Projected Impact of Industrial Assessment Center Program Recommendations on U.S. Manufacturing Energy Consumption

Ahmed Alghandoor and Patrick Phelan, Arizona State University,
Department of Mechanical & Aerospace Engineering
Rene Villalobos, Arizona State University, Department of Industrial Engineering

ABSTRACT

A model based on multivariate regression analysis to model the historical behavior of U.S. manufacturing energy consumption is presented. The model relates the energy consumption to important factors such as energy prices, structural shift, etc., that affect the energy consumption. The model has the advantages of being simple and able to incorporate the effect of energy measures on energy consumption. The energy savings resulting from Industrial Assessment Center (IAC) program recommendations are incorporated into the model to project the impact of IAC energy conservation recommendations on future U.S. manufacturing energy consumption. This projection assumes that these recommendations are adopted gradually over all small-to-medium U.S. manufacturing plants. The results include the projected energy consumption with and without the impact of IAC recommendations; this will give more insight on the impact of the IAC program in future U.S. manufacturing energy consumption. The results shown that the energy consumption of the U.S. manufacturing sector would increase by 10.5% from 2005 to 2015, but if the IAC recommendations are implemented on a gradual basis to all small to medium size plants, the energy consumption is forecasted to rise by only 7.8%.

Introduction

Improving energy efficiency and environmental sustainability is one of the main goals of all nations, especially with the increasing price of energy, possible shortages in energy supply, and the increasing demand of this valuable resource.

Performing energy conservation assessments can contribute largely to improve energy efficiency and environmental performance. For this reason, the United States Department of Energy, Industrial Technology Program, USDOE ITP, is currently funding 26 Industrial Assessment Centers (IAC) throughout the United States to perform energy assessments to contribute to the achievement of this goal. The IAC's are located at accredited engineering schools at universities throughout the USA. The focus of this program is to help industry in reducing energy consumption, improving productivity, and minimizing waste. The assessments are made by teams consisting of faculty and students. The no-cost assessments are performed, mainly, in small- and medium-sized facilities lying within the Standard Industrial Classification code (SIC) of 20 to 39. Normally these assessments consist of a one-day site visit, provided that the facility has annual sales under $100 million, has 500 or less employees, has a total energy bill less than $2 M/yr, has no designated energy manager, and is located within 150 miles from an IAC school.

This program has succeeded in saving the visited industries a significant amount of energy, and hence money, with a short payback period; Table 1 summarizes the average statistics associated with this program from 1997 to 2001 (per facility visited). Although the assessments greatly impact the visited facility, as pointed out by several papers (Gopalakrishnan, Plummer & Iskander 2003; Heffington & Eggebrecht 2003; Office of Industrial Technology 2005; Papadaratsaki, Kasten & Muller 2003), the facilities visited from 1982 to 2003 represented only 7.2% of the total energy[1]used by the U.S. manufacturing sector in 1998, the most recent year for which data for U.S. manufacturing are available. Therefore, the authors feel that the work achieved by IAC centers should be expanded to include as many small and medium US manufacturing plants as possible.

The main aim of this paper is to address the following question: what is the impact of the IAC's energy conservation recommendations on future USA manufacturing sector energy use *if* such recommendations are adopted gradually for all small and medium plants during the near future? The recommendations involving productivity improvement and waste minimization have not been considered in this paper, even though the effective energy savings from productivity improvements can be substantial (Papadaratsaki, Kasten & Muller 2003).

Table 1. Average per Client Statistics Summary of IAC's since 1997

Year	1997	1998	1999	2000	2001
Number of clients	720	723	734	700	588
Energy consumption (MMBtu)	82,995	109,053	104,678	119,143	159,653
Total recommended energy savings (MMBtu)	5,990	6,176	8,797	8,700	15,933
Implemented energy savings (MMBtu)	2,640	2,229	3,078	2,642	4,543
Total recommended energy cost savings ($)	31,590	35,679	43,245	50,702	103,865
Implemented energy cost savings ($)	13,896	11,573	11,958	13,581	25,422
Ratio of total recommended energy savings to energy consumption (%)	7.2	5.7	8.4	7.3	10.0
Total recommended productivity and waste cost savings ($)	166,346	153,077	140,183	146,885	48,492
Total recommended implementation cost ($)	139,673	198,877	203,937	232,829	249,010
Simple payback period (total recommended implementation cost/total recommended cost savings) (YR)	0.7	0.7	0.6	0.7	0.5

Source: Office of Industrial Technologies 2005

Since the visited plant may not implement all the suggested recommendations, we need to distinguish between the implemented and unimplemented recommendations. The *total* term in Table 1 includes the implemented and non implemented recommendations.

[1] In this paper, energy consumption includes the ***purchased*** electricity and fuel that are used to produce heat, power and to generate electricity. The electricity is evaluated as source energy and it assumes that it takes 10,250 Btu's of thermal energy to yield 1 kWh of electricity.

Methodology

The following steps summarize the methodology adopted in this paper:

Step 1: Develop a Model for the USA Manufacturing Energy Consumption Based on Historical Variables Data Using Multivariate Regression Analysis

Regression analysis is widely used to analyze multifactor data through building a model equation that relates the response (variable of interest) to a set of predictor variables. The starting point of this analysis is to define the response variable and the important factors (predictor variables) that are important to explain the response's behavior. In our analysis, energy consumption is the response variable. The energy consumption data was retrieved from the Energy Information Administration online database (MECS 1998, MECS 2002) and have been modified to convert the site electricity consumption into source energy. The following predictor variables are considered for further investigation: real-value-added output (*VT*), real-value-added output ratio (V_I/V_N), electricity and natural gas prices (*E$, and N$*), and the number of employees (*EM*). *Real-value-added output (VT)* represents the monetary value added by each plant to the produced goods. Since there is a broad variety of products manufactured at manufacturing plants, using the monetary metrics rather than the physical metrics makes the analysis simpler. Production level was included in the form of the real value added since each produced good requires energy to be manufactured.

The historical value added of the manufacturing sector is obtained from the U.S. Department of Commerce (U.S. Department of Commerce 1981, 1983, 1984, 1985, 1986, 1987, 1988, 1990, 1991, 1992, 1995, 1996, 1998). In order to convert the value added into real value added, value added has been deflated to 1987 dollars using the chain-weighted price index obtained from the Bureau of Economic Analysis online database (U.S. Department of commerce 2004). The energy consumption is expected to rise when the real-value-added output increases, and *vice versa*. *Real-value-added output ratio* (V_I/V_N) is included in the model since at a given level of output, as the demand changes towards more energy-intensive industries, energy consumption rises. In contrast, if there is a shift towards less energy-intensive industries, energy consumption decreases. To incorporate this effect in the regression model, the aggregate level is disaggregated into two clusters: intensive (I) and non intensive (N) clusters, and the real value-added output ratio between them is included as a variable in the regression model. The intensive cluster includes: paper and allied products, chemical and allied products, petroleum and coal products, stone, clay, and glass products, and primary metal industries, while the non intensive cluster includes the other industries. The energy consumption is expected to rise when this ratio increases, and *vice versa*. *Energy prices* are included in the model since if the price of energy increases, the industry is expected to respond by using energy in a more efficient manner, while if energy is inexpensive, there is probably less consideration for energy consumption. This factor, however, may not in fact affect energy consumption, since the products have to be produced and in most industries, especially non-energy-intensive ones, the fractional cost of energy out of the total cost input is relatively small. The costs of electricity (*E$*) and natural gas (*N$*) are included in the models since electricity and natural gas represent more than 79% of total offsite energy consumption in the U.S. (EIA 2001a). The energy consumption is expected to decrease when the energy prices increase. The energy prices are obtained from the Energy Information Administration database (EIA 2001b, 2001c). The *number of employees* (*EM*) variable can be viewed in two ways. To some degree, technology has replaced human labor in all industries, and therefore energy consumption may increase due to the increased energy consumption of machines, as opposed to human labor. On the other hand, each employee requires additional energy in the form of conditioned air, hot water, lighting, etc., and thus energy consumption could decrease as machines replace human labor. In the first case, the energy consumption is expected to increase when the number of employees decreases, but it should decrease when the number of employees decreases for the second case. The historical data for this variable is obtained from the U.S. Department of Commerce (U.S. Department of Commerce 1981, 1983, 1984, 1985, 1986, 1987, 1988, 1990, 1991, 1992, 1995, 1996, 1998).

Historical data from the year 1977 to 1998[2] are constructed to build the multivariate regression model for U.S. manufacturing energy consumption, and the Minitab software is applied to quantify and test the significance of the variables shown in Eq. (1):

$$(E)_t = \mu_0 + \mu_{I,N}\left(\frac{V_I}{V_N}\right)_t + \mu_1 VT + \mu_2 (E\$)_t + \mu_3 (N\$)_t + \mu_4 (EM)_t + \varepsilon_t \quad (1)$$

where $(E)_t$ is the energy consumption in year t, μ_0 the regression model intercept, $\mu_{I,N}$ the regression model coefficient of the real-value-added output ratio variable between intensive (I) and non intensive (N) clusters, (V_I/V_N) the real-value-added output ratio variable between intensive and non intensive clusters, μ_j the regression model coefficient of the jth variable (j =1, 2, 3, and 4 for real-value-added output (VT), electricity cost ($E\$$), natural gas cost ($N\$$), and the number of employees (EM) variables respectively), t the year, and ε_t the difference between the actual energy consumption and the predicted energy consumption (i.e., the residual).

Step 2: Use the Time Series Forecasting Technique to Forecast Each Variable During the Future Study Period

In order to use the developed regression model, Eq. 1, to forecast energy consumption, predicted future data for the independent variables are required for the regression model. These data can be generated using a forecasting tool based on the time series technique. Graphical analysis of real-value-added output, real-value-added output ratio, electricity cost, natural gas cost and number of employees data show that there is an evident long-run trend; double exponential smoothing forecasting time series method is recommended in such situations (Claycombe & Sullivan 1977). The double exponential forecasting equation is as follows (Claycombe & Sullivan 1977; Makridakis, Wheelwright & McGee 1983):

$$F_{t+m} = a_t + b_t m \quad (2)$$

where F_{t+m} is the forecast after m number of periods ahead, m the number of periods ahead to be forecast, a_t the forecasted intercept, and b_t the forecasted slope.

The intercept a_t and the slope b_t are estimated as follows:

$$a_t = 2S_t^{'} - S_t^{''} \quad (3)$$

$$b_t = \frac{\alpha}{1-\alpha}(S_t^{'} - S_t^{''}) \quad (4)$$

$$0 \le \alpha < 1 \quad (5)$$

[2] The complete data set is available from the authors.

where α is the smoothing constant used to weight current and past observations, and $S_t^{'}$ and $S_t^{''}$ the single and double exponential smoothing values respectively for time *t*. These $S_t^{'}$ and $S_t^{''}$ values are calculated as follows:

$$S_t^{'} = \alpha X_t + (1-\alpha)S_{t-1}^{'} \tag{6}$$

$$S_t^{''} = \alpha S_t^{'} + (1-\alpha)S_{t-1}^{''} \tag{7}$$

The higher α is, the more weight is given to the most recent observations. Before running the analysis, α should be selected. The forecasts for each variable are calculated using different α's, and the α that gives a small mean square error for the forecasts and shows an expected future growth is chosen. In addition to choosing appropriate α, values of $S_{t-1}^{'}$ and $S_{t-1}^{''}$ must be assumed when $t = 1$ since no such values exist for this period. This problem can be solved by assuming that both values are equal to the initial historical data since α values for the different variables considered here are larger than zero and the number of data points is more than 20 (Claycombe & Sullivan 1977; Makridakis, Wheelwright & McGee 1983).

Step 3: Use the Data Obtained from Step 2 in the Regression Model Developed in Step 1 to Forecast Us Manufacturing Energy Consumption

Time series forecasts for each of the predictor variables obtained from the second step are used to feed the energy consumption regression model developed in the first step to predict the future energy consumption of the US manufacturing sector.

Step 4: Implement the Savings Resulting from IAC Recommendations into the Model Developed

After implementing the IAC recommendations, the energy consumption should be reduced. The results obtained from the developed model together with the following derivations will be used to quantify these impacts. The energy savings $(ES)_t$ resulting from IAC recommendations for period *t* is given by Equation 8.

$$(ES)_t = IACSF \times CP \times \left[\left(\frac{E_0 \times t}{T} \right) + \left(E_t - E_0 \right) \right] \tag{8}$$

where *IACSF* is the Industrial Assessment Center Saving Factor of the potential suggested recommendations[3], *CP* the coverage percentage of small to medium industries within all US manufacturing, E_0 the energy consumption of the manufacturing sector at the base year 0 (here is 2005), E_t the predicted energy consumption of the manufacturing sector obtained from the developed model for period *t*, and *T* the study period length (here is 10, from 2005 to 2015). This analysis assumes that a uniform portion of the base energy consumption for each year converts into the proposed IAC recommendations and also that the increase in energy consumption over the base year would implement these recommendations as well.

Fortunately, many of the opportunities for increasing energy efficiency in the small and medium manufacturing facilities are in areas of compressed air systems, boiler and steam

[3] Potential recommendations exclude the impractical recommendations and the recommendations that cause any problem to production issues, i.e., the potential recommendations represent those recommendations that can be viably implemented without causing any problem to the plant.

system, electrical motors, heating, ventilation and air conditioning systems, insulation, lighting, waste heat recovery, and other unique recommendations that do not fall into any of the preceding groups. Improving the efficiency of these systems is more straightforward and replicable than at large process intensive plants (Shipley & Elliott 2001). The *IACSF* from these recommendations can be estimated as follows.

The total average energy recommended savings per client (total energy recommended savings divided by energy consumption) for these groups has been calculated from the historical IAC database since 1982 (IAC current) and found to be 7.42%. However, this number represents both implemented and non implemented recommendations. From the IAC database, it has been estimated that 42%, in terms of energy associated with the recommendations, of recommended energy savings is implemented. The analysis carried out by (Woodruff et al. 1996), in terms of recommendation numbers, showed that 48% of the rejected recommendations is due to financial reasons although the recommendations are viable, 21% of the rejected recommendations are due to production-related concerns, 25% of the recommendations are rejected because they are either unacceptable or impractical, and 6% of the rejected recommendations are due to other reasons. In order to be conservative, the 52% of the rejected recommendations that are not due to financial reasons (production issues, unacceptable or other reasons) will be separated from the 7.42% total average recommended energy saving ratio. Assuming that the results obtained by (Woodruff et al. 1996) are representative of energy savings associated with the recommendations, we can estimate that 2.24% out of 7.42% is due to impractical recommendations. Therefore, the *IACSF* will be considered as 5.18%. This means that 70% of the total energy saving recommendations (in terms of energy savings) will be assumed to be implemented in future.

Since this program is geared to small and medium plants, the potential IAC recommendations will be projected into only small- to medium-size facilities. As reported by MECS 1998 (MECS 2001), the small to medium plants represent 47% of the total energy use by the manufacturing sector; hence, the *CP* is considered to be 47%.

Energy cost savings for period t, $(ECS)_t$, are estimated as[4]

$$(ECS)_t = 0.55 \times (ES)_t \times E\$ + 0.45 \times (ES)_t \times N\$ \quad (9)$$

using the model's forecasts for electricity and natural gas costs since these two energy sources represent the majority of energy recommendation savings, with the electrical energy contributing 55% of the total energy savings and natural gas contributing 45% of total energy savings. These estimates are obtained by averaging the results from the current IAC database.

Demand savings will result from using a smaller capacity load per unit of time. The demand savings from IAC recommendations can be derived as

$$(EDS)_t = \frac{0.55 \times (ES)_t \times C}{AOH}, \quad (10)$$

where $(EDS)_t$ is the electricity demand savings, *AOH* the annual operating hours, and C the constant to convert the source electricity energy into site electricity energy, C = 0.333. The average annual operating hours are obtained from the IAC database and are estimated to be 5,185 hrs/yr. The annual demand cost savings for period t, $(EDCS)_t$, can be estimated from

$$(EDCS)_t = DC \times (EDS)_t \times 12 \text{ mo yr}^{-1} \quad (11)$$

where *DC* is the demand cost. The average demand cost of the facilities assessed by IAC's during the 2004 year is $7.25/ (KW x mo). This value will be used to estimate the demand cost savings.

[4] One should be careful about the conversion units in running these equations.

Since it is expected that the electricity consumption will decrease if IAC recommendations are adopted, it is assumed the utilities will not have to grow as much every year. The installed capacity savings, $(ICS)_t$, can be estimated as follows:

$$(ICS)_t = (EDS)_t \times ICC \qquad (12)$$

where *ICC* is the installed capacity cost and is assumed to be $1000/kW (Flores et al. 2004).

The IAC recommendations will not only affect the energy consumption but also the environmental impact. As an example, this paper will evaluate the effect of these recommendations on carbon dioxide emissions. The emission of carbon dioxide is estimated as carbon avoided measured in carbon equivalent (CE). The average carbon equivalent is assumed to be 20.7 kg/MMBtu (Office of Industrial Technologies 2005).

Results

Table 2 shows the values of the smoothing constants (α's) used to forecast the different variables established in this study. The regression analysis summary output is shown in Table 3. The natural gas cost variable was found to be insignificant, and hence eliminated from the model. The coefficient of multiple determination, R^2, the adjusted R^2, and the predicted R^2 for this model have high values as indicated by the notes of Table 3; this is a strong indication that the model represents its data behavior acceptably (Montgomery, Peck & Vining, 2001). The model does not have a multicollinearity problem since the Variance Inflation Factor, *VIF*, is less than 10 for all variables (Montgomery, Peck & Vining, 2001). The forecasted variables are shown in Table 4. Implementing these variables into Eq. 13, the predicted energy use is estimated from year 2005 to year 2015 ($T = 10$):

$$(\bar{E})_t = 9{,}599 + 4{,}310(\frac{V_I}{V_N})_t + 0.0059VT - 1{,}171(E\$)_t + 0.20(EM)_t \qquad (13)$$

where $(\bar{E})_t$ is the predicted energy use in for period *t*. Using year 2005 as a base year, the energy savings, energy cost savings, demand savings, demand cost savings, installed capacity cost, and the carbon dioxide emission reduction can be now estimated as described above, and these results are summarized in Table 5. Figure 1 shows the predicted U.S. manufacturing energy consumption with and without the implementation of IAC recommendations.

Table 2. Smoothing Constants (α's) for the Different Variables

	Value added	V_I/V_N	Employee	Electricity cost	Natural Gas
Smoothing Constant	0.25	0.7	0.2	0.2	0.25

Table 3. Regression Summary Outputs for the U.S. Manufacturing Energy Use Model

Variable*	Coefficient**	*P*-value	*VIF*
Intercept (TBtu)	9,599	0.000	
VT(TBtu/M$)	0.0058659	0.000	3.7
$V_{I/N}$	4,310	0.100	8.5
*E$* ($/source MMBtu)	-1171.69	0.000	6.3
EM (thousand persons)	0.20051	0.001	3.4

Note: *: R^2= 99.4%, Adjusted R^2= 99.3%, Predicted R^2= 98.9%.
**: Coefficients are significant at the 0.10 level.

Table 4. Predicted Annual U.S. Manufacturing Sector Energy Consumption, Based on Forecasted Independent Variables and the Regression Model (Equation 13)

Year	Predicted Energy (MMBtu)	VT (M$)	V_I/V_N	N$($/MMBtu)	E$ ($/source MMBtu)	EM (1000)
2005	20,000	2,028,256	0.2127	4.11	4.78	15,566
2006	20,210	2,079,424	0.2076	4.20	4.80	15,359
2007	20,421	2,130,593	0.2024	4.30	4.82	15,152
2008	20,631	2,181,761	0.1973	4.38	4.85	14,945
2009	20,841	2,232,930	0.1922	4.47	4.87	14,737
2010	21,052	2,284,099	0.1870	4.57	4.90	14,530
2011	21,262	2,335,267	0.1819	4.66	4.92	14,323
2012	21,473	2,386,436	0.1768	4.75	4.95	14,115
2013	21,683	2,437,604	0.1716	4.84	4.97	13,908
2014	21,894	2,488,773	0.1665	4.94	5.00	13,701
2015	22,104	2,539,941	0.1614	5.02	5.02	13,493

Figure 1. Projected Energy Consumption of the Entire U.S. Manufacturers with and without the Gradual IAC Recommendations Implementation, Energy Consumption vs. Year

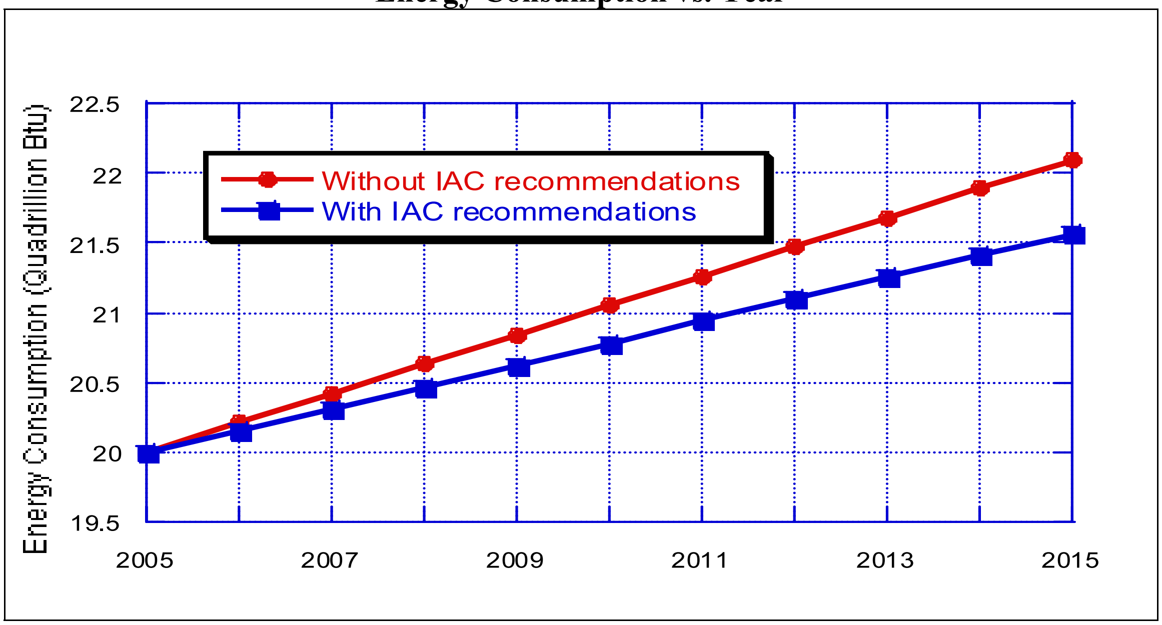

Table 5. Energy Savings and Environmental Impact Results for the Entire U.S. Manufacturing Sector

	Base Year	Forecast									
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Consumption wthout IAC (TriBtu)	20,000	20,210	20,421	20,631	20,841	21,052	21,262	21,473	21,683	21,894	22,104
IAC implementation											
Energy Savings											
Source Energy Savings (TriBtu)		53.86	107.71	161.57	215.43	269.28	323.14	377.00	430.86	484.71	538.57
Energy Cost Saving (M$)		244	494	750	1,011	1,279	1,552	1,831	2,116	2,407	2,703
Demand Saving (1000 KW)		557	1,115	1,672	2,229	2,787	3,344	3,901	4,459	5,016	5,574
Demand Cost Saving (M$)		48	97	145	194	242	291	339	388	436	485
Installed Capacity Savings (M$)		557	1,115	1,672	2,229	2,787	3,344	3,901	4,459	5,016	5,574
Emission											
Carbon Dioxide (1000 metric ton)		1,115	2,230	3,345	4,460	5,575	6,690	7,805	8,920	10,035	11,150

Note: *: Savings are during each time period and are not cumulative.

Discussion

The energy consumption of the entire U.S. manufacturing sector is predicted to increase by 10.5% from 2005 to year 2015 as shown in Table 5 and Figure 1; however, by gradually adopting the IAC recommendations in all small to medium facilities; the energy consumption of the entire U.S. manufacturing is expected to rise by only 7.8% for the same period. Other savings include reduction of electricity demand use and cost, installed capacity savings, and the environmental performance improvement. The preceding savings highlight and emphasize the importance to implement these recommendations at least for small to medium manufacturing plants.

Some suggestions for improving the value of the IAC program including accelerating the implementation rate of the IAC recommendations are given below:

1. The IAC program should concentrate on intensive industries: the potential savings that can be found in the intensive industries are much greater than the non intensive industries.
2. For some facilities, the one-day visit is not enough to evaluate all potential savings that can be achieved; therefore, a multi-day visit is necessary in these situations. As shown by (Heffington & Eggebrecht 2003), the average cost savings increased by 43% for a multi-day visit compared with a single-day visit.
3. Students, in addition to faculty, should be trained to be familiar with the complex processes involved in manufacturing.

Here are some suggestions to accelerate the implementation rate of IAC recommendations:

1. Improve the marketing of the IAC program: Each visit that is done by an IAC team is documented in a database that is publicly accessible at no cost. The driver of the database is the SIC (Standard Industrial Classification system) or NAICS (North American Industrial Classification System) code that is associated with each facility visited. The facilities that are associated with each code are in general similar to each other. Marketing the IAC database will help a facility that has not been visited to check the database to find the possible potential areas of savings that have been done for a sister facility that has similar processes.
2. The government can play an active role for encouraging facilities to adopt energy efficient technologies by giving tax credits and incentives to facilities that use energy-efficient technologies, and penalize those that do not use energy efficient technologies.

Conclusions

Some conclusions that are drawn from this study are summarized below:

1. The present IAC program has already yielded (in 2001) a yearly recommended energy savings of 15,993 MMBtu per client, representing cost savings of $103,865. Expanding the IAC program to all small- and medium-sized US industries will lead to a yearly energy savings of 538.57 Tri Btu by 2015 of total U.S. manufacturing consumption, or corresponding cost savings of 2,703 million dollars.
2. The energy consumption of U.S. manufacturing sector is projected to increase by 10.5% by 2015, but if the IAC recommendations are implemented on a gradual basis to all small to medium size plants; the U.S. manufacturing sector is forecasted to rise by only 7.8% by 2015.
3. Expanding the IAC program to all small- and medium-sized US industries will result in a yearly reduction in carbon dioxide emissions of 11,150 thousands metric tons by 2015.

It should be noted here that the IAC program is only one source of many energy savings measures available to facilities that are willing to reduce their energy use. The Department Of Energy (DOE) offers online tools, case studies, training manuals, and software packages that are available to any facility.

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