U.S. Department of Energy (DOE) Industrial Programs and Their Impacts

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ABSTRACT

The U.S. Department of Energy's (DOE's) Office of Industrial Technologies (OIT), within the Office of Energy Efficiency and Renewable Energy, has been working with industry since 1976 to encourage the development and adoption of new, energy-efficient technologies. OIT's cost-shared research, development and demonstration (RD&D), technology transfer, and information-sharing efforts have helped industry not only use energy and materials more efficiently, but also improve environmental performance, enhance product quality, and increase productivity. Pacific Northwest National Laboratory (PNNL) periodically reviews and analyzes the benefits of OIT programs and documents these benefits in the DOE *Impacts Report* to help OIT determine the impact of its programs. PNNL contacts vendors and users of OIT-sponsored technologies that have been commercialized, estimates the number of units that have penetrated the market, and conducts engineering analysis, in conjunction with the vendors/users, to estimate energy savings and other non-energy benefits associated with the technologies. Estimates of air pollution and carbon-emission reductions are then determined (based on fuel savings and process changes that have environmental benefits). In addition, PNNL investigated the status of emerging technologies, which are expected to result in a commercialized product within 2–3 years. This paper will discuss the results of the PNNL 2000 review.

Introduction

Working in partnership with industry, the U.S. Department of Energy's (DOE's) Office of Industrial Technologies (OIT) is helping reduce industrial energy use, emissions, and waste while boosting productivity. Operating within the Office of Energy Efficiency and Renewable Energy (EE), OIT conducts research, development, demonstration, and technology-transfer efforts that are producing substantial, measurable benefits to industry. These benefits were recently described in the February 2001 DOE *Impacts Report* (OIT, 2001). This paper summarizes some of the impacts of OIT's programs through 1999. The remainder of this introduction gives a brief overview of how the program works and its focus. The second section describes the program elements. The third section then describes how technologies are tracked and how benefits are estimated. The fourth section then reports the results of this tracking process. A final section provides references.

How the Program Works

Over the past 24 years, OIT has supported more than 550 separate research, development, and demonstration (RD&D) projects, producing over 140 technologies. In

1999 alone, successfully commercialized technologies saved more than 185 trillion Btu in measured savings. While these energy savings are impressive, industry has reaped even greater benefits from the productivity improvements, reduced resource consumption, decreased emissions, and enhancements to product quality associated with these technological advances. In addition, many OIT-supported projects have significantly contributed to expanding basic knowledge about complex industrial processes and laid the foundation for the development of future energy-efficient technologies,

Since 1994, OIT has implemented an innovative, customer-driven research strategy known as Industries of the Future. This strategy ensures that OIT projects meet the country's needs and make the most of limited research resources by helping to focus public and private technology investments on industry's most critical research needs.

The Industries of the Future strategy has made it possible for entire industries, many for the first time, to work together to define and pursue their top priorities for RD&D. The new approach takes advantage of the insights and resources industry can bring to the research planning and implementation process. Industry's involvement is designed to ensure adoption and use of the successful energy-efficient technologies.

The Industries of the Future strategy strives to integrate a broad range of efforts to meet industry's current and future needs.

- Collaborative RD&D focuses on the following energy-intensive industries: agriculture, aluminum, chemicals, glass, forest products, metalcasting, mining, petroleum and steel.
- RD&D is also conducted in enabling or cross-cutting technologies, applicable to a wide range of manufacturing industries: combustion, sensors and controls, advanced materials, and continuous-fiber ceramic composites.
- Technical assistance is provided by energy and environmental plant assessments conducted by Industrial Assessment Centers. Other technical assistance is provided by data, decision tools, and recognition programs promoting adoption of a systems approach to increasing the efficiency of electric motors and drive systems, compressed air, and steam.
- Financial assistance is used to encourage cooperative demonstrations of emerging technologies and development of energy-saving ideas and innovations by inventors and small businesses.
- State Assistance is also available to aid in providing similar support to industry at the state level to that provided by OIT at the national level.

The Industries of the Future process affords industry a strong voice in the allocation of federal industrial research dollars while enabling OIT to increase research productivity. The process takes advantage of the inherent relationship between efficiency and production costs, using market drivers to help focus scarce resources where they can effect the greatest improvements in U.S industrial efficiency.

The Industries of the Future allows participating manufacturers, suppliers, and vendors expand their technical knowledge base, gain access to complementary technical expertise and facilities, and acquire a bigger voice in directing RD&D in their industry. Although participating private firms may be the first to benefit from more efficient technologies through pilot testing or demonstration programs, all U.S. industries benefit from these technologies once they have been commercialized.

National Focus

OIT has assisted industry in developing and adopting new energy-efficient technologies since 1976. OIT has shared the costs for research, development, and demonstration (RD&D) as well as technology transfer, and the return on investment has been both measurable and large.

The scope of American industry is enormous, accounting for approximately 25% of the Gross National Product and 75% of exports. Industry provides jobs for over 25 million American workers. It also consumes more energy than any other sector in the U.S. economy (36%) with annual costs of more than $110 billion. Manufacturing companies spend approximately $30 billion per year on equipment and operations for controlling pollution. Therefore, new technologies that reduce industrial energy consumption and pollution have a very large impact on the Nation as a whole. In partnership with OIT, industry has developed technologies to use energy and materials much more efficiently and has also improved environmental performance, enhanced the quality of products, and increased productivity. There is potential for saving over a quadrillion Btu of energy a year, and greenhouse gas emissions could be reduced by over 25 million tons.

OIT works closely with industry to identify priority technology needs and funds projects on a cost-shared or cooperative basis. The RD&D programs described in this document have produced many full applications in industrial processes and over 140 commercialized technologies, but the actual impacts are much greater than these numbers would suggest. For example, these estimates only include information provided by industry partners, but the actual impacts may be much greater because of personnel turnover, buyout by larger firms, and assignment of technology rights to a third party. Also, only the first-generation technologies are generally considered, but second-generation technologies and spinoffs to other applications greatly expand the results.

Besides the direct impacts of these technologies, OIT's programs include many indirect benefits, such as knowledge transferred through workshops, case studies, grants, information clearinghouses, decision tools, and cooperative programs with state and local agencies. These integrated efforts accelerate the development of other advanced technologies, and it is often impossible to quantify the far-reaching effects. The *Impacts Report* (OIT, 2001) shows how the direct benefits of OIT Programs are measured. Just these direct RD&D benefits and the savings from the Industrial Assessment Centers (IACs) amounts to 189.4 trillion Btu in 1999 and a dollar savings to industry that is nearly $820 million.

OIT Program Elements

OIT'S Industries of the Future

The purpose of OIT's Industries of the Future is to ensure that projects meet real industry needs and make the most of limited research resources by helping to focus public and private technology investments on industry's most critical research needs.

This approach takes full advantage of the unique insights and resources industry can bring to the research planning and implementation process. By giving industry "ownership" of the process, the strategy also obtains industry commitment to the research and facilitates industry cost-sharing, which averages 50% over the life of a project. Moreover, industry's involvement essentially ensures adoption and use of the successful energy-efficient technologies.

The industries included in the Industries of the Future are:

- Agriculture
- Aluminum
- Chemicals
- Forest Products
- Glass
- Metalcasting
- Mining
- Petroleum
- Steel

Key attributes of the program are as follows:

Program direction through industry participation. Increasing demands on resources have forced organizations to do more with less — to leverage scarce financial and physical resources to achieve multiple objectives. Both industry and the government have recognized the value of teamwork among key participants. The complexity of many advanced technologies and processes, requiring multidisciplinary research beyond the technical capabilities of a single company, further fuels this trend toward cooperative efforts.

Industry input in direction and priorities. Unlike past industry/government partnerships, the Industries of the Future approach requires that industry take ownership of the "technology roadmapping" process in which each industry establishes a consensus on priorities for the required research. This process helps align public and private resources so they can collectively focus on solving industry's toughest technical challenges. With emphasis on "customer pull" rather than "technology push," this approach obtains strong industry commitment to the research, facilitating widespread adoption of the resulting energy-efficient technologies.

The RD&D portfolio of projects supports technologies that are too risky for individual companies to undertake or are precompetitive. These technologies must have a broad national application as well as significant energy, environmental, and economic benefits.

To help industry access and ensure that its technologies and capabilities are implemented in a timely fashion, OIT has developed an integrated delivery approach for products, services, and emerging technologies through a complementary portfolio of programs, including technical and financial assistance, enabling technologies, and localized state activities. These programs are described in brief below; further details can be obtained from the OIT website, at http://www.oit.doe.gov.

Technical Assistance

Best Practices. OIT's best-practices programs help industrial firms of any size assess the potential benefits of maximizing efficiency using a systems approach. These programs target electric motor and compressed-air as well as steam systems. Through these programs, OIT provides unbiased data, decision tools, technical assistance, and recognition for firms that successfully improve their efficiency.

The motors and compressed air activities help U.S. manufacturers learn about and adopt efficient electric motor and compressed air systems. Industry has about 20-million electric motors in use, which accounts for 69% of the electricity they consume. By 2005, savings are anticipated of more than 5-billion kilowatt-hours of electricity and over a million metric tons of carbon equivalent annually through investment made at over 1000 plant sites. The compressed air activities, a voluntary collaboration among industry, utility companies, state and federal government, and technical trade associations, is dedicated to improving the performance of industrial compressed air systems with the goal of reducing energy needs and costs. These efforts provide education, technical training, and certification to plant personnel using compressed air systems.

Steam systems activities provide U.S. manufacturers with high-quality, reliable information about steam-related technologies and practices. The potential benefits to industry include saving 2.8-quadrillion Btu (quads) of energy by 2010 and eliminating 43-million tons of CO_2 and 30-thousand tons of NO_x emissions. Nonenergy benefits include improved safety, reliability, and productivity. The goal is a 20% total energy savings from steam activities by 2010, which would mean $4 billion in annual energy savings to industry. Attaining that goal would also mean a reduction in CO_2 emissions equivalent to taking 5 million cars off the road.

Industrial Assessment Centers. In addition to the benefits derived from OIT's technology-development programs, U.S. industry has also saved energy, reduced costs, and lowered environmental impacts by taking advantage of OIT's technology access and programs. These programs provide technical assistance, information, and tools to help industry use existing technology to the best of its ability. The impacts of many of these OIT efforts are difficult to quantify. However, the energy and cost savings of one program that supports the IACs have been estimated. Since their inception in 1979, the energy audits of industrial facilities, together with the "ripple effects" associated with training energy auditors who continue to improve energy efficiency through their careers, have saved an estimated 43.1 trillion Btus and $202 millions dollars (through 1999). In 1999 alone, the 734 IAC assessments resulted in new energy savings of 1.6 trillion Btus to the industry. If the benefits of waste reduction and productivity gains are also included, the gross benefits exceed $49 million.

The IAC Program delivers a bonus by providing engineering students with hands-on experience in conducting the audits, supervised by their professors. Therefore, as these students progress into professional careers, they continue to foster the adoption of energy-efficient practices and technologies, creating an energy savings "ripple effect." The program's effectiveness has been further enhanced by developing a "best practices" manual and training materials based on experience accumulated from hundreds of assessments performed by IAC teams.

Financial Assistance

Inventions and Innovation. The Inventions and Innovation Program provides grants of up to $200,000 to individual inventors and small companies with promising ideas and inventions for improving energy efficiency and environmental performance. Emphasis is placed on technologies that address the priorities identified in the Industries of the Future roadmaps. The program also offers practical information to help commercialize technologies and provides a broad range of training and support.

NICE^3. The NICE^3 Program (National Industrial Competitiveness through Energy, Environment, and Economics) provides funding to state-industry partnerships for projects that develop and demonstrate energy-efficient and pollution-preventing technologies. The partnerships match Federal funds, and awardees are expected to commercialize the process or technology. For example, in one NICE^3 project, Chrysler Corporation developed and demonstrated a powder paint coating system for vehicles. This system virtually eliminates volatile organic compound (VOC) emissions and solid waste while greatly reducing energy use.

Enabling Technologies

Advanced Industrial Materials. The Advanced Industrial Materials (AIM) Program develops and commercializes new or improved materials to enhance productivity, product quality, and energy efficiency in the major process industries.

The major projects being supported are:

- Intermetallic Alloy Development
- Improved Composite Tubes for Kraft Recovery Boilers
- Composites by Reactive Metal Infiltration
- Magnetic Field Processing of Polymers.

Sensors and Controls. The Sensors & Controls (S&C) Program develops and deploys integrated measurement systems for operator-independent control of manufacturing processes with broad applicability across multiple industry sectors. The industry sectors served by the S&C Program are those that have established partnerships with DOE's EE to collaborate in joint technology development for the competitiveness and vitality of the industry. The S&C Program will lead in providing the advanced solutions for measurement and control technology to meet the needs of all industry sectors supported by the IOF strategy.

Combustion. The Combustion Program works closely with the industrial combustion community in pursuing RD&D that can achieve the goals and performance targets set forth by the industry in two documents, both accessible from the Combustion home page at http://www.oit.doe.gov/combustion/:

The Industrial Combustion Vision sets performance targets and broad goals for combustion systems in 2020.

The Industrial Combustion Technology Roadmap outlines the RD&D needed to develop the advanced, highly efficient combustion systems that U.S. industry will require in the future.

Continuous Fiber Ceramic Composite. The Continuous Fiber Ceramic Composite (CFCC) Program supports the development of materials that are light, strong, corrosion resistant, and capable of performing in high temperature environments. U.S. industry has a critical need for these materials. Although many ceramics perform well at considerably higher temperatures than conventional metal alloys, they are generally brittle and as a result can undergo catastrophic failure in service. CFCCs are being developed to overcome this limitation. By incorporating continuous ceramic fibers into a ceramic matrix, ceramic products have improved toughness in high-stress environments. Because of these enhanced properties, CFCCs have been recognized as a new class of ceramic materials with the high-temperature stability, corrosion resistance, and toughness necessary for a wide range of applications. In addition, CFCC components used in industrial applications will provide substantial energy, environmental, and economic benefits.

The CFCC Program is a collaborative effort between industry, national laboratories, universities, and the government to develop advanced composite materials to a point at which industry will assume the full risk of development. Participation by industry (which cost shares in this effort) is vital and ensures that the research agenda is based primarily on economic and performance criteria.

State Activities

OIT recently instituted a program called "States Industries of the Future" to help implement the Industries of the Future program within all states and regions of the United States. State governments, State organizations, and energy-intensive industries within the States lead this program. It targets Industries of the Future that are most important within a State, determines their business and technology needs, and then delivers resources needed to meet those needs. Seventeen states received grant awards in 2000.

Technology Tracking Methodology

Program managers within DOE's Office of Industrial Technologies recognize the importance of developing accurate data on the impacts of their programs. Such data are essential for assessing OIT's past performance and can help guide the direction of future research programs.

Energy savings associated with specific technologies is estimated by Pacific Northwest National Laboratory (PNNL) through a rigorous process for tracking and managing data. When a full-scale commercial unit of a technology is operational in a commercial setting, that technology is considered commercially successful and is on the active tracking list. When a commercially successful technology unit has been in operation for approximately ten years, that particular unit is then considered a mature technology and typically is no longer actively tracked. Emerging technologies are those in the late development or early commercialization stage of the technology life cycle (roughly within one to two years of commercialization). While preliminary information is collected on emerging technologies, they are not usually place on the active tracking list until they are commercially available to industry. The active tracking process involves collecting technical and market data on each commercially successful technology, including details on the:

- Number of units sold, installed, and operating in the United States and abroad (including size and location)
- Units decommissioned since the previous year
- Energy saved by the technology
- Environmental benefits from the technology
- Improvements in quality and productivity achieved through use of the technology
- Any other impacts of the technology, such as employment, effects on health and safety, etc.

Methodological Issues

Information on technologies is gathered through direct contact with either vendors or end users of the technology. These contacts provide the data needed to calculate the unit energy savings associated with an individual technology, as well as the number of operating units. Unit energy savings are calculated based on specific details for each individual technology. Technology manufacturers or end users usually provide unit energy saving, or at least enough data for a typical unit energy savings to be calculated. The total number of operating units is equal to the number of units installed minus the number of units decommissioned or classified as mature in a given year--information usually determined from sales data or end user input. Number of operating units and unit energy savings can then be used to calculate total annual energy savings for the technology.

The cumulative energy savings represents the accumulated energy saved for all units for the total time the technology has been in operation. This includes previous savings from now-mature units and decommissioned units, even though these units are not included in the current year's savings.

Once cumulative energy savings have been determined, impacts on the environment are calculated by estimating the associated reduction of air pollutants. This calculation is based on the type of fuel saved and the pollutants typically associated with combustion of that fuel, and uses assumed average emission factors. For example, for every million Btu of coal combusted, we assume approximately 2.5 pounds of sulfur oxides (known acid rain precursors) are emitted to the atmosphere. Thus, every million-Btu reduction in coal use results in the elimination of 2.5 pounds of sulfur oxides.

The cumulative cost savings minus program and implementation costs provides an estimate of the direct **net** economic benefit of the OIT program since its inception. The benefits of the program are based on:

Estimated energy savings. The energy savings (Btu) produced by OIT-supported technologies have been commercialized and tracked since the program began. As of FY 1999, the cumulative value for energy savings since 1976 was 1.6 quadrillion Btu. Since details of the technology are know, the types of fuel saved are also available.

The cost of industrial energy. Average industrial energy prices since 1976 were constructed based on inflation adjusted fuel prices. The nominal prices (in dollars per million Btu) are reported in the Energy Information Administration's *State Energy Price and Expenditures Report* (EIA, 2000); these are adjusted for inflation by the producer price index (available on the web at: http://www.stats.bls.gov) for Number 2 fuel oil, natural gas, coal and electricity. These prices are multiplied by the Btus of the various industrial fuels saved by OIT commercialized and tracked technologies to obtain the inflation adjusted savings in dollar terms.

The costs of the program and implementation are based on:

OIT appropriations. The sum of R&D dollars spent by OIT on its program in each year since the program began, adjusted for inflation. As of FY 1999, the cumulative OIT spending since 1976 was $1.7 billion (in 1999 dollars).

The assumed cost of implementation. Because we do not have reliable information about the costs of installing the new technologies, we made an assumption to account for these costs. We assume industry requires a two-year payback period on investments. So, we ignore the first two years of the cumulated energy savings for each of the technologies, arguing that these saving are needed to "recoup" the capital costs of adopting the new technology.

So, for each technology, the annual energy savings by fuel type is multiplied by the price of that fuel in that year (adjusted for inflation). The sum of all energy saved times the average energy price yields an estimate of the annual savings for all technologies in that particular year. The net economic benefit is equal to the accumulation of these savings over time minus the OIT program costs (appropriations) and the assumed cost of installing the technologies (which is equal to the first two years of savings for each of the technologies tracked).

Several factors make the tracking task challenging. Personnel turnover at developing organizations as well as at user companies makes it difficult to identify applications. Small companies that develop a successful technology may be bought by larger firms, or may assign the technology rights to a third party. As time goes on, the technologies may be incorporated into new products, applied in new industries, or even replaced by newer technologies that are derivative of the developed technology.

Program benefits documented by PNNL are conservative estimates based on technology users' and developers' testimonies. These estimates include neither derivative effects, resulting from other new technologies that spin off of OIT technologies, nor the secondary benefits of the energy and cost savings accrued in the basic manufacturing industries downstream of the new technologies. So actual benefits are likely to be much higher than the numbers reported here. Nonetheless, the benefits-tracking process provides a wealth of information on the program's successes. The process of tracking these benefits is diagramed in Figure 1.

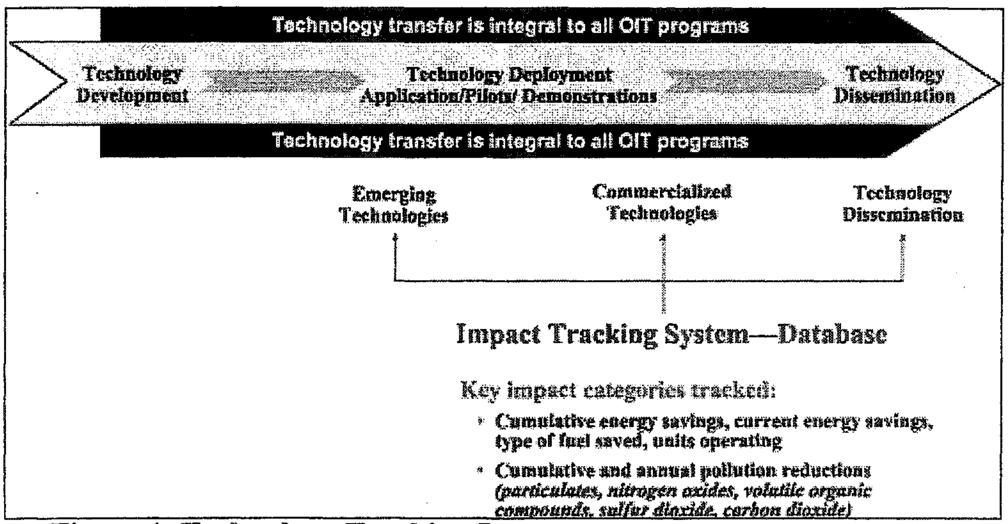

Figure 1. Technology Tracking Process

The IAC program also estimates benefits of its program. The total energy savings and pollution reductions estimated for the IAC program are shown in Table1. However, these estimates are not made by PNNL and the methodology is not described in this paper. For those interested in the methodology for this tracking, see Appendix 4 in (OIT, 2001).

Technology Tracking Results

The RD&D conducted under the OIT's IOF, I&I and NICE[3] Programs has resulted in over 140 successfully commercialized technologies. Table 1 presents the energy savings and pollutant reduction results for these technologies. In 1999, 189.4 trillion Btu was saved, which translates to a dollar savings to industry of nearly $820 million. On a cumulative basis, since 1976, OIT's commercialized technologies have saved 1.6 quads of energy and $6.5 billion. While the energy savings are impressive, industry has reaped even greater benefits from the productivity improvements, reduced resource consumption, decreased emissions, and enhancements to product quality associated with these technological advances. We estimate that the cumulative emission reductions associated with these commercialized technologies equals 121 billion tons of CO_2, 246 thousand tons of NO_x, and 463 thousand tons of SO_x. In addition, many OIT-supported projects have significantly contributed to expanding basic knowledge about complex industrial processes and laid the foundation for the development of future energy-efficient technologies.

Table 1. OIT Technology Program Impacts

			Cumulative Pollution Reductions (10^3 Tons)				
Technologies Commercially Available	Cumulative Energy Savings (10^{12} Btu)	Current Energy Savings (10^{12} Btu)	Particulates	VOCs	SOx	NOx	CO_2
Commercial Technologies Total	1043.63	187.80	35.6	6.74	151	110	76000
IAC Total	43.13	1.60	6.92	0.106	24.5	10.4	3130
Historical Technologies Total	520.81	N/A	81.1	1.24	288	126	41400
GRAND TOTAL	1607.57	189.40	124	8.08	463	246	12100

Figure 2 shows the net benefits curve (cumulative production savings minus program and implementation costs described in the previous section). The values shown for each year represent the cumulative energy savings (in inflation adjusted dollars) of all the technologies and programs, minus the cost of installing the technologies (assuming a two-year payback as described above) and also subtracting OIT's cumulative programmatic costs. The cumulative Federal costs for the OIT Programs through fiscal year 1999 total $1.70 billion. Cumulative energy savings from completed and tracked projects add to approximately 1.6 quadrillion Btu in 1999, representing a net cumulative production cost savings of $3.2 billion. These production cost savings represent the net total value of all energy saved by technologies developed in OIT programs plus any non-energy production cost savings, minus the cost to industry of using the technologies (estimated by assuming a two-year payback on investment) minus OIT Program costs. The graph shows that benefits substantially exceed costs.

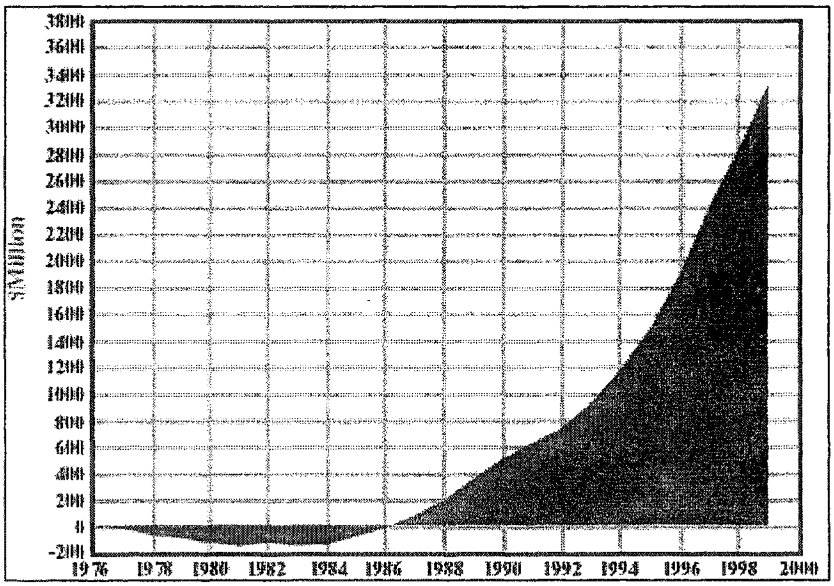

Figure 2. Cumulative Production Cost Savings Minus Cumulative Program and Implementation Cost.

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