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Assessing Improvement in the Energy Efficiency of U.S. Auto Assembly Plants

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Abstract

The U.S. Environmental Protection Agency's (EPA) ENERGY STAR® program promotes energy efficiency as a strategy to reduce greenhouse gas emissions in the industrial sector. To achieve the this objective and to provide a measure of a manufacturing plant's energy efficiency, ENERGY STAR developed a statistical benchmarking approach. This approach, embodied in the ENERGY STAR Energy Performance Indicator (EPI), estimates the energy use of "best in class" plants and the range of performance across the industry. The first EPI was developed for automobile assembly plants using data from the year 2000, and was updated in a second EPI with 2005 as the base year. In addition to providing the industry with a tool to benchmark its plant energy performance, the process of updating the tool has allowed EPA to document improvement in the industry's overall energy performance for 2000–2005. We find that electricity use per vehicle in the best plants improved by 2%, while the fuel use per vehicle improved a dramatic 12%. These changes resulted in a reduction of 696 million pounds of carbon dioxide (CO_2) emissions at the plants used for this study. The range of performance in fuel use has also narrowed over time, implying that other plants have been catching up to the best-in-class plants. This catching up contributes a reduction of another 766 million pounds of CO_2, for a total reduction of nearly 1.5 billion pounds of CO_2. This paper describes the voluntary ENERGY STAR program policy approach selected to engage and motivate the automobile manufacturing industry to improve its energy performance, and the results of the industry's efforts to advance energy management as measured by the updated EPI.

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1. INTRODUCTION

The U.S. industrial sector was responsible for 27% of energy-related greenhouse gas (GHG) emissions in 2008, and 29% of all U.S. GHG emissions. Carbon dioxide (CO_2) is predominant among those emissions, mainly due to energy consumption for manufacturing processes. CO_2 comprises 85% of manufacturing GHG emissions on a CO_2-equivalent basis.[1]

An important strategy for reducing CO_2 emissions is to improve energy efficiency. In manufacturing, energy efficiency is usually understood as using less energy to produce the same amount of product. Reducing energy requirements can result in lower combustion-generated CO_2 emissions; hence, energy efficiency is the most cost-effective strategy for reducing CO_2 emissions since it lowers both emissions and fuel costs.

Recognizing the potential of energy efficiency to reduce CO_2 emissions, the U.S. Environmental Protection Agency (EPA) launched the ENERGY STAR program for industry to educate manufacturers on steps to improve their energy efficiency. EPA examined many of the market barriers to adoption of cost-effective practices and technologies, and determined that an approach focused on information and energy management strategy offered a new opportunity to overcome market barriers and transform decision making.

EPA observed that the absence of information on whole-plant energy intensity and lack of a system for benchmarking industrial plant energy efficiency represented a major obstacle to improving U.S. industrial energy efficiency. While energy efficiency standards and measures were sometimes available for specific technologies, there was no way to determine how well these technologies operated as a system when measured at the whole-plant level. Moreover, the actual operational efficiency of one plant versus another could only be captured by benchmarking the energy efficiency of the whole plant and not by looking at its components. Because of competitiveness issues among companies, the data necessary for benchmarking industrial energy efficiency was usually considered proprietary, and thus very few industrial plant energy efficiency benchmarking systems had been developed.

By offering a tool that would enable a corporation or industrial plant to compare energy performance to the rest of its industry, EPA hoped to help manufacturers answer key questions:

How do I know whether my plants are energy-efficient?
How much can my plants improve?
Which plants should I target for efficiency improvements?
Which plants should I examine for best practices?

By helping companies answer these questions, EPA also believed it could arrive at a "best in class" type of energy efficiency benchmark that could help strengthen overall energy management practices within an industry. As noted, energy management strategy is a key component of the ENERGY STAR approach.[2] This paper focuses primarily on development of the ENERGY STAR industrial energy efficiency benchmarking system and the change in the industry observed when the benchmarking system was updated.

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[1] From EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008*, April 15, 2010. EPA 430-R-10-006.
[2] For more information on ENERGY STAR energy management resources, visit www.energystar.gov/industry.

2. IDENTIFYING A KEY BARRIER TO ENERGY EFFICIENCY

An inability to determine whether a manufacturing facility is energy-efficient is common to most industries. Within an industry, such as automobile assembly, some companies can determine the performance of similar plants in a single portfolio. However, few companies can determine how well their plants perform compared to similar plants outside their own portfolios across the United States. This missing piece of information limits a company's ability to set competitive goals for a plant's improvement, and prevents understanding how well the best plants in that industry are performing.

EPA set out to develop a new set of tools for the industrial marketplace that would enable U.S. industries to judge their plant energy performance and set goals for improving energy efficiency. These new tools, known as the ENERGY STAR Energy Performance Indicators (EPI), fulfill the need that many industries have for obtaining objective, quantitative information on whether a manufacturing facility is energy-efficient within its industry.

To develop the first EPI, EPA engaged automobile manufacturers with plants in the United States in a collaborative initiative called the ENERGY STAR Focus on Energy Efficiency in Motor Vehicle Manufacturing (the Focus). The objectives for the Focus were to produce an "energy guide"[3] for the industry, develop the auto assembly plant EPI, and foster discussions of energy management best practices.

EPA's first step was to engage a group of energy professionals within the automobile industry to guide them in implementing corporate energy management programs within their companies. EPA approached senior executives to establish the business case for energy management and secure assignment of a responsible energy director for each corporation where one was lacking, toward enabling the companies to build or improve the necessary internal energy management functions and networks. ENERGY STAR energy management tools (such as simplified program evaluation checklists, energy management guidelines, and information on forming energy management teams) guided refinement of the energy management programs at each participating company.

The Focus gave particular attention to messaging and promoting early energy achievements, as these served as motivation for expanding energy management for senior executives and production-line employees alike. EPA guided the corporate energy managers to implement the elements of their energy management systems, from setting goals to creating action plans and communicating success. EPA learned early on that there is great benefit to the industry when energy directors network to share best practices and discuss management strategies. Through ENERGY STAR, EPA facilitated discussions among directors that led to greater dissemination of knowledge throughout the industry.

All of these activities have contributed in some fashion to facilitating the improvement in energy efficiency that is now being observed in the industry.

The first EPI for the automobile assembly industry was released in 2006. Since then, companies participating in the Focus have benchmarked multiple sites. Many companies have also made the EPI an integral part of their corporate energy management programs.

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[3] See *Energy Efficiency Improvement and Cost Saving Opportunities for the Vehicle Assembly Industry* (http://www.energystar.gov/ia/business/industry/LBNL-50939.pdf)

Development of the first auto assembly EPI began more than a decade ago. With genuine effort over time, the companies improved the energy efficiency of their plants using the EPI to gauge energy performance. Communicating with EPA through the Focus, they made it clear that a new version of the EPI based on more recent data was needed to continue to motivate energy improvement at auto plants. EPA agreed, developed a new EPI based on new data, and released it to the industry so further improvement could be achieved.

By updating the automobile assembly EPI and comparing the two versions, we are able to quantify the improvement in the industry and help better understand how the industry has strived to improve energy efficiency. The remainder of this paper describes the data and underlying statistical analysis used to update the ENERGY STAR EPI for automobile assembly plants, how the parameter estimates of the original and updated models have changed over time (in particular, the treatment of climate impacts from plant locations and capacity utilization), and how several measures were computed to illustrate how the distribution of energy efficiency has shifted over time.

3. ENERGY PERFORMANCE INDICATOR

The EPI is a statistical model of plant-level energy use that enables comparison across sites with different levels and types of production-related activities that influence energy use. EPIs are developed for a specific type of manufacturing plant (such as auto assembly or cement). An EPI is designed to enable identification of the “best in class” energy performance for the industry. The EPI assigns a plant a specific energy performance score on a scale of 1 to 100. EPA defines average performance as the 50th percentile, while efficient is in the 75th percentile or higher. This section describes the history of the model development, the underlying data and statistical analysis, and estimates of the shift in the energy intensity distribution over time.

3.1. History of the auto assembly EPI

The first version of the EPI auto assembly model—its background, motivation, data, and results—are described in Boyd (2005). Companies in the Focus volunteered data for the years 1998–2000 to conduct the analysis for the prior version. The development process involved a period of testing and use that led to eventual acceptance of the model by industry energy managers as a useful tool for benchmarking plant performance (Boyd, Dutrow, and Tunnessen, 2008). Based in part on industry’s acceptance, EPA began using the EPI to measure and recognize superior performance, awarding the ENERGY STAR to manufacturing plants in the top quartile of energy efficiency for their industries.[4] The auto industry requested to update the data in the analysis so the EPI would reflect more recent levels of energy efficiency, and agreed to voluntarily provide the necessary proprietary plant data, protected by a nondisclosure agreement with researchers at Duke University, to perform the analysis.[5]

3.2. Statistical modeling of auto assembly plant data

Data on energy use, production, capacity, and vehicle size were received from 33 plants in the United States, representing six companies. Based on the ZIP code location, annual

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[4] Other criteria also apply. See http://www.energystar.gov/index.cfm?c=industry.bus_industry_plants for more information.

[5] 5th Annual Motor Vehicle Assembly ENERGY STAR Focus Meeting, Washington DC, 2006.

heating and cooling degree days (HDD and CDD, respectively) from an EPA ENERGY STAR database were merged with the industry-provided data. Data for three years (2003–2005) were included in the analysis. Since the focus is on the most recent year, 2005, summary statistics for 2005 are shown in Table 1.

For purposes of the model update, the same basic functional form and distributional assumptions for stochastic frontier used in Boyd (2005) were followed. The primary difference was to use annual fixed effects, in the form of year dummy variable for the intercept term for 2003 and 2004, in order for the model to capture time-varying shifts in the frontier from the earlier years relative to the last year, 2005. In development of the previous version of the model, linear and quadratic terms for utilization, HDD, and CDD were tested. Based on t-tests, nonsignificant variables were dropped from the model. A similar procedure was used here resulting in slightly different specifications for the electricity and fuel equations.

Table 1. Summary statistics for 2005.

Variable	Mean	Standard Deviation	Lower Decile	Upper Decile
HDD	4,764	1,532	1,937	7,052
CDD	1,413	507	703	2,999
Wheel Base (inches)	121	16.5	103	157
Production (vehicles per year)[6]	213,128	68,219	142,600	260,760
Capacity (vehicles per year)	223,806	45,271	169,090	256,200
KWH per vehicle	641	210	416	887
MMBTU per vehicle	4.63	2.3	2.52	7.36

The final version of the equation for electricity is

$$E_i / Y_i = A + A_{2003} + A_{2004} + \beta_1 WBASE_i + \beta_2 HDD_i + \beta_3 HDD_i^2 + \beta_4 Util_i + \beta_5 CDD_i + \beta_6 CDD_i^2 + \beta_7 AC_i + u_i - v_i \qquad (1)$$

where

E = total site electricity use in kWh;
Y = number of vehicles produced;
UTIL = plant utilization rate, defined as output/capacity;
HDD = heating degree days for the plant location and year;
CDD = cooling degree days for the plant location and year if the plant is air tempered and zero otherwise;
AC = dummy variable equal to one if the plant is air tempered and zero otherwise
WBASE= wheelbase of the largest vehicle produced; and
β = vector of parameters to be estimated.

[6] Two plants operate as separate entities under one roof. These plants are treated as two separate plants for purposes of measuring production and capacity for this and the previous analysis.

The variable v is statistical random error and is normally distributed as N(0, σ_v^2). The variable u is the inefficiency and is distributed as a gamma distribution. The gamma distribution and density function are

$$f(u) = [\theta^P / \Gamma(P)]e^{-\theta u}u^{P-1},\ u, P, \theta > 0$$
$$F(x) = \int_0^x f(u)du \qquad (2)$$

This distribution provides a more flexible parameterization of the distribution than either exponential or half normal, which are commonly used for estimation of stochastic frontier models.

The estimated parameters of the model are shown in Table 2. All parameters except those for the cooling degree variables are statistically significant at the 99% level or greater in a two-tailed test. The small size of σ_v suggests the model has much less error attributable to random noise and most departures are attributable to the one-sided error term representing inefficiency.

The final version of the equation for fossil fuel is

$$F/Y_i = A + \beta_1 WBASE + \beta_2 Util + \beta_4 HDD + \mathrm{u_i} - \mathrm{v_i} \qquad (3)$$

where

F = total site fossil fuel use in 10^6 Btu.

All other variables are defined, and u and v are distributed as described above. The parameter estimates of the model are shown in Table 3. All parameters are statistically significant at the 95% level in a two-tailed test. The size of σ_v is larger than for the electric equation, which suggests the fuel model is estimated with somewhat more error attributable to random noise and most departures are attributable to inefficiency.

Table 2. Electricity energy model estimates.

Variable	Estimate	Standard Error	t-ratio
Constant	-91.8485	105.3997	-0.871
Y03	23.92846	9.843368	2.431
Y04	10.784	2.545143	4.237
WBASE	2.032419	0.401544	5.062
HDD	163.0618	36.33689	4.487
HDD^2	-15.1721	4.041763	-3.754
UTIL	-112.544	59.12416	-1.904
CDD	-223.899	170.7279	-1.311
CDD^2	86.61689	60.1926	1.439
AC	124.5492	108.496	1.148
Θ	0.00331	0.000819	4.041
P	0.65475	0.157012	4.17
σ_v	0.110233	2.295552	0.048

Table 3. Fuel energy model estimates.

Variable	Estimate	Standard Error	t-ratio
Constant	-0.526	1.40	-0.37
WBASE	0.019	0.008	2.48
UTIL	-0.720	0.62	-1.15
HDD	0.439	0.14	3.07
Θ	0.390	0.18	2.14
P	0.667	0.37	1.81
σ_v	0.676	0.21	3.28

The dummy variables are included to control for common industry effects for each year, presumably shifts that are improvements in average efficiency over time. For electricity, these estimates suggest that frontier use in 2003 and 2004 was higher by 24 and 11 kilowatt-hours (kWh) per vehicle, respectively. While the estimates appear to show a pattern of higher energy use in 2003 relative to 2004, the differences between the two years are not statistically significant. For fuel use these estimates suggest that the frontier energy use in 2003 and 2004 was lower, not higher. These fixed effects were not significant and were dropped from the estimation. The model estimates without the year effects are shown in Table 3.

Since this is intended as an update of the model using prior year data, it is useful to compare the two versions to see how much the coefficients have changed. The model based on the 1998–2000 data will be labeled version one and the model described here as version two. Table 4 compares the estimates of the two electricity models. While the estimates for wheel base and utilization are quite similar, the climate variables appear very different. This is due partly to the correlation between HDD and CDD, and the impact both of these variables have on electricity consumption and the quadratic specification. If we compute the slope of CDD evaluated at the median of the data, the impact is 0.018 kWh per vehicle for every increase in degree day. The slope increases as CDD increases. Table 5 compares the estimates of the two fuel models. The utilization coefficients show the most change. If we look at the slope of the curve evaluated at 100% utilization, we find that every 1% change in utilization decreases energy per vehicle by 0.02 Million British thermal units (MMBtu) in version one and 0.007 MMBtu in version two. In version two, the linear form with the much lower slope fits better than the quadratic. This suggests that changes in energy practice have reduced the impact of utilization on energy use per unit. This may result from changes in shutdown procedures and energy management.

3.3. Estimating the shift in the distribution of energy intensity and its implications for energy efficiency and CO_2 emission reductions

The availability of data from the prior years 1998–2000 provides another way to measure possible shifts in the frontier. Two measures of efficiency for each plant in the dataset used to develop version one (i.e., the 1998–2000 data) are computed using both version one and version two. If the frontier has unambiguously shifted, then the best practice energy use will be smaller and the measure of inefficiency will be larger using the more recent version of the model. The average changes in the frontier for both energy types are shown in Table 6. The frontier has improved electricity use by 2%, while fuel use has improved for these leading plants by 12%. If we multiply the average change in energy use by the appropriate

CO_2 emission factor and the total production of the plants in this study, we get an estimate of the carbon emission change that has resulted from the improvement in industry best practices and technology. The total CO_2 implication of the change in the frontier is 696 million pounds of CO_2.

The model comparison can also provide useful information on whether industry is keeping pace with these changes, catching up, or falling behind by comparing the estimated parameters of the gamma distributed efficiency term. Table 7 translates the parameters of the gamma distribution into a more familiar mean and variance. For electricity use we see that the mean inefficiency (amount by which the typical plant exceeded best practice) rose slightly and the variance declined. The difference in the mean is very small but the reduction in the variance suggests the range of performance has declined.

Table 4. Comparison of electricity energy model estimates.

	Version One		Version Two	
Variable	Estimate	Standard Error	Estimate	Standard Error
Constant	369.39	86.89	-91.84	105.39
Y03			23.92	9.84
Y04			10.78	2.54
WBASE	2.77	0.01	2.03	0.40
HDD	–48.41	26.26	163.06	36.33
HDD^2	4.79	2.60	-15.17	4.04
UTIL	–138.61	34.31	-112.54	59.12
CDD	–59.32	5.23	-223.89	170.72
CDD^2	41.91	0.99	86.61	60.19
AC			124.54	108.49
Θ	0.0028	0.00006	0.00331	0.000819
P	0.5424	0.116	0.65475	0.157
σ_v	0.000004	0.00048	0.110233	2.295

Table 5. Fuel energy model estimates.

	Version One		Version Two	
Variable	Estimate	Standard Error	Estimate	Standard Error
Constant	3.827	0.837	-0.526	1.40
WBASE	0.00322	0.000061	0.019	0.008
UTIL	–6.788	1.280	-0.720	0.62
$UTIL^2$	2.399	0.622		
HDD	–0.545	0.121	0.439	0.14
HDD^2	0.11	0.00131		
Θ	0.268	0.00694	0.390	0.18
P	0.724	0.144	0.667	0.37
σ_v	0.000701	0.00698	0.676	0.21

Table 6. Average change in frontier energy use (best practice) implied by the difference between version two and version one.

	Electricity (kWh/unit)	Fuel (MMBtu/unit)
Frontier per-unit change	15.5	0.66
% frontier change	2%	12%
Reduction in frontier CO_2 emissions (10^6 lbs)	164	531

A more dramatic story emerges for fuel use. Mean inefficiency is 1.0 MMBtu per vehicle lower and the variance is reduced by more than half. We can compute the change in CO_2 in the same manner as the change in the frontier practices. The total CO_2 implication of the change in efficiency is slightly larger than the change in the frontier, 766 vs. 696 million pounds of CO_2. The total is 1,462 million pounds of CO_2.

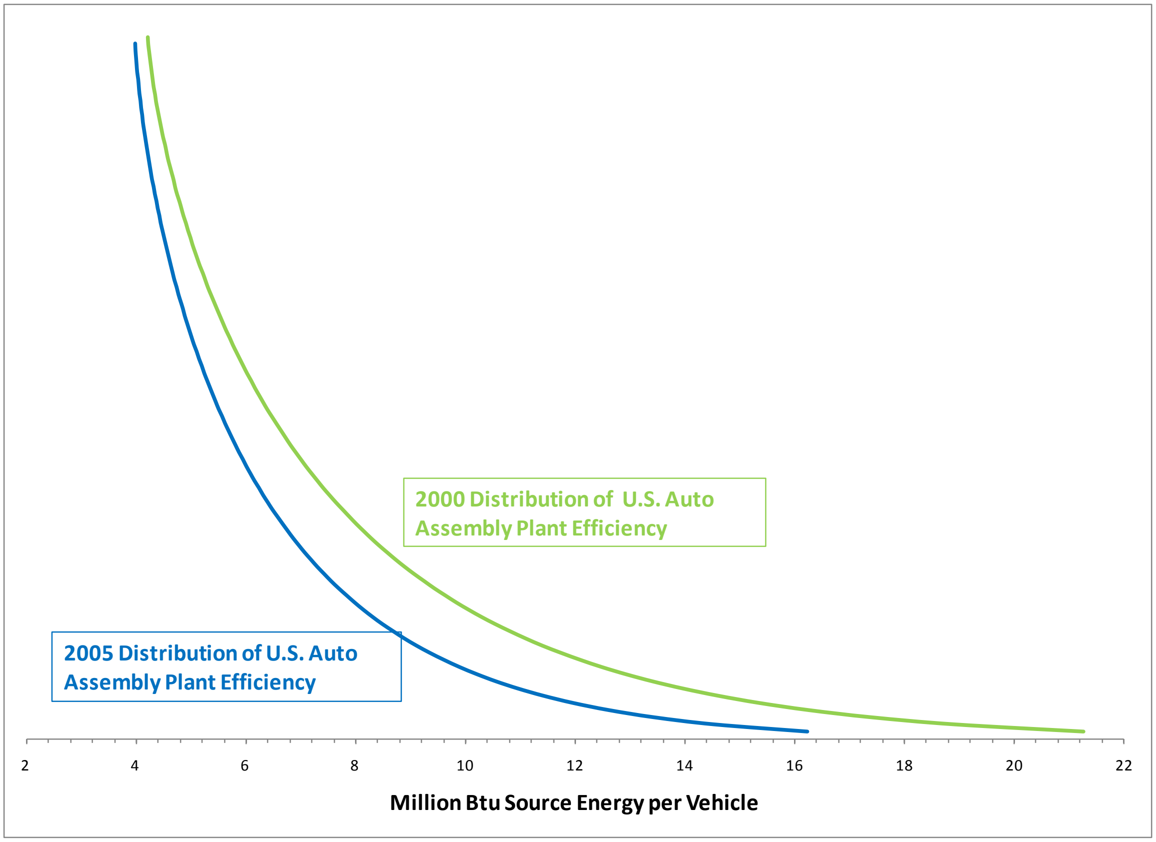
Table 7. Average change in inefficiency (best practice) implied by the difference between version two and version one.

	Electric (kWh/unit)	Fuel (MMBtu/unit)
Mean version one	194	2.70
Variance version one	69,184	10.1
Mean version two	198	1.71
Variance version two	59,761	4.4
Reduction in CO_2 emissions due to efficiency (10^6 lbs)	42	809

Another way to see how the distribution of energy intensity has changed over time is to use each model to simulate the range of performance for a hypothetical plant. Figure 1 shows how each model would predict the range of performance, normalized for a hypothetical plant.[7] When we compare version one of the EPI, with a base year of 2000, to the updated model, with the base year of 2005, we see that the simulated distribution has shifted to the left. The best practice (frontier) segment, represented by the right-most portion of each curve, has shifted less than the middle of the distribution. This shows that while the best plants have only improved slightly, the new distribution is steeper and has a shorter tail. This implies that the "pack" has made progress in catching up with the industry leaders.

[7] This hypothetical plant produces 222,000 vehicles with a 120-inch wheel base per year, at a line speed of 65 vehicles per hour, in a climate that has an average of 3,457 HDD and 1,417 CDD per year.

Figure 1. Comparison of the distribution of energy intensity.



4. CONCLUSION

The ENERGY STAR program's goal for industry is to improve energy efficiency through better energy management. The policy approach selected by EPA has enabled the auto assembly industry to improve its energy efficiency, positively affecting CO_2 emissions as well. By addressing several barriers to energy efficiency in the industry, ENERGY STAR has empowered the industry to overcome informational limitations. EPA recognizes that other forces impact energy efficiency in the industrial marketplace, and is pleased to be part of this improvement.

One important component of this policy approach is the quantification of energy efficiency at the whole-plant level. This paper describes data and analysis to update the ENERGY STAR auto assembly plant EPI to a base year of 2005. Periodic update of any manufacturing plant EPI is needed to provide a useful energy management tool if the industry's performance is changing over time. The update process provides an estimate of how much the industry has improved, in aggregate or on average. There are two sources of improvement: changes in the industry energy frontier, i.e., best practices and technology; and changes in efficiency, i.e., whether plants are catching up or falling behind. Results suggest that efficiency changes have slightly outpaced frontier changes. This effect primarily manifests itself in improvements in fossil fuel use; changes in efficiency of electricity use have been negligible. The combined effect when evaluated against the 7-million-plus vehicles produced in 2005 by the plants in our study implies a reduction of 1,462 million pounds of CO_2 attributable to changes in observed industry energy efficiency practices.

The auto assembly industry is the first industry for which EPA has created an EPI, and the first to have its baseline updated. EPI tools exist or are under development for more than 20 other industries or industry segments, and the list is growing. Updates for existing EPI tools in cement manufacturing and wet corn refining are underway. Development of these tools enables companies to assess their performance against their industry peers, and provides EPA and the public a more nuanced examination of how energy use is changing in these industries as well.

Whole-plant benchmarking can motivate industry action to improve a plant's energy performance, as demonstrated by the shift in energy performance for the entire auto industry and by the auto industry's interest in achieving positive recognition from ENERGY STAR for top energy performance in the industry. EPA will continue to work with industries to help them improve energy performance through use of this unique approach to environmental protection.

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