QUANTIFYING THE BENEFITS: ENERGY, COST, AND EMPLOYMENT IMPACTS OF ADVANCED INDUSTRIAL TECHNOLOGIES

Gregory P. Sullivan, Pacific Northwest National Laboratory
Joseph M. Roop, Pacific Northwest National Laboratory
Robert W. Schultz, Pacific Northwest National Laboratory

ABSTRACT

This development effort was supported by the Technologies Partnerships Program established through the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy via the Office of Industrial Technology (OIT). This program supports research, development, and demonstration of industrial technologies aimed at improving energy efficiency and productivity while reducing pollution, material waste, and operations/maintenance costs. The goal of this program is to develop cost-shared partnerships with industry, government and non-government organizations to foster improved efficiency, productivity, and pollution prevention technologies. This partnership program is believed to be one way that energy efficiency will be delivered to industry in the 21st Century.

This paper reports on the development of the Industrial Technology Employment Analysis Model (ITEAM) which calculates economy-wide employment impacts of specific partnership program technologies, using data developed by the technology partner.

ITEAM is a desk-top computer model that allows users to evaluate base-case partnership data and/or run sensitivity tests using its graphical-user-interface features. It allows the user to select program technologies, view and edit selected data, execute the economy-wide impacts calculations, and reports the results of a "run" in preview and print formats. Program technologies can be grouped and run as a set or run individually. This feature allows the user to customize a model run to represent either a specific industry or a particular technology. Additionally, all run specifications can be readily saved to database files for use in subsequent sessions and as a means of maintaining an audit trail. The program technology algorithm calculates economy-wide employment impacts using the 1987 benchmark input-output (I/O) account methodology.

To demonstrate the capabilities of ITEAM, an analysis is presented for the chemicals industry. In addition, the following major industries have been analyzed and summary data are presented: aluminum, stone/clay/glass, forest products, chemicals, metal casting, steel, and petroleum.

This paper addresses the development, function, and use of ITEAM. Included is a presentation of key assumptions along with user inputs and a discussion of sensitivities. The results of ITEAM runs for over 20 technology projects in 7 program areas are reported. The paper also explains how the project data are used to modify the 1987 I/O table to impact output and employment. The calculations are explained and the approach is rationalized. The argument for this approach rests on the proposition that improvements in efficiency reduce costs and increase the well being of the entire economy.

INTRODUCTION

In support of the Department of Energy planning, budgeting and analysis requirements, OIT needed, in 1995, a better understanding of the national level economic impacts from implementing OIT technologies currently under development, and especially the employment changes that result from implementing these technologies. At that time, OIT was undertaking a data collection effort for OIT Project Data under the Quality Metrics (QM) Program that could be used to modify existing employment impact tools to ascertain the employment impacts of implementing OIT technologies. Since the Pacific Northwest National Laboratory (PNNL) was funded to do something very similar for Office of Building Technology (OBT) it was proposed that PNNL would first modify existing employment impacts tools to provide the employment impacts for OIT technologies with tool development being jointly funded by both OIT and

OBT. The bulk of the effort under both projects would then be devoted to implementing the tool to investigate impacts for the developing technologies.

This analysis is designed to answer the question: What impact will the implementation of OIT technologies have on the economic performance of industries and especially on over-all employment of the economy? Because detailed technology data is being used, it was determined that the input-output (I/O) structure used to assess impacts would have to be at least as large as the 1987 Benchmark I/O table at the "85-Sector" level. The tool development portion of this project has produced a Beta development version of a Visual Basic (VB) user interface and a Fortran based I/O "calculator." The integration of these two programs allows one to select from a menu of QM projects, modify some of the information obtained, and have the tool return employment impacts from that particular technology.

The basic source data used for this analysis will be the Quality Metrics Project Data Summary Sheets and the 1987 Benchmark I/O table of the United States. The work was conducted as three simultaneous tasks: 1) translation of the QM data into changes to the I/O table, 2) development of the I/O calculator, and 3) development of the VB front-end program. Outputs of the analysis includes changes in employment and hours worked that result from the implementation of OIT technologies.

The first of these tasks required that industry-specific QM project data, especially the cost and efficiency information, be translated into reductions in material and energy inputs as they appear in the I/O table. For industry-specific technologies, changes in the recipe of production were fairly easy to assess. For cross-cutting technologies, it was necessary to classify industries into "types" so that the same percentage changes to components of the I/O matrix can be affected without making changes to all columns of the matrix. Our research considered four such cases:

- The single-industry case
- The set of industries that engage in substantial cogeneration
- Truly cross-cutting technologies such as combustion improvements
- The set of industries that are classified in the group Metals Fabrication

ITEAM METHODOLOGY

Fundamental to the estimation of the employment consequences of the adoption of OIT technologies is the assumption that *any* technological improvement will improve efficiency. The adoption of the technology will free resources that, when put to work at alternative uses, will allow greater output with the same set of inputs. The process by which this actually occurs is a complicated one, not well treated in the economics or technology innovation literature.[1]

Because of these complications, some simplifying assumptions have been made that make the problem more tractable. The first of these is that the costs and benefits of the technology are annualized, so that there is no concern about the timing and financing of the investment that embodies the technology. As a result of this assumption, the only dynamic impacts are the result of market penetration of the technology over time. A second assumption is that the resource savings, represented by the reduction in costs to the industry adopting the technology, instantly is translated into increases in final demand. How this transfer occurs is not addressed in this model.

Employment impacts of the adoption of OIT technologies are estimated by inserting annualized costs and benefits of the technology into a model of the economy as depicted in the Benchmark I/O table of the U.S. economy for 1987, published by the U.S. Department of Commerce.

> The annualized benefits (costs) are subtracted from (added to) the purchases of commodities by the adopting industry as represented in the Use matrix. This represents a net resource savings that is attributed to an increase in value added

---

[1] The only systematic treatments of this issue are by Henry (1977), who focuses on energy conservation changes, and Carter (1990), who codifies the impacts of various technical innovations in a static input-output framework. The consequence of technology change in a dynamic context may be addressable using a model such as the one presented by Persson (1984), although this model assumes full employment of resources also. For there to be positive employment impacts, there must be an elastic labor supply response function. See Scott, *et al.*, for financing implications.

and hence must be added to the final demand vector. This modified Use matrix is then used to construct a modified direct and indirect requirements matrix, which with the modified final demands, is used to calculate industry output. These outputs are then multiplied by the employment intensities for each industry and summed to determine how employment changes as the technology is put to use. This calculation is repeated annually as the technology penetrates into the market, providing a picture of how the impacts will change with the adoption of the technology. The base period is always the employment that would have occurred absent the technical changes to the use matrix. *This is equivalent to translating net benefits of the technology adoption expressed in dollars of GDP into employment units.*

There are a number of issues that this approach does not address that need to be identified, though not resolved. An input-output representation of the economy is a static concept -- it is a snapshot at a particular point in time. Using a static model neither allows any consideration of the adjustment process, nor does it take into account how the investment might be financed, nor does it consider adjustments that might occur in the labor and other goods markets as a result of freeing resources from the industry making the innovation. The treatment by Carter (1990) shows that when resources are fully employed after the technological change, output may be larger, but there is nothing intrinsic to the I/O approach that would assure that these resources are put back to work. The approach taken here assumes that the resource savings is instantly translated into greater final demand (i.e., higher GDP).

This assumption ignores the fact that a "benefit" to one industry in the form of lower costs is a decline in sales (i.e., a "cost") to another industry. As such, the value added increase in the innovating industry should be precisely offset by a decrease in other industries. By ignoring these other industry impacts, we are supposing a lengthy chain of events that might first show up as lower costs, and that these costs would wash throughout the economy, allowing all industries to make marginal adjustments to the mix of labor, capital and materials that would, after adjustments, yield greater real output fully utilizing the available set of resources. If there are unemployed resources, these might be brought into productive use through these impacts. Unfortunately, a static tool like I/O analysis, does not fully allow for this type of adjustment. Hence the simplifying assumptions.

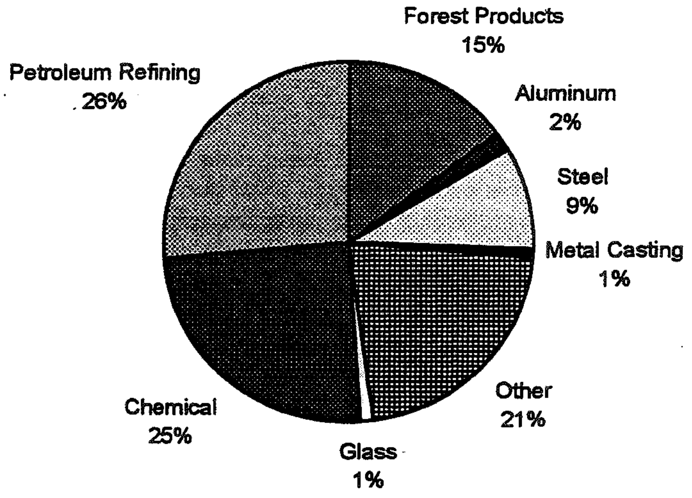
PROGRAM AREAS AND TECHNOLOGIES

The Energy Information Administration estimated the 1994 manufacturing sectors total end-use energy consumption to be 22.4 quads (OIT 1997). Figure 1 breaks this energy use down into seven key industries representing about 80% of the total end-use energy. Because of their relative importance, these seven industries will be examined in this paper. However, due to constraints on publication length, only the chemical industry OIT technologies will be examine in detail.

As mentioned, the data used in this analysis were collected as part of OIT's QM program. These QM data were collected directly from the OIT program managers responsible for each technology and assembled in a uniform format in *OIT Project Benefit Analysis Worksheets* (Benefits Worksheets). For each of the OIT technologies the following information was collected:

- Installed capital cost
- Annual non-energy cost components (e.g., non-fuel operations and maintenance, other raw materials and supplies, labor, pollution/waste disposal, transportation)
- Annual energy use
- Annual waste/pollution generation

Figure 1. Manufacturing Energy Consumption by Industry, 1994. Total Consumption 22.4 Quads.



These data were assembled in the Benefits Worksheets on a per unit basis, that is, each of the cost/use parameters are listed for a piece of equipment/technology of specific size and capacity. Furthermore, the Benefits Worksheets employ a model which estimates the market penetration of a technology based on the capital cost, the calculated internal rate of return, introductory market share assumptions, and a user-entered "hurdle rate" for the investment.

Given these data, the Benefits Worksheet model calculates the energy savings, production cost savings, and emissions/waste reductions of the OIT advanced technology compared to the existing conventional technology; again, these calculations are done on a per unit basis. The total net benefit of a given technology is the net per unit benefit multiplied by the expected number of units in operation in a given year. While the complete analysis examined all benefits for the years 2000 through 2025, because of spacial constraints this paper will focus only on the benefits in the year 2005.

Chemical Industry

The Chemical Industry used approximately 5.5 quads of energy in 1994 representing the second largest energy consuming industry. Four of the Chemical Industry OIT Advanced Technologies are discussed below, in addition, data from the Benefits Worksheets are presented. These data serve as the inputs to the ITEAM model and are as found in the Benefits Worksheets at the end of fiscal year 1996; it should be noted that the Benefits Worksheet data are periodically updated.

In addition to the data, the impacted I/O sector from the 85 sector table are reported. The sectors to be impacted were determined based on an engineering assessment of the technology considered, the specifics of the non-fuel O&M savings, and the type of energy savings. For some technologies there was more than one sector impacted, in such cases the value was distributed across the relevant sectors.

For each chemical technology listed the resulting energy savings, production cost savings, and employment impacts are presented. As mentioned, due to spacial constraints, the results are presented only for the year 2005.

Chemical Technology 1: Phenolics from Wood Waste

Phenol formaldehyde resins are used in a variety of furniture and other wood composite products. These resins are traditionally made using petroleum-based phenol, a relatively expensive component in the process. This advanced technology focusses on developing low-cost phenolic compounds from waste biomass. The program has designed processes for developing the compounds directly from waste biomass as well as combining this product with petroleum-derived phenol to produce the desired resins.

Included in Table 1 below are the technology impacts as listed in the Benefits Worksheets. Also included are the I/O sectors impacted by this technology. The listed sectors are modified in the I/O table and these modifications are translated into the changes in the final demand.

Table 1. Phenolics from Wood Waste Technology Impacts:

Category	Conventional Technology	OIT Advanced Technology	Savings	Impacted I/O Sector
Installed Capital Cost (millions $)	64.1	46	18.1	Sector 48: Special Industrial Machinery and Equipment
Annual Non-fuel O&M (millions $)	5.5	10.6	-5.1	Sector 73B: Engineering and Related Services
Annual Energy Use (trillion Btu)	2.043	0.420	1.623	Sectors 7, 31, 68A, 68B: Coal, Petroleum, Electricity, Natural Gas

It is interesting to note where the projected savings occur. The capital cost of the advanced technology has a significant savings over the conventional equipment, however, the annual non-fuel O&M show an increase for the advanced technology over the conventional technology. The resulting annual energy savings affect the coal, petroleum, electricity, and natural gas sectors.

From these data and the estimated technology penetration of 6 units in the year 2005, and using the ITEAM model (set to assume all benefits are directed to increased final demand), the following results are reported:

Estimated energy savings:	9.7 trillion Btu in 2005
Estimated production cost savings:	$4.2 million in 2005
Estimated employment impact:	500 new jobs in 2005.

Chemical Technology 2: Inorganic Polymer Compounds

Polymer membranes are used in a variety of organic and inorganic chemical separations. Important commercial uses of these membranes include separating impurities out of natural gas and producing other industrial gases. Some of the restrictions on traditional polymer membranes include their lack of thermal stability and their low resistance to thermal stability.

This advanced technology focusses on developing a new class of polymers known as polyphosphazenes. These advanced polymers have a higher resistance to solvents and high temperatures. In addition, these new membranes are estimated to reduce separation energy requirements by one-third. Table 2 below highlights the technology impacts as listed in the Benefits Worksheets and the impacted I/O sectors.

Table 2. Inorganic Polymer Membrane Technology Impacts:

Category	Conventional Technology	OIT Advanced Technology	Savings	Impacted I/O Sector
Installed Capital Cost (millions $)	1.2	0.54	0.66	Sector 48: Special Industrial Machinery and Equipment
Annual Non-fuel O&M (millions $)	0.25	0.21	0.04	Sector 73B: Engineering and Related Services
Annual Energy Use (trillion Btu)	0.17	0.10	0.07	Sectors 31, 68B: Petroleum, Natural Gas

From these data and the estimated technology penetration of 464 units in the year 2005, and using the ITEAM model (set to assume all benefits are directed to increased final demand), the following results are reported:

• Estimated energy savings:	32.5 trillion Btu in 2005
• Estimated production cost savings:	$146 million in 2005
• Estimated employment impact:	950 new jobs in 2005.

Chemical Technology 3: Auto Shredder Residue

Auto shredder residue (ASR) is the non-metallic material remaining from the recycling of automobiles which usually takes place primarily for steel recovery. This process allows for the separation and recovery of polyethylene foam, iron-oxide rich fines, and a variety of thermoplastics. Applications for the recovered products include carpet padding and other foam-based products; the iron oxide fines are upgraded and used in the replacement industry (OIT 1997). Additional savings from this technology result from reduced landfill "tipping" fees.

The current status of this technology is the recent completion of a pilot scale field demonstration. Table 3 below lists the technology impacts as given in the Benefits Worksheets and the impacts to the I/O sectors.

Table 3. Auto Shredder Residue Technology Impacts:

Category	Conventional Technology	OIT Advanced Technology	Savings	Impacted I/O Sector
Installed Capital Cost (millions $)	0	0.693	-0.693	Sector 49, 11: General Industrial Machinery and Equipment, New Construction
Annual Non-fuel O&M (millions $)	0	-0.713 [1]	0.713	Sector 73B, 68C, 28: Engineering and Related Services, Water and Sanitary Services, Plastics and Synthetic Materials
Annual Energy Use (trillion Btu)	0.072	0.037	0.035	Sectors 68A, 68B: Electricity, Natural Gas

[1] Includes revenues generated from sales of thermoplastics and foam.

From these data and the estimated technology penetration of 222 units in the year 2005, and using the ITEAM model (set to assume all benefits are directed to increased final demand), the following results are reported:

Estimated energy savings:	7.8 trillion Btu in 2005
Estimated production cost savings:	$110 million in 2005
Estimated employment impact:	1,570 new jobs in 2005.

Chemical Technology 4: Waste Tire Utilization

Each year the scrap materials contained in tire rubber represent nearly 2 billion pounds of rubber and 200 million pounds of steel fiber. These values are in addition to an estimated 22 billion pounds of rubber and 2 billion pounds of steel and fiber already accumulated (OIT 1997). This technology focusses on a process used to convert finely ground tire rubber into polymer composites; the final product is called surface treated rubber (STR). The goal of this project is to use STR in place of conventional polymer resins for use in a variety of rubber and plastic products.

The current status of this technology is a pilot scale field demonstration in progress. Table 4 below lists the technology impacts as given in the Benefits Worksheets and the impacted I/O sectors.

Table 4. Waste Tire Utilization Technology Impacts:

Category	Conventional Technology	OIT Advanced Technology	Savings	Impacted I/O Sector
Installed Capital Cost (millions $)	0	9.0	-9.0	Sector 48: Special Industrial Machinery and Equipment
Annual Non-fuel O&M (millions $)	0	-10.5 [1]	10.5	Sector 28, 37, 73B : Plastics and Synthetic Materials, Primary Iron and Steel, Engineering and Related Services,
Annual Energy Use (trillion Btu)	2.487	.917	1.581	Sectors 68A, 68B, : Electricity, Natural Gas
[1] Includes revenues generated from sales of recycled materials.				

From these data and the estimated technology penetration of 24 units in the year 2005, and using the ITEAM model (set to assume all benefits are directed to increased final demand), the following results are reported:

Estimated energy savings:	38 trillion Btu in 2005
Estimated production cost savings:	$133 million in 2005
Estimated employment impact:	1,290 new jobs in 2005.

Other Manufacturing Industry Results

The tables below highlight a selection of 19 of the OIT funded technologies for the remaining 6 most energy intensive industrial manufacturing sectors (chemical industry already discussed). These tables report the major industry, the applicable technologies, estimates of energy savings, estimates of production cost savings, and economy-wide employment impacts.

Table 5. Aluminum Industry Advanced Industrial Technologies

Program Area	Technology	2005 Energy Savings (trillion Btu)	2005 Production Cost Savings (millions $)	2005 Employment Impacts (new jobs)
Aluminum	Inert Anode/Cathode for Smelting	139.1	1,924	10,220
	Spray Forming	25.4	146	910
	Energy Efficient Calciner	3.2	9.7	110
	Recycle Saltcake	4.4	18	250
	Total	172.1	2,097.7	11,490

Table 6. Steel Industry Advanced Industrial Technologies

Program Area	Technology	2005 Energy Savings (trillion Btu)	2005 Production Cost Savings (millions $)	2005 Employment Impacts (new jobs)
Steel	Waste Oxide Recycling	9.5	305	-520
	Electrochemical Dezinking of Scrap Steel	20.6	45	740
	Advanced Process Control	23.7	307	-370
	Total	53.8	657	-150

Table 7. Metal Casting Industry Advanced Industrial Technologies

Program Area	Technology	2005 Energy Savings (trillion Btu)	2005 Production Cost Savings (millions $)	2005 Employment Impacts (new jobs)
Metal Casting	Advanced Lost Foam Casting	3.7	15	120
	Cupola Furnace Control	0.14	7	80
	Dimensional Control and Life Predication	0.13	13	20
	High Performance Die Steels	0.03	8	20
	Total	4	43	235

Table 8. Glass Industry Advanced Industrial Technologies

Program Area	Technology	2005 Energy Savings (trillion Btu)	2005 Production Cost Savings (millions $)	2005 Employment Impacts (new jobs)
Glass	Furnace Oxygen Enrichment	5.3	35	280
	Cullet Preheating	4.1	8	110
	Glass Temperature Sensor	25.5	73	810
	Total	34.9	116	1200

Table 9. Forest Products Industry Advanced Industrial Technologies

Program Area	Technology	2005 Energy Savings (trillion Btu)	2005 Production Cost Savings (millions $)	2005 Employment Impacts (new jobs)
Forest Products	Black Liquor Gasification	7.7	19	260
	Impulse Drying	8.9	711	4,280
	Ultrasonic Sensors	5.3	10	110
	Black Liquor Electrolysis	1.2	547	6090
	Total	23.1	1,287	10,740

Table 10. Petroleum Refining Industry Advanced Industrial Technologies

Program Area	Technology	2005 Energy Savings (trillion Btu)	2005 Production Cost Savings (millions $)	2005 Employment Impacts (new jobs)
Petroleum Refining	Advanced Membrane Devices	0.003	56.6	190
	Combustion Air Toxics	4	6	160
	HiPHES Ethylene Cracker	1.9	14.9	27
	Hybrid Membrane Separation-Olefin Recovery	0	263	340
	Total	5.903	340.5	717

CONCLUSIONS

The purpose of this study was to establish a defendable methodology for estimating economy-wide employment impacts resulting from advanced industrial technologies. The methodology adopted modifies the 1987 Input/Output table to derive impacts to sector-specific output and final demand values. These modified values are used to generate a revised I/O table, calculate new outputs, and then, coupled with employment intensities, used to estimate employment impacts.

The framework in which these modifications take place is the ITEAM model. This model is publicly available tool which readily allows for a variety of parametric changes and sensitivity analyses to be completed. While there are some limitations to this analysis and model, the strengths lie in the consistency with which employment impact calculations are made and the ability the user has to select, modify, and combine different technologies and program areas.

The results of specific ITEAM model runs indicate significant variation in potential employment impacts. Notably, the technologies examined for the Aluminum and the Forest Products program areas are quite significant with both estimated to increase employment by over 10,000 jobs by the year 2005. The only program area with a net loss of jobs for the technologies examined is the Steel program area. The loss of these jobs can be traced to the replacement of very labor intensive output with output of a lower employment intensity.

REFERENCES

Carter, A.P. (1990). "Upstream and Downstream Benefits of Innovation. " *Economic Systems Research* 2(3): 241-257.

Henry, E. W. (1977). "An Input-Output Approach to Cost-Benefit Analysis of Energy Conservation Methods," *Economic and Social Review.* (9:1) 1977, pp. 1-26.

OIT 1997. *Enhancing the Competitiveness, Efficiency, and Environmental Quality of American Industry Through Technology Partnerships*. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Washington D.C.

Persson, H. (1984). "A Way of Modeling Investment in a Multi sectoral Model," *Regional Science and Urban Economics.* 14, 1984, pp. 331-343.

Scott, M.J., D.J. Hostick, and D.B. Belzer (1996). *ImBuild: Economic Impact of Building Energy Conservation Programs.* Richland, Washington: Pacific Northwest National Laboratory.