EVALUATING THE ECONOMIC, ENERGY, AND ENVIRONMENTAL IMPACTS OF A TECHNOLOGY COMMERCIALIZATION PROGRAM

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Abstract

This paper describes the results of the latest evaluation of the Energy-Related Inventions Program (ERIP), one of the longest-running commercialization assistance programs in the U. S. Four performance metrics are used to evaluate the Program: (1) the market entry of new products, (2) commercial sales, (3) energy savings, and (4) greenhouse gas emissions reductions. The methodology used to estimate each metric is described, and the strengths and weaknesses of the metrics are discussed. The results of the Program evaluation are compared with other published program metrics, suggesting the Program's high success. Issues that must be addressed to fairly appraise public investments in technology commercialization programs are also highlighted.

Introduction

Over the past 15 years, numerous federal and state programs have been created to spur the development of technology-based new companies by providing commercialization assistance. The Energy-Related Inventions Program (ERIP) was one of the first programs to offer such assistance to small business and independent inventors, and its continuous operation since 1974 makes it one of the most long-standing commercialization assistance programs in the United States (U.S.).

Since the Program's inception, evaluators have systematically monitored the progress of the inventions it has supported. More than 100 case studies of ERIP inventions have been completed, and – in combination with survey data from 464 program participants – the evaluators have been able to identify characteristics of the technologies, inventors, markets, and business strategies that are common to commercial success, and those that typify commercial failures (Rorke and Livesay, 1986; Brown, et al., 1993; Livesay, Lux, and Brown, 1996). In addition, performance metrics have been compiled, providing quantitative estimates of the Program's costs and benefits (Brown, et al., 1994; Braid, et al., 1996; Brown, 1997). The objective of these metrics is to assess the effectiveness of ERIP by monitoring the progress of the inventions it has supported. These metrics have been used by the U.S. Department of Energy (DOE) in its strategic planning and to meet the requirements of the 1993 Government Performance and Results Act.

A wide range of impacts are addressed by the Program's performance metrics. The economic impacts have been measured in terms of the entry of new products into the marketplace, the creation of start-up companies, commercial sales of the technologies, licensing revenues, spin-off technologies, the generation and retention of jobs, and the return of tax revenues to the U.S. Treasury. Energy and environmental impacts of the Program have been measured in terms of the energy saved by ERIP technologies and the accompanying reduction in greenhouse gas emissions.

This paper describes four of the most important performance metrics resulting from the latest quantitative evaluation of ERIP: the market entry of new products, commercial sales, energy savings, and greenhouse gas emissions reductions. The methodology used to estimate each of these metrics is described, strengths and weaknesses of the metrics are discussed, and the results are compared with other published program metrics.

History and Operation of the Program

Established in 1974 under the Federal Nonnuclear Energy Research and Development Act (P.L. 93-577), ERIP is directed to assist the development of nonnuclear energy-related inventions with outstanding potential for saving or producing energy, "particularly those submitted by individual inventors and small companies." The goal is to help individual and small company inventors with promising technologies develop their inventions to a stage of development that would attract the investment necessary for private sector commercialization. Many of these technologies face significant market and industry barriers that reduce their ability to attract early funding and intensify the difficulties of product development. Individual and small business inventors often lack the business experience needed to surmount these hurdles.

Anyone can submit an invention at any stage of development to the Program for a free, confidential evaluation. The legislation provides for the National Institute of Standards and Technology (NIST), previously called the National Bureau of Standards, to evaluate the inventions submitted, assessing them for technical feasibility, energy conservation or supply potential, and commercial possibilities. Only two percent of the inventions pass through

[1]Oak Ridge National Laboratory is managed by Lockheed Martin Energy Research Corporation for the U. S. Department of Energy (DOE) under Contract DE-AC05-96OR22464.

the screening process and are recommended to DOE for technical and financial support.

DOE grants are provided to most of these recommendees to pay for technical research, prototype development, testing, and a variety of other activities that help move the technologies one step closer to the market. In addition, ERIP conducts Commercialization Planning Workshops for inventors in the Program. These Workshops were initiated in 1986, when it became clear from previous program evaluations that many inventors were failing in the marketplace because of their lack of business acumen. To find inventors and encourage innovation, ERIP holds several National Innovation Workshops each year in different regions of the country, jointly sponsored by local businesses, inventor organizations, and universities.

Since the Program's 1974 beginning, more than 31,000 inventions have been submitted to NIST for evaluation, and more than 650 of these have been recommended to DOE for support. Seventy-eight percent of these recommendees have received DOE grants averaging $78,000 (in current dollars). Approximately half of the Program's funding is spent by NIST to conduct the technical evaluation of applications to the Program, 15 percent is for DOE's program office (to support its Workshops, technical assistance, grant processing, and program evaluation), and 35 percent goes toward new grants. These proportions can vary from year-to-year, depending upon program needs.

Market Entry of ERIP Technologies

Methodology

From the Program's inception through 1993, a total of 609 applicants to the ERIP were recommended for DOE funding by NIST. These 609 inventions constitute the population of interest for all of the performance metrics described in this paper. Previous evaluations of the Program concluded that data could no longer be obtained for 159 of these inventions due to the deaths of several inventors, incomplete addresses, and refusals to participate in surveying. To reduce the cost of data collection while maximizing the coverage of successful ERIP technologies, a two-part sampling design was employed. The first subsample included 98 inventions identified by past research and key informants to be most promising in terms of market entry and commercial success. The second subsample contained the remaining 352 inventions. An attempt was made to reach all 450 inventors, but a special effort was made to contact the 98 promising inventors.

A 14-page questionnaire was developed to collect sales, employment, and other data through 1994. The questionnaire was mailed in two waves to program participants, and telephone surveying was used to contact nonrespondents among the promising inventions, to maximize their response rate. In total, data were collected on 211 inventions, or 47 percent of the 450 ERIP inventions. Historic information from previous evaluations is also available for 253 additional inventions.

Results

Significant progress has been made by ERIP inventions in terms of movement from concept development and laboratory experiments to prototype development and entry into the marketplace. By the end of 1994, 144 ERIP inventions are known to have achieved sales. This represents 24 percent of the population of 609 ERIP technologies, which is similar to the estimate of 23 percent provided by the evaluation conducted two years previously. Both figures are probably underestimates of the true percentage, since we were unable to collect information on all of the technologies.

Figure 1 provides the market entry rates for two-year cohorts of participants based on date of acceptance into the ERIP program. With the exception of the low success rate of the initial cohort, the earlier periods generally experienced a higher rate of market entry than the later cohorts. If the 609 technologies are divided into two nearly equal cohorts – pre- and post-September, 1985 – the rate of market entry is significantly higher for the earlier half (29 percent) than for the more recent half (18 percent). The more recent cohorts also include virtually all of the most recent market entries, but some of these new successes derive from technologies that joined the ERIP program as far back as 1984. This findings suggests the need to collect survey data for at least ten years after acceptance into the Program in order to account for all of the Program's market entries.

The 24 percent success rate compares favorably with the success rates of innovations as a whole. The widely cited Booz-Allen & Hamilton studies (Booz-Allen & Hamilton, 1982), for instance, reported that despite considerable investments in up-front stages of exploration, screening, and business analysis, it still takes seven new product efforts to get one product to market–that is, only 14 percent of new products are successfully introduced. Venture capitalists derive their profits from the one or two successes that offset the costs associated with nine or ten failures (Florida and Smith, 1993). These comparisons suggest that ERIP inventions are at least as successful as innovations generally, although meaningful comparisons are difficult to make because of differences between ERIP technologies and the types of products and technologies covered by other market entry statistics.

Another way to assess the Program's commercial progress is to compare the number of ERIP technologies that have experienced sales to the cost of the Program. From 1978 through 1994, ERIP expended $82 million (in current dollars). At least 144 of the technologies it has supported have entered the market. Comparable program statistics are available for (1) the Gas Research Institute (GRI), which has operated a research and development

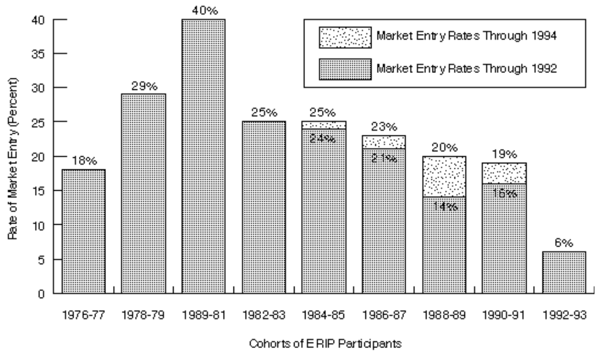

Figure 1. Rates of Market Entry Across Cohorts of Program Participants

(R&D) program since 1978, and (2) the European Community (EC), which has operated a promotion and exploitation program since 1968 (*Chemistry and Engineering News*, July 8, 1991). By early 1991, 111 new or improved products, processes and techniques had been sold or were in commercial service, due to GRI's R&D budget of $1.41 billion (Dombrowski, et al., 1991). By 1990, approximately 50 inventions supported by the EC had been put on the market as the result of several billion dollars of R&D funding. ERIP's accomplishments compare favorably with both of these other programs.

Commercial Sales of ERIP Technologies

Methodology

Data on annual sales of ERIP technologies have been collected by mail and/or telephone surveys that have been conducted every other year since 1984. To enhance the accuracy of these sales data, we shared the compilation of information from past surveying with the respondents in 1995, so that they could make any necessary corrections. In addition, case studies have been completed that include personal interviews with many of the most commercially successful inventors. This has allowed a first-hand assessment of the inventor's business and manufacturing facilities and detailed discussions about past and planned marketing activities, all of which have proven useful to corroborate the sales data. Occasionally, news releases, other media coverage, technical publications, and discussions with customers and licensees have helped to substantiate the inventor's sales data or have led to further surveying to resolve inconsistencies.

Results

It is estimated that the total cumulative sales of ERIP technologies from 1980 through 1994 is $774 million in current year dollars; this translates to nearly one billion (i.e., $961 million) of cumulative sales in 1994 dollars.

ERIP sales show an almost steady rise from $20 million in 1980 to $77 million in 1989 with the exception of a $5 million decline in 1984. A second sales decline in total sales of about $8 million was experienced in 1990, followed by a very substantial drop of $16 million more in 1991 to $53 million. The most recent three years have seen sales recover to $66 million, $61 million, and most recently, $71 million. Thus, since 1986, when the sales of ERIP technologies reached $62 million, the annual sales of ERIP technologies have fluctuated within a band ranging from $53 million to $77 million. Different mixes of technologies account for these sales each year, but the overall sales attributed to ERIP technologies have been relatively stable for the past nine years.

As is typical of new products and new technologies in general, there is great variation in the levels of sales generated by the ERIP technologies. Cumulative sales of individual inventions range from less than $10,000 to $132 million through the end of 1994. Sixty-nine (or almost half) of the inventions have had cumulative sales of less than $500,000. The average cumulative sales of these 144 ERIP technologies is $5.4 million, which is much larger than the median ($737,000) due to the impact of a small number of highly successful technologies. Over the years, detailed case studies have been conducted of the Program's most successful technologies, in order to ensure the validity of their sales and employment data, since they have such a strong influence on the Program's performance metrics.

As an indicator of the effectiveness of ERIP, the $961 million (in 1994 dollars) in cumulative sales generated by ERIP inventions can be compared with program appropriations and grant awards (i.e., "program costs"). Approximately $47.5 million (in 1994 dollars) in grants were awarded through 1994, and program appropriations totaled about $124 million. Thus, the ERIP program has generated a 20:1 return in terms of the value of sales to grants, and an 8:1 return in terms of sales to total program appropriations.

These ratios have remained remarkably steady since 1986. Only in the early 1980s, when the Program was less than a decade old, was the ratio of sales to program costs considerably lower. These results illustrate that there can be a considerable lag time in the ability to observe the overall benefits of commercialization programs. This fact is underscored by Figure 2, which shows that a considerable portion of the most recent commercial sales have been derived from program participants who were supported by ERIP in the late 1970s.

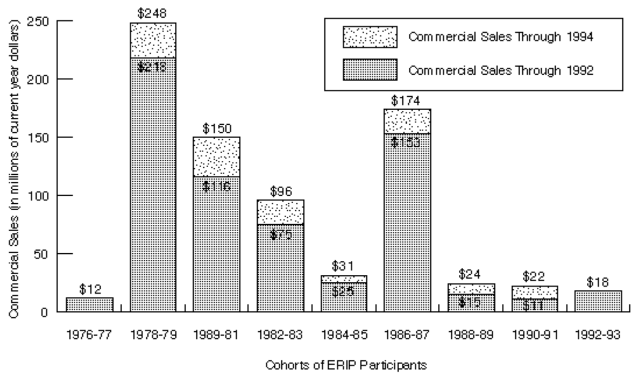

Figure 2. Levels of Commercial Sales Across Cohorts of Program Participants

The impressiveness of these statistics is underscored when compared to the sales performance of the Small Business Innovation Research (SBIR) Program, a much larger federal commercialization assistance program. Between 1983 and 1993, 11 federal agencies gave nearly 25,000 SBIR awards worth over $3.2 billion to more than 50,000 firms. While many of these investments are still maturing, it is estimated that by 1992, SBIR firms had received only $471 million in sales (U.S. Congress, Office of Technology Assessment, 1995, p. 81).

Another point of comparison is offered by New York's Manufacturing Extension Program (Nexus Associates, Inc., 1996). Between April 1993 and December 1994, New York State invested $12.9 million in manufacturing assistance. This resulted in a value-added impact of $29 to $108.7 million. ERIP invested $12.4 million in assistance to inventors during 1993 and 1994, and over that period the investments it has supported have generated $133.0 million in sales. Thus, the economic impact of ERIP compares favorably with that of the New York Manufacturing Extension Program.

Energy Savings

Methodology

The energy impacts resulting from the introduction of a new technology are difficult to estimate. One must consider a wide range of factors including:

- the energy consumed by technologies that the new technology has displaced,
- changes in the energy efficiency and cost of the new technology over its lifetime, and
- differences in the embodied energy required to produce the new technology and the technologies that are displaced.

Because of these complexities, it was not feasible to assess the energy saved by all of the ERIP-supported technologies that have entered the market. Instead, we examined the 15 ERIP-supported technologies that had achieved the greatest dollar value of cumulative sales through 1994 under the assumption that these represent the technologies that are likely to have generated the greatest energy benefits. Each of these 15 technologies was examined to assess the feasibility of producing an estimate of energy savings based on available documentation and resources to conduct the assessments. This process resulted in narrowing the analysis to five technologies. It is anticipated that future research will address the energy savings of some of the remaining technologies.

A similar set of steps was taken for each of the five technologies to estimate their energy savings. First, existing documentation on the technology was reviewed, including the NIST technical evaluation and information from previous Oak Ridge National Laboratory (ORNL) evaluations of the Program. Additional information on the technology was solicited from the inventor and/or the licensee, including documentation from third-party assessments of the technology and monitored demonstration projects. Information from secondary sources was compiled, such as statistics on fuel use and energy prices from the Energy Information Administration. Second, a preliminary analysis of energy savings was prepared by the Program evaluators and sent to a researcher at ORNL with expertise in the field of the particular technology. The preliminary analysis was then revised, based on comments by the expert. Third, the revised analysis was sent to the inventor and DOE for review. The analysis was then finalized based on feedback from these reviewers.

The five inventions that are examined to assess energy savings are described below. These technologies account for $362 million (or 45 percent) of the cumulative sales of ERIP inventions through 1994.

Brandon steam turbine packing rings**.** The steam turbine packing rings developed by Ronald E. Brandon are a modification to existing turbine packing rings. Packing rings are installed at various locations between the turbine stationary parts and the rotating shaft to minimize steam leakages between stages and at places where the shaft protrudes out of the turbine cylinder. The invention employs springs to keep the packing ring segments away from the turbine shaft during turbine start-up, when packing ring damage is most likely to occur. The Brandon replacement packing rings prevent damage over time that occurs with conventional packing rings due to start-up, thermal distortion, and shaft vibration. The efficiency loss due to original packing rings is assumed to progress linearly from zero percent to its maximum efficiency loss of one percent after five years. The Brandon steam packing rings prevent this gradual loss in efficiency.

Electronic Octane®. Developed by John A. McDougal, Electronic Octane® is an ignition control system used in automotive internal combustion engines. This system senses the onset of predetonation ("knocking" or "pinging") caused by either carbon deposits, valve and spark timing, and/or wall temperatures, and provides feedback parameters in order to retard the spark advance as necessary in individual cylinders. Predetonation or knock, if allowed to continue, is destructive to automotive engines. The design of conventional vacuum control spark ignition systems overcompensates for the potential for knock in one or two individual cylinders by reducing the spark advance more than necessary for the rest of the cylinders that are operating normally. This reduces engine efficiency in order to prevent knocking in the one or two cylinders that require more control than the others. At a mid-RPM range of 2800 RPM, a 2.2 percent efficiency gain is expected for engines with the individual knock control system compared to a "global" knock control system. In addition, a lower octane can be used.

SolaRoll®. Michael F. Zinn developed SolaRoll®. It is a solar collector that provides a low-cost method to provide solar heating to swimming pools. The majority of the pools having the SolaRoll® system installed are heated by conventional natural gas or electric heat pump systems. SolaRoll® is a flexible rubber tubing solar collector. The rubber components have a lifetime expectancy of 20 years or more. The SolaRoll® product has a relatively high efficiency accompanied by a low relative cost per square foot of collector area. SolaRoll® is used in both in-ground and above-ground pools. The average pool in the U.S. will likely realize an annual reduction of 55 percent in heating costs. The use of a SolaRoll collector and associated equipment will result in annual energy savings of 42 million Btus for a pool heated with a conventional gas-fired system; the annual savings will be approximately 11 million Btus for a pool heated by a heat pump system.

System 100®. Alex Rutshtein and Naum Staroselsky developed System 100®. The purpose of the System 100® control system is to permit the efficient use of large centrifugal and axial compressors employed in process applications such as refineries and gas transmission pipelines. System 100® allows a compressor to operate closer to its surge limit, increases stall protection, and generally enables the compressor to operate in a more efficient region. Prior to the System 100®, the traditional control method used for compressors powering the natural gas flow on gas transmission pipelines was either a manual or the more common, two-function controller. The two-function controller regulates the blow-off valve (regulating pressure across the compressor) and the speed of the compressor drive independently, and must be detuned to prevent system oscillation. This reduces system efficiency, especially in high speed compressors. System 100® provides integrated control of compressor speed and output pressure, allowing the compressor to operate more efficiently. Energy savings, depending on the application, are typically in the 5 percent to 10 percent range, which translates to annual savings of approximately 23.5 million cubic feet of natural gas per unit installed.

Thermefficient-100®. Developed by Harry E. Wood, Thermefficient-100® is a high efficiency gas-fired water heater that allows most of the total heat of combustion of the unit to be utilized. A direct-contact heat exchanger using packed rings or a similar adaptation operates in a counterflow arrangement such that the combustion product's exhaust temperature is very close to the temperature of the incoming water. In conventional water heaters, the latent heat of vaporization of the combustion produced water is totally lost. The Thermefficient-100® system has a thermal efficiency close to 100 percent compared to approximately 70 percent for conventional water heaters. The design allows heated water to collect at the bottom of the water storage tank with no start-up time required for water temperature to increase to normal operating temperature. The Thermefficient-100® system is very compact, requiring only 32 percent of the floor space of a conventional water heater of equivalent capacity.

Results

The cumulative energy savings for sales of the five technologies are shown in Table 1. These cumulative values are the total of annual energy savings through 1994. In total, it is estimated that these five technologies saved 0.58 Quads of energy between 1980 and 1994. In 1994 alone, it is estimated that these five technologies saved 0.116 Quads of energy. This is enough to meet the United States' energy requirements for 12 hours.

The energy savings by fuel type for the Brandon replacement packing rings was estimated by using the distribution of annual sales of the packing rings from 1986 through 1994, by primary fuel of the turbines fitted. It is assumed that turbines can be operated for a maximum of 8,760 hours per year at an average capacity of 75 percent. The average size of turbine capacity in the U. S. of coal, natural gas, and oil units was utilized to complete the apportionment of total estimated energy savings (Energy Information Administration, 1991). The percentage of energy savings by fuel type for the packing rings is as follows:

- Coal — 78.7 percent
- Natural gas — 9.0 percent
- Oil — 12.3 percent

These percentages multiplied by total energy savings for the packing rings in 1994 result in the following energy savings in trillion Btus: for coal—26.1, natural gas —2.98, and oil—4.08.

Table 1. Cumulative Energy Savings of Five ERIP Technologies, Through 1994

	Brandon Packing Rings	Electronic Octane®	SolaRoll®	System 100®	Therm-efficient-100®	Total
Years in the Market	1986-94	1984-94	1980-94	1980-94	1981-94	—
Energy Savings (in Trillions of Btus)	108.8	51.9	21.7	362.1	31.4	575.8

The Electronic Octane® is utilized in eight automobile models. For each of these models, data were collected on sales by year. Annual mileage was assumed to be 55 percent city and 45 percent highway, and the total mileage driven each year, per auto, was assumed to be the average for all passenger cars that year. A survival rate was applied to account for normal scrappage. Energy savings is calculated by multiplying annual gasoline consumption by 0.0216, which is the fraction of gasoline saved by Electronic Octane®. Based on these calculations it is estimated that this ERIP technology saved approximately 7.61 trillion Btus of gasoline in 1994, which translates to 1.45 million barrels of gasoline, or 2.9 million barrels of oil.

The energy saved by SolaRoll® is estimated using the total square footage of the product sold by year between 1979 and 1994. Based on a model of swimming pool energy costs, it is assumed that SolaRoll® saves 0.0233 million Btu/sq. ft/year for pools using electric heat pumps and 0.089 million Btu/sq. ft/year for pools heated by natural gas. We assume that 70 percent of the square footage of SolaRoll® is applied to gas-heated pools, and 30 percent to electrically heated pools. To determine the amounts of individual fuels saved by the displaced electricity, we assume that 60 percent of electricity is generated by coal, 8 percent by gas, and 2 percent by oil. Based on these assumptions, it is estimated that SolaRoll® saved 2.45 trillion Btus of energy in 1994. These savings include 25,000 tons of coal, 3,042 barrels of oil, and 2,220,000 thousand cubic feet of natural gas.

The energy savings for System 100® was based on the number of units sold each year between 1980 and 1994. We assume that sales of the systems are evenly divided between natural gas-powered pipeline compressors (with average annual savings of 27.82 billion Btus per system) and steam-powered industrial compressors (with average annual savings of 20.21 billion Btus per system). Based on these assumptions it is estimated that System 100® installations to date saved 66.34 trillion Btus of natural gas in 1994. This savings amounted to 64,349,800 thousand cubic feet of natural gas.

Thermefficient-100® water heaters have increased in both hours of use and energy use per hour, since 1981 when they first entered the market. These changes are due to a trend toward consolidation in the industries using the hot water systems. The energy consumption of the Thermefficient-100® technology is calculated as the product of hours of usage per year (2,000 hours in 1981, rising by 200 hours/year to 4,000 hours of usage in 1991) and energy use per hour (4 million Btus in 1981, rising to 4.6 million Btus in 1988 and 7.0 million Btus in 1992). Conventional industrial water heaters are assumed to consume 1.43 times as much energy, based on their relative thermal efficiencies. The energy savings is then the difference between conventional use and Thermefficient-100® use. Based on the methodology, the Thermefficient-100® water heater saved 6.448 trillion Btus of natural gas in 1994. This translates into 6,254,230 thousand cubic feet of natural gas saved.

A summary of energy savings in 1994 by fuel type for the five technologies is presented in Table 2. The equivalent energy savings in trillion Btus are presented in Table 3.

The value of the energy saved by each of the five technologies is dependent on the price of the particular fuel saved. The energy saved by the Brandon replacement packing rings is priced by the cost of fossil fuels faced by electric utilities. The approximate cost of fossil fuel energy for an electric utility in 1994 is $1.53 per million Btus (Energy Information Administration, 1996). Therefore, the value of the energy savings in 1994 for the turbine units having the Brandon rings installed between 1986 and 1994 is approximately $51 million in 1994 dollars (33.166 trillion Btus X 1.53 $/million Btus = 50.74 million dollars).

Table 2. Energy Savings by Fuel Type and Value, in 1994

Technology	Coal (tons)	Oil (barrels)	Natural gas (KCF)
Brandon packing rings	1,262,589	653,645	2,900,000
Electronic Octane®	—	2,896,000	—
SolaRoll®	25,231	3,042	2,220,000
System 100®	—	—	64,349,800
Thermefficient-100®	—	—	6,254,230
Total	1,287,820	3,552,687	75,724,030

KCF=thousand cubic feet.

Table 3. Energy Savings, in Trillions of Btus, in 1994

Technology	Coal	Oil	Gas	Total
Brandon Packing Rings	26.10	4.08	2.98	33.16
Electronic Octane®	—	7.61	—	7.61
SolaRoll®	0.15	0.01	2.23	2.39
System 100®	—	—	66.34	66.34
Thermefficient-100®	—	—	6.45	6.45
Total	26.25	11.70	78.00	115.95

The value of the energy savings in 1994 for sales of autos reported to have the Electronic Octane® technology installed is estimated to be $71.3 million in constant 1994 dollars. This value was calculated using the estimate of energy savings in gallons (1.45 million barrels of gasoline), times the average annual price of unleaded regular gasoline of 1.17 $/gal (we used regular unleaded gasoline for most auto brands and premium unleaded gasoline for those automobile brands having high compression engines).

The value of energy savings in 1994 for sales of SolaRoll® during the 1980 through 1994 period is $27.6 million in 1994 dollars. This value was based on an estimated annual savings of $253 in heating costs, per pool, attributed to the use of SolaRoll® (RSPEC, 1993). Further, cumulative sales figures indicate that in 1994 approximately 108,923 pools used SolaRoll® ($253/pool x 108,923 pools = $27.6 million).

The value of energy savings in 1994 for sales of System-100® for the 1980 through 1994 period equal $157.7 million in constant 1994 dollars. This was calculated using a composite price of $2.45/thousand cubic feet (KCF) of natural gas (Energy Information Administration, 1996) ($2.45/KCF x 64.35x106 KCF = $157.7 million).

The value of energy savings in 1994 for sales of Thermefficient-100® units during the 1980 through the 1994 time period is $26.5 million in constant 1994 dollars. This value was calculated using the 1994 estimate of energy savings in KCF of natural gas times the average annual price of natural gas [we used the average natural gas price for commercial and industrial users (Energy Information Administration, 1996)]. This calculation also takes into consideration the increase in hours of operation, per unit, from 2,000 hours/year in 1981 to 4000 hours/year in 1994 (6.254 x 106 KCF x $4.24/KCF = $26.5 million). This increase in hours of operation is largely attributed to consolidation in the industries utilizing the hot water systems.

For the purposes of this analysis, we have estimated a very simple payback by calculating the time period over which the cumulative energy savings will be equivalent to the initial capital costs of the new technology. A more sophisticated payback calculation, which would take into account such factors as reduction of downtime, reduced operations and maintenance costs and product longevity, cannot be calculated with the data available at this time. The value of energy savings and cost effectiveness (measured by payback period) for the five technologies are shown in Table 4. The value of the total 1994 energy savings for the technologies is $333.8 million. The payback periods for the five technologies — calculated by dividing the cost of the new technology by the annual energy savings in 1994 dollars — range from 2 to 8.3 years.

Table 4. Value of Energy Savings in 1994

	Brandon Packing Rings	Electronic Octane®	SolaRoll®	System 100®	Thermefficient 100®	Total
Value of 1994 energy savings (in million 1994 $)	50.7	71.3	27.6	157.7	26.5	333.8
Payback period (yrs)	3.51	3.91	8.3	2[a]	4.68	—

[a]Costs for this technology are difficult to estimate because of associated equipment costs. A payback period for a similar system was estimated to be under two years (Devlin, et al., 1992).

Reduction of Greenhouse Gas Emissions

Methodology

The magnitude of the reductions in greenhouse gas emissions that have resulted from ERIP is estimated from the energy savings calculated for the five ERIP technologies described above. Knowing the amount of different types of fuels that have been conserved, we turned to publications of the Energy Information Administration (1995) to assess the resulting carbon and methane reductions. In order to have a single yardstick by which reductions in greenhouse gas emissions can be compared, emissions of carbon and methane are reported both individually and in terms of CO_2 equivalents. The CO_2 resulting from the emission of elemental carbon is calculated by multiplying units of carbon by 3.67, the proportional difference in molecular weights. The factor for converting methane into CO_2 equivalents is 35, since methane has 35 times the warming potential of CO_2.

Results

In 1994, the five ERIP technologies reduced carbon emissions by an estimated 2.1 million metric tons and methane emissions by an estimated 102.5 metric tons. This results in a total reduction of the equivalent of approximately 7.5 million metric tons of CO_2. This reduction in greenhouse gas emissions is equivalent to removing 2.3 million cars from U.S. roadways.[2]

Tables 5 and 6 present estimates of the reductions in emissions of carbon and methane in 1994 associated with the sales to date (1980-1994) of Brandon packing rings, Electronic Octane®, SolaRoll®, System 100® and Thermefficient-100®. The base data for greenhouse gas emissions come from the Energy Information Administration (1995b), and energy use data required for the estimates come from the Energy Information Administration (1996).

The estimates of methane reductions are comprehensive for coal, but they do not include methane emissions associated with production, transmission, and distribution of natural gas. The bulk of methane emissions from natural gas occurs during those steps rather than during end use, and inclusion of reductions in those emissions as well would multiply the estimates in Table 5 by a factor of 135.

These reductions of CO_2 equivalent emissions in 1994 (from sales during 1980-1994) are shown in Table 7.

Conclusions

Many issues must be addressed to fairly appraise public investments in technology commercialization programs. These include: (1) the need to track the progress of program participants for extended periods; (2) threats to the external and internal validity of program evaluations; and (3) challenges created by performance data that are dominated by a small number of highly successful technologies. These issues are discussed below.

Evaluations of public investments in technology commercialization programs are made difficult by the fact that inventions can take five to ten years, or more, to move from the laboratory to the marketplace. As a result, evaluators need to track the progress of program participants for extended periods. In addition, determining what portion of the impacts are attributable to the Program can be difficult. For future evaluations of ERIP, the U.S. Department of Energy is considering an across-the-board limitation that would restrict the period for calculating benefits to 12 years from the first commercial sale of the invention. This would help prevent DOE from taking unwarranted credit for its assistance.

The internal and external validity of program evaluations are critical to the defense of evaluation results (Campbell and Stanley, 1971). Internal validity refers to the validity of the estimated program impacts for the sample selected. Are the impacts attributable to the Program, and can alternative explanations be ruled out? External validity refers to the ability of the sample-based results to be extrapolated to one or more larger populations. Is the sample representative, and can results be extrapolated to other participants, or to next year's participants? Because

[2]This calculation is based on the following statistics: the transportation sector in the U.S. produced 446 million metric tons of carbon emissions in 1994; 39.1 percent of these emissions were the result of the 190.4 million passenger cars operating in the U.S. (U.S. Department of Transportation, Bureau of Transportation Statistics, 1994, pages 17 and 152). Thus, each passenger car produces 0.913 metric tons of carbon emissions each year.

they are difficult and costly to assess, internal and external validity were the subject of special studies conducted only once during the years that ERIP has been evaluated.

- In 1994, a test for internal validity was conducted that compared ERIP technologies to a sample of 79 inventions labeled "program referrals" (Brown, Curlee, and Elliott, 1995). The results indicated significant differences in terms of several indicators of commercial success. These findings supported the supposition that ERIP technologies enjoy greater success than programs referrals, and that ERIP technologies achieved their considerable commercial success at least in part because of the support provided by the Program.
- The second special study involved an assessment of nonresponse bias (Brown, et al., 1994). Specifically, a sample of 11 nonrespondents was interviewed to determine whether or not it was feasible to generalize from responding participants to the entire population of participants. It was concluded that generalizations from respondents were justifiable only for indicators that measure progress to date (such as those discussed in this paper), and not on measures of current activity or likely future progress, since respondents generally were more actively engaged in the development of their technologies compared with nonrespondents.

These studies have provided valuable evidence for rebutting critics of the evaluation's findings.

Finally, sales data are the foundation of the ERIP evaluation–they are used to estimate the economic, energy, and environmental performance metrics described in this paper, and they also are the foundation for estimating employment impacts, tax revenues, and other metrics that are discussed elsewhere (Brown, 1997). However, sales have a positively skewed distribution, such that the total sales summed across all participants are significantly influenced by a small number of highly successful inventions. The accuracy of the sales data from these "big hits" requires extra attention in order to be confident of the Program's performance metrics. This has been accomplished in the ERIP evaluation through selected case studies and the use of multiple data sources, where possible.

The result of the evaluation activities described in this paper is a series of program metrics that, when compared with performance indicators from other technology innovation efforts, suggest that ERIP has been a cost-effective government investment. By the end of 1994, at least 144 ERIP inventions (or 24 percent of the 609 participating inventions) had entered the market, generating total cumulative sales of $961 million (in 1994–$). With $124 million in program appropriations from 1975 through 1994, ERIP has generated an 8:1 return in terms of sales to program costs. Based on case study data, it is concluded that 116 trillion Btus of energy and $334 million of energy expenditures were saved in 1994 as a result of the commercial success of five ERIP technologies. These energy savings resulted in reduced emissions of 2.1 million metric tons of carbon in 1994.

Table 5. Reduction in Carbon Emissions in 1994, in Metric Tons

	Coal	Oil	Gas	Total
Brandon Packing Rings	671,031	84,538	43,121	798,690
Electronic Octane®	—	163,082	—	163,082
SolaRoll®	3,857	207	32,268	36,332
System 100®	—	—	959,940	959,940
Thermefficient-100®	—	—	93,332	93,332
Total	674,888	232,607	1,128,661	2,051,376

Table 6. Reduction in Methane Emissions in 1994, in Metric Tons (excluding emissions in associated production, transmission, and distribution)

	Coal	Oil	Gas	Total
Brandon Packing Rings	17.4	—	3.2	20.6
Electronic Octane®	—	—	—	—
SolaRoll®	0.1	—	2.5	2.6
System 100®	—	—	72.3	72.3
Thermefficient-100®	—	—	7.0	7.0
Total	17.5	—	85.0	102.5

Table 7. Reductions in Emissions of CO_2 Equivalents from Carbon and Methane

Component	Metric Tons	Factor Converting to CO_2 Equivalents	Metric Tons of CO_2 Equivalent
Carbon	2,036,156	3.67	7,472,693
Methane	102.51	35	3,588
Total	—	—	7,476,281

Acknowledgments

The research reported in this paper was sponsored by DOE's Office of Energy Efficiency and Renewable Energy. The authors acknowledge and appreciate the contributions of Charlotte Franchuk, Bob Wilson and Bob Braid to the completion of this research.

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