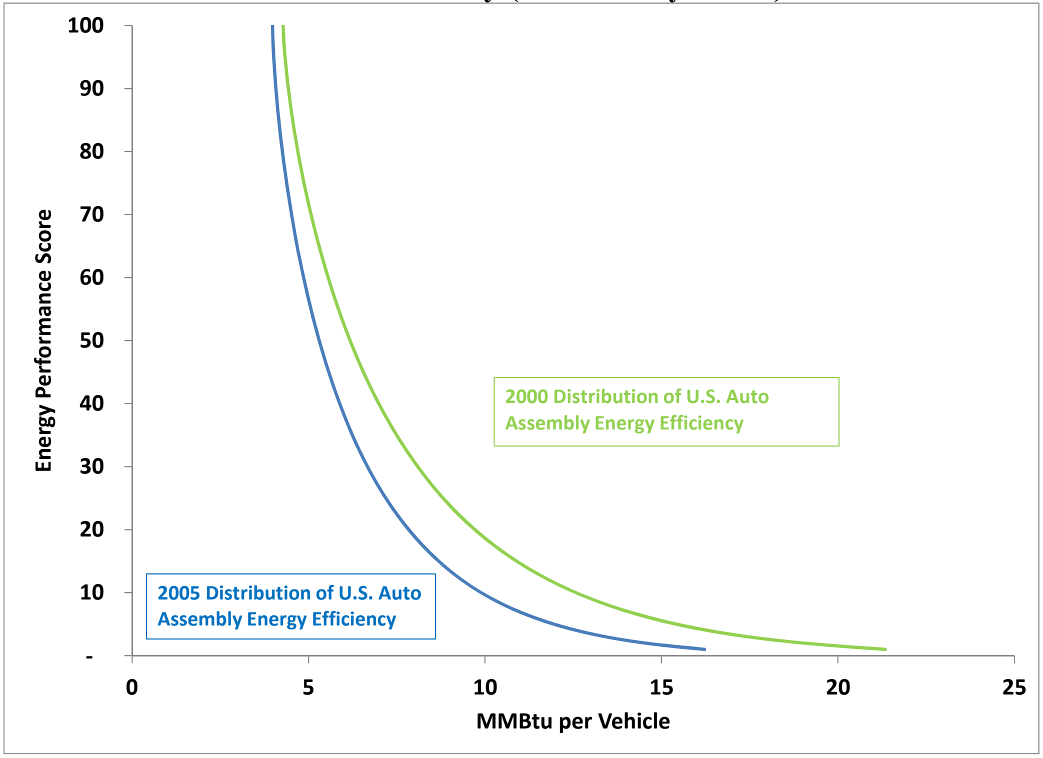
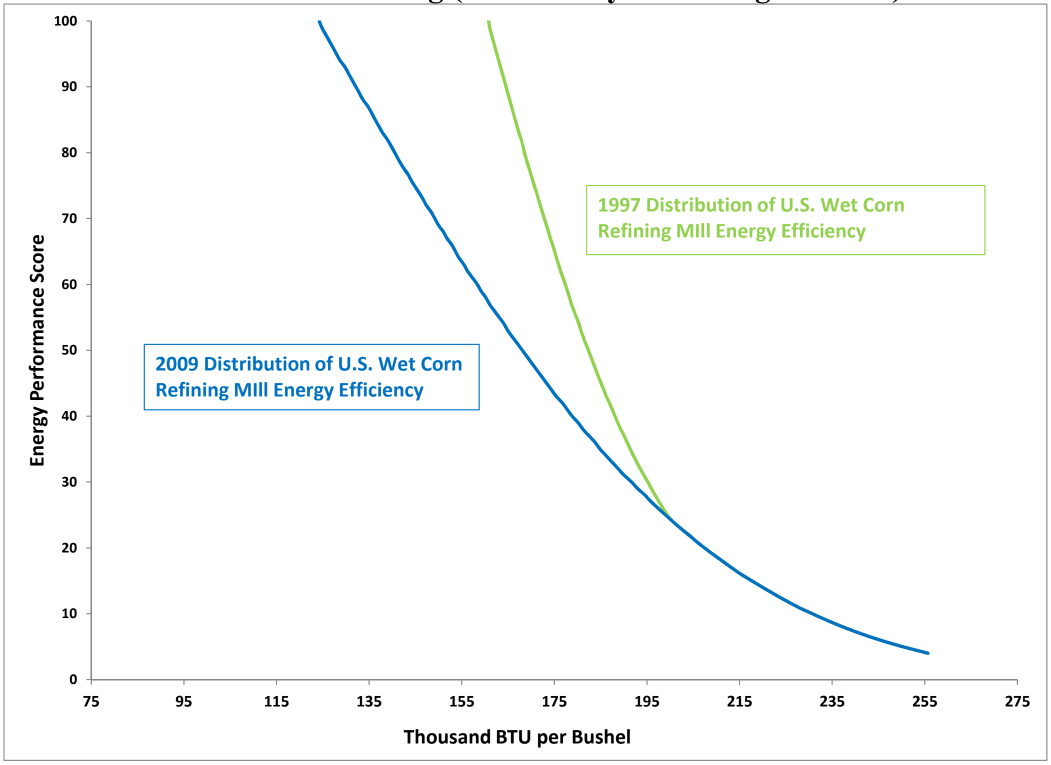


Figure 4. Comparison of Two Benchmark Distributions of Energy Efficiency in Wet Corn Refining (source: Boyd and Delgado 2012)



The change in the distribution of energy efficiency for a representative corn refining plant is shown in figure 4. If we multiply this plant-specific change in energy intensity by the level of corn input production for each plant operating in the industry in 2009, and total across all plants, we compute a reduction of 6.7 trillion Btu in annual energy use. Relative to an average annual total source energy consumption of 155 trillion Btu in 2009 for all the plants in our data set, this represents about a 4.3% reduction in overall energy use by this industry. When energy-related greenhouse gas emissions are considered, this represents an annual reduction of 470 million kg of energy-related CO_2 equivalent emissions from improved energy efficiency.

The change in performance from these three industry are all quite different. Cement reflects the case where best practice has changed very little, but "catching up" comprises the main source of improvements. Corn refining is at the opposite end of this spectrum, where there are substantial changes in the best plants, but laggards remain or in some sense are even falling behind by failing to keep pace. The auto assembly plants are a mixture of changes in best practice and some modest "catching up". These benchmark updates also reflect different time periods. When we compute the average annual change from the total reduction in energy use for each sector we see that the auto industry has made the greatest strides (see table 3).

Table 3. ES-EPI Benchmarks Updates: Rate of Change by Industry

Sector	New benchmark Year	Old Benchmark Year	Time period	Total reduction	Average annual change
Auto	**2005**	**2000**	**5**	**12.0%**	**2.3%**
Cement	**2008**	**1997**	**11**	**13.0%**	**1.2%**
Corn	**2009**	**1997**	**12**	**4.3%**	**0.4%**

Conclusions

The objective for developing sector-specific energy performance benchmarks was to create a tool that would motivate companies to take actions to improve the energy efficiency of their plants and ultimately help reduce greenhouse gas emissions in the industrial sectors benchmarked. As of December 2012, EPA had released 11 EPIs, awarded 120 ENERGY STAR plant labels, and engaged an additional twelve industrial sectors and subsectors in the EPIs development process. Compared to average plants (EPS score of 50) EPA estimated in 2011 that plants earning the ENERGY STAR have saved an estimated 314,190,357 MMBtus. [8]Companies using the ES-EPI report that they find the tools valuable and beneficial for evaluating current performance and setting efficiency goals. Many companies report they have incorporated the ES-EPI into their energy management programs and have made achieving ENERGY STAR certification as an objective.

Initially, ENERGY STAR faced some skepticism that a whole-plant benchmark could be developed. Skeptics largely believed that each plant is too "unique" for whole plant comparisons to be made. However, both the process and method used by EPA to develop the ES-EPIs has helped change skeptics participating in the industrial focus process into supporters for the ES-EPI. The *process* of engaging the industry in the development of the EPIs has been critical to the success of ENERGY STAR industrial benchmarking program. By developing the EPIs in a

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[8] US EPA (2012)

transparent, objective, and collaborative process, EPA enabled industry participants to be directly involved in its design and testing from the beginning. This process enabled the ENERGY STAR team to identify potential factors for normalization, receive timely feedback on draft tools, quickly address concerns, and ultimately ensure a high degree of support and "buy-in" for the tool. By using a benchmarking method based on actual operational data and that allowed for normalization to address specific differences between plants, the ENERGY STAR team was able to overcome concerns that industrial plants are too heterogeneous, even within a specific sub-sector, to be able to benchmark.

The availability of sector-wide energy and production data through the US Census Bureau was critical for the initial development of the ES-EPIs. One the greatest barrier to any benchmarking exercise is inadequate or unrepresentative data. The ENERGY STAR program has benefited from the robust industrial energy and production data collected by the US Census through the Census of Manufacturing (CM) and the Manufacturing Energy Consumption Survey (MECS). The availability of this data for use in developing the statistical models behind the EPIs has been critical to ensuring the early success of the ENERGY STAR industrial benchmarking program. First, it provided EPA with the ability to develop the benchmarks without having to undertake a data collection. Second, by working with Census data, which has strict confidentially requirements, the ENERGY STAR team was able to build trust amongst industry participants that the company specific data used for benchmarking would be kept confidential and would not be shared with either focus participants and the EPA. While some of the more recent ES-EPIs have drawn on data provided by the industry, the availability and quality of the CM and MECS data enabled ENERGY STAR to successfully develop the first ES-EPIs and demonstrate that whole-plant energy performance benchmarking is possible.

The process of developing EPIs has uncovered new insights into energy use and the drivers of efficiency within the sectors benchmarked. Additionally, the establishment of industry baselines has enabled EPA to visualize the range of performance within a sector. Visualizing the distribution of performance offers important information for policy makers and others interested in promoting efficiency or reducing GHG emissions from specific industrial sectors. The slope of the baseline curve generated by the EPI can help policy makers and others evaluate what action is needed to improve the performance of the industry. For example, sectors with steep baseline curves and distributions indicate that the opportunities for improving energy efficiency through existing measures may be limited. These sectors should be considered for R&D investments to develop new technology that can create a step change in the level of performance. Additionally, these sectors may face greater difficulties reducing their GHG emissions through existing energy management measures. Whereas sectors with flatter curves indicate that more opportunities are available through existing technologies and practices. In these sectors, there is a greater distribution of performance, which usually suggests that existing energy management measures and investments can improve performance.

The process of benchmarking and re-benchmarking a sector provides further insights into the improvement potential of the industry over time. Understanding how the distribution of energy performance in a sector is changing or not changing can provide valuable information for policy makers as well as business leader in developing strategies to drive future performance gains.

The approach and method used by ENERGY STAR to benchmark whole-plant energy performance has potential applicability to other sustainability metrics, such as water and waste, as well as sub-systems within plants. While developing such benchmarks is beyond the scope of the ENERGY STAR program, several companies participating in the Industrial Focus process have recently initiated an independent effort that applies the ENERGY STAR benchmarking approach to process lines within the plant and to non-energy measures such as water. If successful, the results of this effort will break new ground in advancing the field of energy performance and sustainability benchmarking.

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