Incorporating the Productivity Benefits into the Assessment of Cost-Effective Energy Savings Potential Using Conservation Supply Curves

John A. "Skip" Laitner, U.S. Environmental Protection Agency
Michael B. Ruth, Lawrence Berkeley Laboratory
Ernst Worrell, Lawrence Berkeley Laboratory

ABSTRACT

We review the relationship between energy efficiency improvement measures and productivity in industry. We propose a method to include productivity benefits in the economic assessment of the potential for energy efficiency improvement. The paper explores the implications of how this change in perspective might affect the evaluation of energy-efficient technologies for a study of the iron and steel industry in the U.S. It is found that including productivity benefits explicitly in the modeling parameters would double the cost-effective potential for energy efficiency improvement, compared to an analysis excluding those benefits. We provide suggestions for future research for this important area.

Introduction

Research and development efforts across all industries are driven by the goal of improving the productivity of industrial processes. Improvements can come in a variety of ways, including lower capital costs and operating costs, increased yields, and reductions in resource and energy use. Any industrial technology development will incorporate one or more of these improvements. Some innovations may primarily be aimed at one goal, but also generally include beneficial impacts on other impacts of a production process. Energy-efficient technologies often include these "additional" benefits. Certain technologies that are identified as being "energy-efficient" because they reduce the use of energy will bring a number of additional enhancements to the production process. These improvements are collectively referred to as "productivity benefits" because in addition to reducing energy, they all increase the productivity of the firm[1]. On the other hand, measures or technologies implemented for other reasons than energy efficiency may well result in additional energy savings. Understanding the productivity benefits and properly incorporating them into cost analyses is important because these improvements can significantly change the cost assessment of the technology and result in a more favorable evaluation. At the project level, the effect of productivity benefits on cost assessments could determine whether or not a project is undertaken. From a macro-perspective, the evaluation of productivity benefits will influence the assessment of total energy-efficiency potential. Industry and sectoral studies often do not include an evaluation of the productivity benefits in assessments of the potential for energy-efficiency improvement.

This paper focuses on the role of productivity benefits in assessing total energy-efficiency potential across an entire industry. The cost-effective potential can be influenced by productivity benefits. Still, productivity benefits are often not quantified or included in most studies of energy-efficiency potential. In general, this omission of productivity benefits

[1] Other authors have referred to these as 'non-energy benefits' or NEBs.

results in an underestimation of cost-effective savings potential. This paper proposes a methodology using conservation supply curves to quantify productivity benefits and incorporate them into energy-efficiency analysis.

Overview of Current Approaches

Productivity benefits comprise a wide range of potential positive effects from energy-efficiency projects. Case studies of efficiency projects across industry have shown a wide range of productivity benefits. These can be grouped into several major categories, which are listed in Table 1 with examples of each category. Table 1 also includes some general comments about how each category of benefits might be quantified and how difficult it might be.

Table 1. Categories of Productivity Benefits

Benefit Category	Examples	Comments
Production Improvements	Increased yield of product, shorter processing cycles, improved quality	Because these are direct impacts on production, their impact can be directly quantified relative to output and production costs.
Operating and Maintenance Savings	Lower O&M costs, reduced wear and tear on equipment, increased reliability	Easily measured as changes in O&M expenses, reduced stoppages, reduced replacement of equipment or components. Determining financial impacts should be straightforward.
Working Environment	Safer conditions, reduced noise, improved lighting, improved air quality, improved temperature control	Less tangible and affect production indirectly so they will be harder to quantify and monetize. Could be improvements in lighting & HVAC expenses.
Waste Reduction	Reduced wastes of product, water, and hazardous materials, reduced raw materials use, effective reutilization of waste heat	Could be evaluated as lower expenditures on raw materials and energy or on the handling/treatment of wastes.
Emissions Reduction	Reduced emissions of dust and criteria pollutants, cost savings from avoided mitigation expenses or fines	These benefits will be directly quantifiable for pollutants and regions where emissions controls or permit trading exists. Otherwise, assumptions about externality costs are required

Much of the information on productivity benefits of energy conservation projects comes from two potential sources: articles on projects from trade literature, and case studies on groups of demonstration projects or government-funded projects. Pye and McKane (1999) analyzed a set of projects undertaken through the Department of Energy's Motor Challenge Program to explore how energy efficiency projects increase shareholder value. They found that new motors led to better operations of entire systems, reducing wear and tear and extending the lifetime of system components. The reduced capital expenditures and labor costs that resulted were larger than the energy savings in every case they analyzed. Lilly and

Pearson (1999) analyzed another set of industrial projects[2] where the energy conservation components added through the project helped to "streamline" the production process, leading to lower maintenance costs and replacement costs of related components. For a cement plant they analyzed, an efficient milling system led to more uniform raw material, which allowed the kiln to operate at lower temperatures with increased stability. This led to decreased emissions of SO_2 and NO_x, the former of which is regulated in the region where the plant operates, so fines were avoided. Finally, Finman and Laitner (2001) reviewed 77 industrial energy efficiency projects and found that the payback fell from 4.3 years with energy only savings included in the analysis to 1.9 years when all energy and non-energy benefits were included in the assessment.

The findings of these studies should help bolster the role of productivity benefits in promoting industrial energy efficiency projects. Ingram (1995) points out that early DSM projects presented to industry intentionally avoided addressing productivity benefits and instead focused on maintaining the same processes and changing only existing equipment – e.g. lights and motors. The reasons for this focus were that production changes contained considerable risk for the investor. It is now clear that even without making process changes, productivity benefits can be reaped from energy efficiency investments.

While the case for productivity benefits is being made at the project level, there is still little incorporation of this information into sector- or country-wide analyses or into the engineering-economic models that are used to support these analyses. One problem is that these models often do not contain explicit information on specific technologies. Two models used in many studies of U.S. energy forecasts are the Long-range Industrial Energy Forecasting (LIEF) model and the National Energy Modeling System (NEMS), neither of which includes specific equipment information. Another modeling framework is found in the ISTUM/ITEMS class of models, which have been used for national studies in the U.S. and Canada. The ITEMS/ISTUM models use a detailed breakdown of industrial processes and allow for technology choice at each step. The technology choice methodology is based on life-cycle costs of the various options. This framework would allow for productivity benefits to be included in the cost calculations, although this is not part of the model currently. Various (international) models do incorporate detailed information on individual technologies to assess the future potential for energy efficiency improvement and CO_2 emission reduction. The MARKAL-model is used mainly in IEA countries by many institutes. Although the model can handle a large number of technologies, the size of the technology database varies by institute and country.

In this section we have discussed several examples of productivity benefits associated with energy efficiency investments, but observed that few sectoral analyses or models are designed to include these impacts. As awareness of and knowledge about productivity benefits increases through analysis at the project level, it will become impossible to ignore these benefits at the level of sector- or industry-wide analysis. With the deregulation of the electricity sector, utility sponsored energy-efficiency programs are in transition, and perhaps will disappear. At the same time, this deregulation could lead to lower electricity prices, removing an incentive for efficiency. In this climate, productivity benefits could become the driving force behind efficiency projects and programs, a path suggested by a recent report on California's energy efficiency programs (Bernstein et al. 2000). Analysts need to better

[2] These projects were done through the Energy Savings Plan (ESP) funded by the Bonneville Power Association and Seattle City Light.

understand and include these benefits in order to make accurate forecasts of energy trends. The next section introduces a methodology for incorporating productivity benefits in assessments of energy efficiency potential.

Methodology

A framework for evaluating the productivity benefits of energy efficiency technologies is laid out in the steps below. In order to incorporate these into an economic analysis, these impacts then need to be translated into economic terms wherever possible. This framework is useful for making the cost calculations and it makes the evaluation process transparent for the analyst.

(1) **Identify and describe the productivity benefits associated with a given measure.** This involves listing all the significant impacts of a measure aside from energy savings.

(2) **Quantify these impacts as much as possible.** Here the benefits identified above should be quantified in the most direct terms possible. For example, if one benefit is the extended lifetime of electrodes in electric steelmaking, give the change in lifetime or the reduced electrode consumption per tonne of steel. At this point, a benefit may be deemed "non-quantifiable". For example, adopting a technology may enhance a firm's reputation as an innovator and leader, but this is too intangible to quantify.

(3) **Identify all the assumptions needed to translate the benefits into cost impacts.** The quantities identified above should be direct measures of benefits, but these may not be directly applicable to the production costs of the firm. Making this connection to production costs will require certain assumptions or intermediate values.

(4) **Calculate cost impacts of productivity benefits.** Relying on the assumptions listed in the above step, the magnitude of the productivity benefits can be calculated in cost terms.

By following the framework detailed above, the cost evaluation of productivity benefits is formalized and transparent. Since the evaluation of productivity benefits is not always unambiguous, the transparency of this evaluation framework is important both to give credibility to the calculation and to provide flexibility to a user looking to apply productivity benefits in another scenario. Once productivity benefits have been evaluated in cost terms, an effective way of incorporating them into an energy scenario analysis is by using bottom-up energy conservation supply curves (CSCs). In these curves, the amount of energy conserved is plotted against the cost of attaining this conservation, with costs expressed on a per energy unit basis. From another perspective, the CSC shows how much energy conservation would be 'supplied' under a given energy price. The term "bottom-up" is used to describe CSCs that are constructed starting from technology data and cost data for each energy-conserving technology or measure. For each measure, total conservation potential and the costs of conserving energy (CCE) can be determined from engineering principles. The CCE of a particular option is calculated as:

$$CCE = \frac{I \cdot q + M}{S} \qquad \text{where:} \qquad q = \frac{d}{(1-(1+d)^{-n})}$$

CCE = Cost of Conserved Energy for the energy efficiency measure, in $/GJ
I = Capital cost ($)
q = Capital recovery factor
M = Annual change in O&M costs ($)
S = Annual energy savings (GJ)
d = discount rate
n = lifetime of the conservation measure (years)

The CCE represents the sum of the annualized capital costs and the incremental operating and maintenance costs, divided by the annual energy savings. By expressing the CCE on a per-energy-unit basis, it can be compared to the energy price. If the CCE of a given investment at a given discount rate is below the energy price, it is cheaper to make the investment in the energy-efficient technology and conserve energy than it would be to purchase the energy. To construct a CSC, CCEs can be calculated for each energy conservation measure and then ranked in order of increasing CCE. These can be plotted consecutively with cumulative energy savings along the x-axis and CCE along the y-axis. The point at which the curve crosses the price of energy gives the cost-effective energy savings potential. Accounting for productivity benefits will offset some of the annual costs of an energy efficiency measure, thereby lowering the CCE. Adjusting the CCE calculation to account for productivity benefits would look like this:

$$CCE = \frac{I \cdot q + M - B}{S}$$

B = annual total of productivity benefits ($)

Once the productivity benefits have been included in the CCE, some measures will be more cost-effective and the order of the measures in the CSC may be different from when no benefits were included. These changes will effect the CSC in two ways: there will be an overall downward shift in the curve and the shape of the curve may change. The total technical potential for energy conservation will not change, but more measures may now have a CCE that falls below the threshold of energy price, so the cost-effective savings potential may be larger. In the next section data from the iron and steel industry is used to construct conservation supply curves that demonstrate the importance of productivity benefits.

Productivity Benefits in Iron and Steel

A recent Lawrence Berkeley National Laboratory report (Worrell et al. 1999) presents an opportunity for looking at productivity benefits using conservation supply curves. This study constructed energy conservation supply curves for the entire U.S. iron and steel industry. Forty-seven commercially available energy efficiency measures are identified: 26 of these are specific to integrated steelmaking, 11 options pertain to electric steelmaking, and 10 measures apply to both integrated and electric processes. These efficiency measures are listed in Table 2. The energy savings of individual measures have been adjusted to reflect savings captured by competing energy efficiency measures. This has been done by assuming a lower market penetration rate, or on the basis of cost-effectiveness, where the most cost-effective measure is implemented first, unless other information is available on the preferred implementation order.

Table 2. Energy Efficiency Measures in the U.S. Iron and Steel Industry

Overall Measures (measures apply to both integrated and secondary plants unless otherwise specified)	
Preventative maintenance	
Energy monitoring and management systems	
Variable speed drives for flue gas control, pumps, and fans (integrated only)	
Cogeneration (integrated only)	
Integrated Steel Making Measures	**Secondary Steel Making Measures**
Iron Ore Preparation (Sintermaking)	*Electric Arc Furnace*
Sinter plant heat recovery	Improved process control (neural networks)
Use of waste fuels in the sinter plant	Flue gas monitoring and control
Reduction of air leakage	Transformer efficiency measures
Increasing bed depth	Bottom stirring/gas injection
Improved process control	Foamy slag practices
Coke Making	Oxy-fuel burners/lancing
Coal moisture control	Eccentric bottom tapping (EBT)
Programmed heating	Direct current (DC) arc furnaces
Variable speed drive on coke oven gas compressors	*Scrap preheating*
Coke dry quenching	Consteel process
Iron Making – Blast Furnace	Fuchs shaft furnace
Pulverized coal injection (medium and high levels)	Twin shell DC arc furnace
Injection of natural gas	
Top pressure recovery turbines (wet type)	
Recovery of blast furnace gas	
Hot blast stove automation	
Recuperator on the hot blast stove	
Improved blast furnace control	
Steel Making - Basic Oxygen Furnace	
BOF gas & sensible heat recovery (suppressed combustion)	
Variable speed drive on ventilation fans	
Casting and Rolling (measures apply to integrated and secondary plants unless otherwise specified)	
Rolling	*Casting*
Hot charging (integrated only)	Adopt continuous casting (integrated only)
Recuperative burners in the reheating furnace	Efficient ladle preheating
Process control in the hot strip mill	Thin slab casting
Insulation of furnaces	
Energy efficient drives in the hot rolling mill	
Waste heat recovery from cooling water	
Controlling oxygen levels and variable speed drives on combustion air fans	
Heat recovery on the annealing line (integrated only)	
Automated monitoring & targeting system (integrated only)	
Reduced steam use in the pickling line (integrated only)	

The authors of the study estimated the total penetration of each measure and then calculated the conservation in terms of reductions of energy intensity for the industry as a whole. Energy intensity of steel production[3] in 1994 was approximately 26 GJ/t, and the 47 measures identified could reduce the intensity by 5.9 GJ/t. For all of the measures a cost of conserved energy was calculated that included information on investment costs, operating and maintenance costs, and energy costs and savings. In addition, productivity benefits were

[3] Defined as primary energy use for SIC 331 and 332 per metric ton of steel produced.

identified for 14 of the measures. Excluding productivity benefits, the CCEs for the iron and steel measures range from $0/GJ (no incremental cost) to over $50/GJ. The weighted average price of primary fuel used in the sector is indicated on the figure. As mentioned above, the intersection of the CSC and the fuel price indicates the amount of cost-effective savings. This illustrates that 23 of the measures are cost effective, totaling 1.9 GJ/t.

When evaluation of productivity benefits is included in the CCE calculation, the CSC can change significantly. The authors of the report identified quantifiable productivity benefits for 14 of the 47 energy-efficiency measures. Table 3 lists these measures and the source of the productivity benefit.

Table 3. Conservation Measures in the Iron and Steel Industry that Include Productivity Benefits

Energy Efficiency Measure	Productivity Benefit	Cost Savings (US$/tonne steel)
Electric Steelmaking:		
Oxy-fuel burners	Reduces tap-to-tap times	$1.00
Scrap preheater – FUCHS shaft furnace	Reduces electrode consumption Improves yield Saves waste handling costs	$0.80
Bottom stirring –Stirring gas injection	Improves yield Cuts need for inert gas purchases	$0.22
Improved process control	Reduces electrode consumption Improves yield Saves maintenance costs	$0.90
DC-Arc furnace	Reduces electrode consumption Reduces tap-to-tap time	$0.13
Scrap preheater - CONSTEEL	Reduces electrode consumption Improves yield	$0.38
Scrap preheater – Twin shell	Reduces tap-to-tap time	$0.11
Foamy slag	Reduces tap-to-tap time	$0.63
Integrated Steelmaking:		
Injection of NG – 140 kg/thm	Decreases coke use: O&M and other cost savings at the coke battery	$0.36
Pulverized coal injection – 130 kg/thm	Decreases coke use: O&M and other cost savings at the coke battery	$1.43
Pulverized coal injection – 225 kg/thm	Decreases coke use: O&M and other cost savings at the coke battery	$0.27
Adopt continuous casting	Saves equipment/handling costs Reduces material losses	$5.36
Hot charging	Reduces material losses Reduced processing time and handling	$0.25
Both Electric and Integrated:		
Thin slab casting	Reduced capital costs compared to conventional route Reduced processing time and handling	$6.27

When these productivity benefits are quantified and included in the cost-effectiveness calculations, the evaluations and the CSC look very different. In Table 4, each of the 14 measures with productivity benefits are evaluated with and without the benefits included. The table shows the CCE in each case, how each measure ranked out of the 47 total measures (where 1 is the most cost-effective), and whether the measure is cost-effective when compared to the average primary energy price in the sector. The CCEs of these measures change significantly when the productivity benefits are included. Once these benefits are accounted for, these 14 measures include the eight most cost-effective conservation measures identified in the study and 11 that fall below the average energy price threshold for cost-effectiveness. Without the productivity benefits, none of these measures was cost-effective.

Table 4. Effect of Productivity Benefits on the Cost-Effectiveness of Energy Efficiency Measures

Measure	*Without* Productivity Benefit			*Including* Productivity Benefit		
	CCE ($/GJ)	Rank (of 47)	Cost-Effective?	CCE ($/GJ)	Rank (of 47)	Cost-Effective?
Inj. of NG – 140	3.1	19	NO	-0.5	8	YES
Coal inj. – 225	3.9	22	NO	1.0	23	YES
Coal inj. – 130	4.4	23	NO	0.1	11	YES
DC-Arc furnace	5.0	26	NO	-1.3	6	YES
Process control	5.6	27	NO	-2.1	5	YES
Scrap preheating	6.7	31	NO	-0.6	7	YES
Thin slab casting	8.5	35	NO	1.9	27	YES
Hot charging	8.9	36	NO	5.3	35	NO
FUCHS furnace	12.7	37	NO	-3.5	3	YES
Adopt cont. cast	14.3	39	NO	-3.5	2	YES
Twin shell	16.6	40	NO	3.3	30	NO
Oxy-fuel burners	17.4	41	NO	-5.5	1	YES
Bottom stirring	20.5	45	NO	-2.4	4	YES
Foamy slag	30.1	46	NO	7.2	40	NO

NOTE: These CCE and cost-effectiveness calculations are based on a discount rate of 30% and an average primary energy price of $2.14/GJ.

Re-evaluating the measures as shown in Table 4 results in a very different CSC for the iron and steel industry, shown in Figure 1. Many of the measures having high CCE without productivity benefits have much lower costs with the benefits, so their position in the curve moves toward the x-axis. In general this shifts the CSC downwards. The point at which the CSC meets the price of energy (giving the total cost-effective savings) will move further away from the y-axis. While the total *technical* potential for primary energy savings remains the same, 5.9 GJ/tonne of steel produced, the potential for *cost-effective* savings has increased by 100%, to 3.8 GJ/tonne. Figure 1 shows both the CSCs, one accounting for productivity benefits and one not. The higher cost options are cut off the top of this figure to show the detail of measures close to the average energy prices.

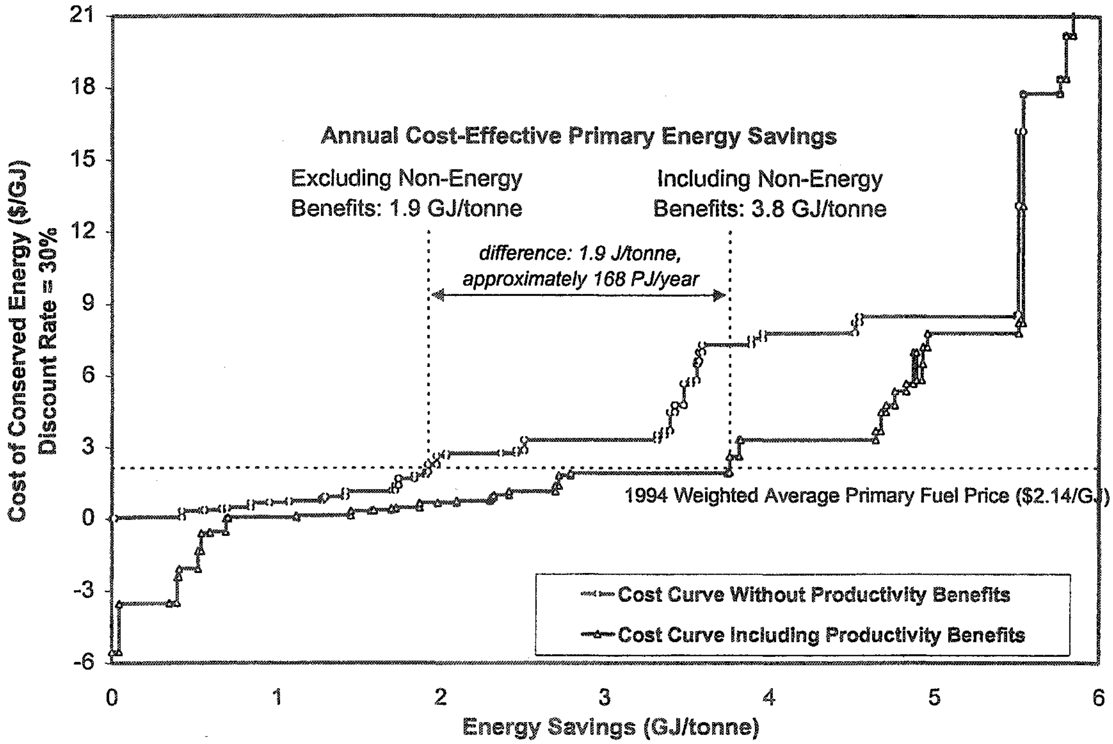

Figure 1. Conservation Supply Curves for the Iron and Steel Industry without Productivity Benefits and Including Productivity Benefits

Discussion

Including productivity benefits in the evaluation of energy-efficiency measures leads to a more accurate understanding of cost-effective energy savings potential across an industry. However, there are complicating factors that make the assessment of these productivity benefits and their incorporation into a quantitative analytical framework difficult. Special attention should be paid to how these complications are addressed to assure the robust nature of the analysis.

One complication is the uncertainty in evaluating some productivity benefits. Within the cost curve methodology it is necessary to evaluate the monetary value of all productivity benefits, but not all these benefits are easily quantified in financial terms. For example, improved working environments that lead to greater safety and employee satisfaction may very well enhance the productivity of the firm, but any quantifiable correlation will be difficult. Reduced emissions of criteria pollutants are another important benefit that often accompanies energy-efficiency, but the value of this benefit will depend on the location of the plant.

The fact that much of the information on productivity benefits comes from case studies of individual projects gives rise to another complication. While the energy performance of a piece of efficient equipment may be extensively tested and even guaranteed by the manufacturer, the reported productivity benefits are generally observations from one or more facilities. It is reasonable to expect variation between plants in the benefits observed. Many of the benefits are not just a function of the efficiency measure, but also of site-specific factors, such as the scale of the project, the maintenance schedule of the facility, and the capacity at which the equipment is operated.

A third complication in assessing productivity benefits is that there may also be negative impacts associated with energy efficiency measures that will offset some of the benefits. These impacts may be just as difficult to quantify as productivity benefits. One potential offset to the benefits of an energy-efficiency measure is that if it involves new technology, there will be some risk in making the investment. Firms may need to train personnel to use the new equipment, and may have difficulty maintaining or repairing the equipment. Additionally, a new project may require a shutdown of production during implementation, leading to production losses. Since these negative impacts will certainly play a role in the decision making of the investor at the firm level, they should be included in the assessment of total energy conservation potential.

In the face of these complications it is important to use a standard framework for analyzing productivity benefits for energy-efficiency projects, such as the one described in the methodology section of this paper. By following this framework, the cost evaluation of productivity benefits is formalized and transparent. Since the evaluation of productivity benefits is not always unambiguous, the transparency of this evaluation framework is important both to give credibility to calculation and to provide flexibility to a user looking to apply the CSC framework to another scenario.

Conclusion

All analyses of how industries make decisions about technology return to the basic principle of "the bottom line", i.e. how will this technology affect the production costs of the firm. This is true when making decisions about a project at an individual facility or when assessing trends across an industry. The interaction of new technologies and production costs must be understood in order to make realistic forecasts of industrial behavior. For new energy-efficient technologies, one primary effect on cost analysis may be a reduction in fuel expenses. At the same time, these technologies may introduce one or more productivity benefits that could lower the firm's production costs. Capturing the effect of these benefits on "the bottom line" is important for assessing the likelihood of a technology's adoption and penetration and the impact this will have on energy use patterns.

In this paper we propose a methodology for assessing productivity benefits of energy efficiency investments and incorporating them into assessments of energy saving potential across an industry. This approach begins with documenting the additional benefits associated with an energy-efficient technology and noting all of the assumptions needed to quantify this benefit in cost terms, if possible. These economic factors are then included in calculations of the cost of conserved energy (CCE) for the measures, and the CCEs are used to construct conservation supply curves (CSC). The CSCs indicate the potential for energy efficiency improvement across an industry or sector.

We have preliminarily tested this methodology using available data on energy-efficiency options in the U.S. iron and steel industry. To illustrate the importance of including productivity benefits we constructed CSCs with and without the inclusion of productivity benefits that had been identified for 14 energy efficiency options in a previous study. These two curves show how productivity benefits can change the shape and placement of the CSC. For the iron and steel sector, removing the productivity benefits from the cost calculations cut the potential for energy savings in half, from 3.8 GJ per tonne of steel to 1.9 GJ. This difference amounts to nearly 170 PJ per year for the entire sector.

While including these productivity benefits is important, and conservation supply curves provide an effective means for including them in an analysis, estimating the magnitude of these benefits can be difficult. When the benefit identified has a direct relationship to the production process, quantifying changes in productivity can be straightforward. When the benefit is not easily quantified, such as improved working conditions, or not linked to productivity, such as lower emission of criteria pollutants, assumptions will be needed to translate the benefit into a comparable cost figure. When quantified benefits are available for a given efficiency measure, the values often come from a published case study, or limited number of observations, so the robustness of the value is uncertain. Also, there is the potential for negative cost impacts to play a role in the cost evaluation of a project. These impacts should also be assessed. In general, using a transparent framework that documents the productivity benefits and the assumptions needed to translate them into useful cost figures, leads to a more credible evaluation.

Acknowledgments

This work was supported by the Office of Atmospheric Programs of the U.S. Environmental Protection Agency, prepared for the U.S. Department of Energy under Contract No. DE-AC03-76SF00098. However, any mistakes within this paper remain the responsibility of the authors. The views expressed in this paper do not necessarily reflect those of the U.S. Environmental Protection Agency, the U.S. Department of Energy, or the U.S. Government.

References

Bernstein, M., Lempert, R., Loughran, D., and Ortiz, D. 2000. *The Public Benefit of California's Investments in Energy Efficiency.* MR-1212.0-CEC. RAND Corporation. Santa Monica, California.

Finman, Hodayah, 2001. "Industry, Energy Efficiency and Productivity Improvements." *Proceeding of the 2001 Summer Study on Energy Efficiency in Industry.* Washington D.C.: American Council for an Energy-Efficient Economy (forthcoming).

Ingram, A.E., 1995. "Recognizing and Defining the Productivity Gains as Part of Electical DSM Installations in the Paper Industy." *Proceeding of the 1995 Summer Study on Energy Efficiency in Industry.* Washington D.C.: American Council for an Energy-Efficient Economy.

Koomey, J.G., Atkinson, C., Meier, A., McMahon, J.E., Boghosian, S., Atkinson, B., Turiel, I., Levine, M.D., Nordman, B., and Chan, P., 1991. *The Potential for Electricity Efficiency Improvements in the U.S. Residential Sector.* . Berkeley, CA: Lawrence Berkeley National Laboratory (LBNL-30477).

Lilly, P. and Pearson, D., 1999. "Determining the Full Value of Industrial Efficiency Programs." *Proceeding of the 1999 Summer Study on Energy Efficiency in Industry.* Washington D.C.: American Council for an Energy-Efficient Economy.

Pye, M., and McKane, A., 1999. "Enhancing Shareholder Value: Making a More Compelling Energy Efficiency Case to Industry by Quantifying on-Energy Benefits" *Proceeding of the 1999 Summer Study on Energy Efficiency in Industry.* Washington D.C.: American Council for an Energy-Efficient Economy.

Worrell, E., Martin, N., and Price, L., 1999. *Energy Efficiency and Carbon Dioxide Emissions Reduction Opportunities in the U.S. Iron and Steel Sector.* Berkeley, CA: Lawrence Berkeley National Laboratory (LBNL-41724).