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OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

The Economic, Energy, and Environmental Impacts of the Energy-Related Inventions Program

Marilyn A. Brown
C. Robert Wilson
Charlotte A. Franchuk
Steve M. Cohn
Donald Jones

MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
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Marilyn A. Brown
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Charlotte A. Franchuk

With assistance from:

Steve M. Cohn
Donald Jones

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NOTICE This document contains information of a preliminary nature. It is subject to revision or correction and therefore does not represent a final report.

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ABSTRACT

This report provides information on the economic, energy, and environmental impacts of inventions supported by the Energy-Related Inventions Program (ERIP)—a program jointly operated by the U.S. Department of Energy and the National Institute of Standards and Technology (NIST). It describes the results of the latest in a series of ERIP evaluation projects that have been completed since 1980. The period of interest is 1980 through 1992. The evaluation is based on data collected in 1993 through mail and telephone surveys of 253 program participants, and historical data collected during previous evaluations for an additional 189 participants.

As of October 1991, a total of 557 inventions were recommended to DOE by the National Institute for Standards and Technology, which screens all submitted inventions for technical merit, potential for commercial success, and potential energy impact. By the end of 1992, at least 129 of these inventions had entered the market, generating total cumulative sales of $763 million (in 1992 dollars). The success of ERIP inventors is also shown in their licensing revenues. It is estimated that in 1992 ERIP inventors earned royalties of $1.0 million, and over the lifetime of the program, royalties total $18.6 million. With $41 million in grants awarded from 1975 through 1992, and $106 million in program appropriations over the same period, ERIP has generated a 19:1 return in terms of sales values to grants, and a 7:1 return in sales versus program appropriations. At least 23% of the 557 ERIP inventions had achieved sales by the end of 1992. Comparisons between these performance indicators and measures of the success of other technological innovations suggests that the ERIP figures are impressive.

The commercial progress of spinoff technologies is also documented. Altogether, 36 spinoff technologies have generated sales of $63 million (in 1992 dollars). Further, it is estimated that at least 668 full-time equivalent employees were working on ERIP technologies in 1992, and that this resulted in a return of approximately $2.7 million in individual income taxes to the U.S. Treasury. Finally, more than $531 million of energy expenditures has been saved over the past decade as a result of the commercial success of three ERIP projects. These energy savings have resulted in reduced emissions of nearly one million metric tons of carbon. An analysis of sources of funding provides additional evidence of positive program impacts.

EXECUTIVE SUMMARY

This report presents the results of an evaluation of the economic impacts of the Energy-Related Inventions Program (ERIP), a joint program of the U.S. Department of Energy (DOE) and the National Institute of Standards and Technology (NIST). The evaluation was undertaken primarily to obtain up-to-date information on the commercial progress of ERIP inventions—including the market entry of ERIP technologies and the resulting sales and jobs. In addition, the evaluation seeks to: (1) estimate the energy and environmental benefits of ERIP technologies, (2) document and assess the amount and sources of funds that have been used to develop ERIP inventions, and (3) identify other commercial products that have spun off from ERIP projects.

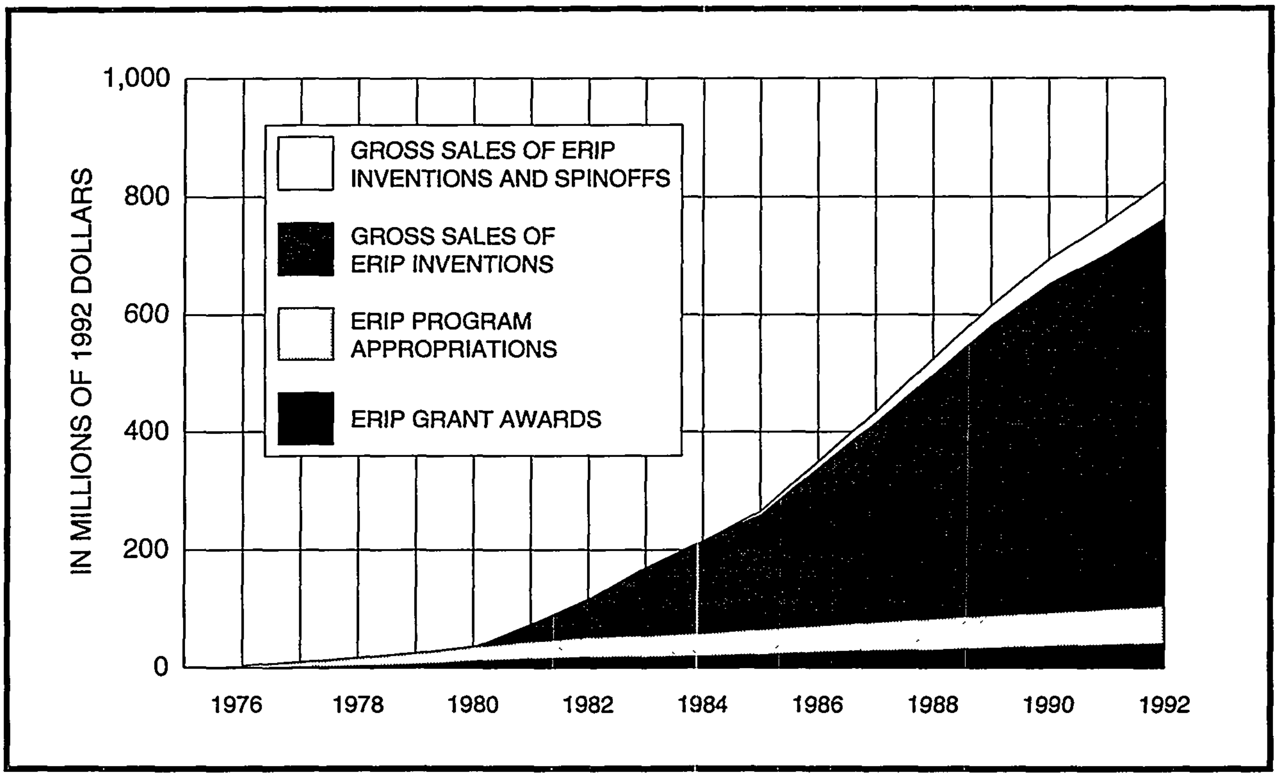
As of October 1991, a total of 557 inventions were recommended to DOE by NIST, which screens all submitted inventions in terms of technical merit, likelihood of commercial success, and potential energy impact. To reduce the cost of data collection while maximizing the coverage of successful ERIP technologies, a sampling design involving two subsamples was employed. The first subsample includes 133 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 424 inventions. An attempt was made to reach all 557 inventors, but a special effort was made to contact the subsample of 133 promising inventors.

A 16-page questionnaire was developed to collect sales, employment, fund-raising, and other data for 1991 and 1992. Ultimately, survey data were collected from 253 inventors (105 promising inventors and 148 of the other inventors), or 45% of the 557 ERIP inventors. Most of the surveys were conducted by mail (N=197), and the remaining (N=56) by telephone. Nonresponse bias was found to exist, but could be addressed in the data analysis. Historic information from previous evaluations is also available for 189 additional inventors, bringing the total sample size to 442 of the 557 inventions.

Analysis of the survey data reveals that 1991-92 was a successful period for many ERIP technologies.

- By the end of 1992, at least 129 ERIP technologies had entered the market, representing a 23% commercialization rate.
- These 129 technologies generated total cumulative sales of $763 million (in 1992 dollars).
- In 1992 ERIP inventors earned royalties of $1.0 million, and over the lifetime of the program, royalties total $18.6 million.
- With $41 million in grants awarded from 1975 through 1992, and $106 million in program appropriations over the same period, ERIP has generated a 19:1 return in terms of sales values to grants and a 7:1 ratio of sales to program appropriations.

An analysis of spinoff technologies provides numerous examples of derivative Program impacts. Over time, spinoff technologies have grown in importance as by-products of the Program. Altogether, 36 spinoff technologies have generated sales of $63 million (in 1992 dollars). Most of these involve alternative market applications, but some of them are second-generation technologies. Thus, the Program's total cumulative sales are $826 million when the sales of ERIP's spin-offs are included. Figure A.1 portrays the cumulative sales of ERIP's inventions and spinoff technologies over the lifetime of the program, and compares these values to ERIP program appropriations and grants.



[a] Based on constant 1992 dollars.

Fig. A.1 Cumulative Sales of ERIP Inventions and Spinoff Technologies[a]

During earlier years of the Program, the market entry of ERIP technologies far outpaced the market exits. Since 1984, the number of technologies entering the market each year has been approximately counterbalanced by the exit of older technologies from the market. Through this process, the total number of technologies in the marketplace in any one year has remained relatively stable—ranging from 57 to 64. Nevertheless, fewer ERIP technologies were in the market in 1991 and 1992 than in the five earlier years, indicating a slight slow-down in the commercial success of ERIP technologies. This may reflect the general economic downturn experienced by the U.S. during the same two years.

Limited financial resources inhibit the development of many of those ERIP inventors who have yet to achieve sales or whose sales have not yet been significant. The ERIP technologies surveyed in 1993 were able to raise \$3.88 for every ERIP grant dollar received:

- \$0.93 of this was raised prior to application to the Program,
- \$0.94 was raised while their application was being processed, and
- \$2.01 was raised after receipt of their ERIP grant.

ERIP technologies that have entered the market have attracted different quantities and types of funding relative to those that have not yet entered the market. On average, ERIP inventions with sales were able to raise \$927,000, while those without sales garnered only \$326,000. Personal sources provide the majority of funding prior to application to ERIP, both for those with and without sales, but these resources are typically exhausted during the developmental cycle. After receipt of the ERIP grant, corporate and commercial sources of funding become more important, especially for inventions that experience sales. Follow-on funding from other federal agencies is relatively unimportant for those inventors who have successfully reached the market, but has been a valuable source of support for those not yet in the market.

In addition to creating new businesses, products, and sales, ERIP participants have also produced significant employment and tax benefits.

- At least 668 full-time equivalent employees were working on ERIP technologies in 1992.
- Assuming the national per capita earnings for these workers, this employment is associated with a return of approximately \$2.7 million in individual income taxes to the U.S. Treasury.

Additional tax revenues are associated with royalty payments on ERIP inventions, corporate income taxes, state and local sales and income taxes, and personal income taxes paid by indirect employment beneficiaries of the program.

Finally, this evaluation assessed the energy and environmental benefits associated with ERIP technologies.

- More than \$531 million of energy expenditures has been saved over the past decade as a result of the commercial success of three ERIP projects.
- These energy savings have resulted in reduced emissions of nearly one million metric tons of carbon.

Table A.1 presents some of the indicators of program impacts that are discussed in the report. Comparisons between these performance indicators and measures of the success of other technological innovations suggests that the ERIP figures are impressive.

Table. A.1 Indicators of Program Impacts

Category of Benefit	Indicator of Program Impact
Market Entries	• At least 129 ERIP technologies commercialized, representing a 23% commercialization rate.
Sales	• $763 million (in 1992 dollars) of sales generated by these 129 technologies through 1992.
Licensing Revenues	• $18.6 million (in 1992 dollars) for licensed sales of ERIP technologies through 1992.
Spinoffs	• An additional $63 million in sales generated by 36 spinoff technologies.
Funds Raised	• $2.01 raised by inventors after receipt of ERIP grant for every ERIP grant dollar.
Jobs	• 668 full-time equivalent jobs directly supported by ERIP technologies in 1992.
Taxes	• $2.7 million in ERIP-related tax revenues returned to the U.S. Treasury through 1992.
Energy Savings	• $531 million (in 1992 dollars) of energy expenditures saved by three ERIP technologies
Environmental Benefits	• Carbon emissions reduced by almost 1.0 million metric tons, as the result of three ERIP technologies

1. INTRODUCTION

1.1 GOALS OF THE EVALUATION

Since the inception of the Energy-Related Inventions Program (ERIP), the U.S. Department of Energy (DOE) has systematically monitored the progress of the inventions it has supported. Case studies of ERIP inventions have been completed (Rorke and Livesay, 1986), and the economic impacts of the Program have been assessed (Brown, et al., 1987; Brown and Snell, 1988; Brown and Wilson, 1990). Past evaluations have also examined characteristics of the inventions, inventors, markets, and business strategies that contribute to success. This report presents the results of the most recent evaluation of the Energy-Related Inventions Program.

The evaluation was undertaken primarily to obtain up-to-date information on the economic, energy, and environmental impacts of ERIP-supported inventions. In addition, the evaluation seeks to answer a wide array of questions relevant to the mission and operation of the Program, such as:

- How successful has licensing been as a strategy for commercializing ERIP's technologies?
- How much does it cost for ERIP inventors to commercialize their technologies, and which sources of funding provide the greatest financial support?
- Which types of ERIP assistance are valued most by program participants?

These and many more questions are addressed within this report.

1.2 OVERVIEW OF THE PROGRAM

Established in 1974 under the Federal Nonnuclear Energy Research and Development Act (P.L. 93-577), the Energy-Related Inventions Program 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 (NBS), to evaluate the inventions submitted, assessing them for technical feasibility, energy conservation or supply potential, and commercial possibilities. The most promising inventions are recommended to DOE for consideration of 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. 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 625 of these have been recommended to DOE for support. Approximately 80% of these recommendees have received DOE grants averaging $77,000.

1.3 MEASURES OF PROGRAM SUCCESS

A program such as ERIP has an impact on diverse stakeholder groups (such as independent inventors, the business community, policy makers, and taxpayers), each of which evaluates the program's success in different ways. Inventors want to know the benefits of program participation in terms of technical assistance, commercialization planning, and help with the subsequent acquisition of funding. The business community might want to know about the relationship between the program and the creation of viable businesses, then would evaluate the technologies in terms of profit margins, sales levels, return-on-investment, or comparative advantage. Policy makers are concerned about whether the program meets its objectives of conserving or producing energy, the creation of new businesses and employment, and development of promising new energy technologies. Taxpayers are most concerned about the relationship between program costs and the extent to which these costs are counterbalanced by economic returns to the treasury. This evaluation attempts to address at least some of the concerns of all of these stakeholder groups.

1.4 OVERVIEW OF THE REPORT

This report begins by describing the evaluation design employed here, including the sampling strategy and collection of data (Chapter 2). Results are presented in the remaining chapters. Chapter 3 focuses on the market status of ERIP inventions and estimates of invention sales. Chapter 4 documents the commercial impact of the inventions and products that spin off from the technology, market, and business developments supported by the Program. Chapter 5 examines the employment and tax revenues generated by the program. Attention then turns to the funds raised by program participants (Chapter 6). The energy and environmental impacts of the Program are described in Chapter 7. The report ends with an analysis of participant ratings of Program assistance and a brief discussion of its findings (Chapter 8).

Along with presenting current statistics for the Program and its technologies, previous research is reviewed and findings compared with the results for ERIP. In addition, a special effort is made to compare and contrast the commercial success of different cohorts of ERIP technologies over different time periods in order to assess longitudinal aspects of the Program and the technologies it has supported.

2. EVALUATION DESIGN

2.1 SAMPLING STRATEGY

The sampling strategy for the 1993 evaluation of economic impacts is by far the most extensive in the history of the ORNL evaluation effort. In particular, it represents the first attempt since 1985 to collect information on the entire population of ERIP inventions, and it involves an analysis of nonrespondents to the data collection survey.

Between October 1, 1976, and September 30, 1991, a total of 557 inventions were recommended to DOE's Energy-Related Inventions Program by the National Institute of Standards and Technology. These inventions are described in the most recent ERIP annual status report (U.S. Department of Commerce, 1993), and they are the technologies of interest to this evaluation.

Previous ERIP evaluations reduced survey costs by drawing samples of ERIP technologies for surveying. This was necessitated by the heavy reliance on costly telephone interviewing. The most recent evaluation (Brown, Wilson, and Franchuk, 1991) represented the first attempt to rely primarily on mail surveying, supplemented by telephone interviewing. Because of the success with that experience, the evaluators decided to mail a questionnaire to the entire population of ERIP inventors as the primary means of collecting data for the current evaluation.

Two samples of inventions were used to conduct targeted telephone surveying of nonrespondents to the mail survey. The goals of this universal mailing combined with a targeted followup of nonrespondents were (1) to survey enough of the inventions so that the entire population of 557 technologies could be characterized, (2) to collect information on as many as possible of the most successful inventions, and (3) to collect information on a sample of nonrespondents so that nonresponse bias could be assessed.

The first sample contained 133 inventions that were judged to be especially "promising" in terms of the likelihood of market entry and commercial success. This sample of "promising" inventions was identified from the results of past ORNL evaluations and by the Program's invention coordinators. A targeted effort to contact this sample maximized the inclusion of the most successful inventions in the impact evaluation.

The second sample was randomly drawn from the set of 424 inventions that were not earmarked as promising (i.e., the population of 557 inventions minus the sample of 133 promising inventions). At the time the sample was drawn, there were approximately 320 nonrespondents among these "other" inventions. The 10% random sample of other inventions therefore contains 32 inventions. A targeted effort to contact this sample allows us to test for nonresponse bias (see Section 2.3).

2.2 DATA COLLECTION

Data collection was initiated during the summer of 1993 by mailing a 16-page questionnaire to all 557 ERIP participants. The questionnaire was divided into sections that dealt with:

- technology description
- contact and inventor information
- distribution strategy
- development timeline
- field tests and demonstrations
- sales data and licensing revenues
- employment
- spinoff technologies
- sources of funding
- technology characteristics
- ratings of types of ERIP assistance
- additional comments

(A blank copy of the questionnaire is reproduced in Appendix A.)

While most of these lines of inquiry have been pursued over several years as part of the ERIP evaluation effort, several of them represent either new treatments of issues considered years ago, or entirely new issues for the evaluation effort. The role of field tests and demonstrations in technology commercialization is one example of a new issue for the impact evaluation. While a series of case studies on experiences with demonstration was conducted for the ERIP in 1992, this is the first time that the ERIP evaluation questionnaire has sought data concerning field tests and demonstrations. Similarly, the 1993 impact evaluation solicited ratings of the value of different types of ERIP assistance. Previous case studies of ERIP-supported inventions have asked for feedback on the performance of the program. However, this impact evaluation represents the first time that systematic ratings of ERIP assistance have been obtained from large numbers of ERIP participants.

Those 343 participants who had been interviewed during previous evaluations were sent a questionnaire that was completed, as much as possible, from information in the existing ORNL database. The 214 participants who had not been included in any of the previous impact evaluations were mailed a questionnaire that was blank except for the information on the contact, inventor, and a technology description obtained from DOE and NIST files. Thus, all of the questionnaires covered the same topics, but they differed in terms of the amount and types of data that they contained when mailed to each respondent. In addition to collecting new data, the mail survey offered an opportunity for previously interviewed ERIP participants to review the data collected from them during earlier evaluations.

After the one-month deadline for return of the mail survey, nonrespondents were mailed a second questionnaire. A national residential telephone directory on CD ROM[1] was used to locate approximately ten inventors who had moved since the Program last contacted them. In addition, letters to Postmasters regarding 32 returned questionnaires resulted in 6 completed surveys.

Altogether, 191 of the 557 participants returned their questionnaires by mail as a result of these two mailings. An additional 6 respondents completed their survey by telephone, bringing the total number of respondents to 197 (Table 2.1). The response rate for the promising inventions (60

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1 PhoneDisc (R) CD.ROm, Version 3.17.04, Software Copyright 1986-1993 Digital Directory Assistance, Inc.

out of 133 or 45%) was considerably higher than the response rate for the other inventions (137 out of 424 or 32%).

Data were collected for an additional 56 technologies as the result of targeted follow-up interviewing of nonrespondents. Most of these targeted interviews involved promising inventions (N=45); only 11 were from the random sample. All but 8 of the interviews took place by telephone; in 8 cases, the telephone call prompted a response by mail.[2]

The 28 nonrespondents from among the promising inventions included 2 deceased inventors, 1 refusal, and 25 inventors who either could not be located or would not return telephone calls. The 21 nonrespondents from among the random sample included 2 deceased inventors and 19 inventors who either could not be located or would not return calls.[3]

In total, data were collected in 1993 on 253 inventions, or 45% of the 557 ERIP inventions. Historic information from previous evaluations is also available for 189 additional inventions. To illustrate, an inventor who reported sales during the 1985 evaluation would still be included in the cumulative count of inventions that have experienced sales, even if further information were not obtained in subsequent evaluations. Altogether, some evaluation data are available for a total of 442 of the 557 inventions.

Table 2.1 Summary of Survey Responses

Samples of Inventors	Respondents to the Mail Survey	Targeted Follow-up of Non-respondents	Non-respondents	Total
Promising Inventions	60	45[a]	28	133
Other Inventions (Excluding Random Sample)	137[b]	0	255	392
Random Sample of Nonrespondents	0	11[c]	21	32
Total	197	56	304	557

[a]6 of these responded by mail as the result of a telephone follow-up.
[b]6 of these inventors responded by telephone rather than by mail.
[c]2 of these responded by mail as the result of a telephone follow-up.

2 Because of the spacious layout of the questionnaire, the 16 pages typically required less than 20 minutes to complete. However, the telephone interviews ranged widely, from perhaps 10 minutes for participants who had been interviewed before and had little activity to report, to 45 minutes for those participants who wanted to elaborate on the status of their ERIP project.

3 In all four cases of deceased inventors, it was determined that the technology had not been passed on to another company or individual who was working on it.

2.3 ANALYSIS OF NONRESPONSE BIAS

The analysis of nonresponse bias was designed to answer the following question: "Can we generalize from our sample of 105 "promising" inventors and 131 "other" inventors to the total population of 557 inventors?" The response rate for the group of "promising" inventors was so high—at 79%—that the impact of any nonresponse bias could have only minimal impact on the evaluation's findings. As a result, the existence of nonresponse bias in surveying these inventors was not assessed. The response rate for "other" inventors, however, was sufficiently low—at 35%—that nonresponse bias could significantly influence the evaluation's findings. As a result, the nature and extent of any nonresponse bias in this sample was assessed.

Our approach to examining nonresponse bias involves comparing various indicators of commercial progress for the sample of 131 "other" inventors with the sample of 11 inventors from the "targeted followup." The results are presented in Tables 2.2 and 2.3. Due to the small sample sizes, it is not possible to apply statistical tests to determine the significance of any differences between the two groups.

Table 2.2 Analysis of Response Bias: Sales and Licensing

Activity Category:	Targeted Followup (N=11)		Other Inventors (N=131)	
	Number of Respondents	Percent of Respondents	Number of Respondents	Percent of Respondents
Technologies with sales	1	9%	22	17%
Licensed technologies	1	9%	10	8%

The two samples of inventors are not notably different in terms of the stage of development of their technologies or the incidence of sales and licensing. One inventor (i.e., 9%) in the targeted followup sample of 11 inventors experienced modest sales in the early 1980's as the result of a licensing agreement.[4] This is similar to the 17% rate of sales and 8% rate of licensing among the sample of 131 other inventors. The major difference between the two samples is in activity status: none of the targeted followup sample of inventors is actively pursuing the development of their ERIP technologies, while 63% of the other technologies are being actively developed. This finding suggests that we can generalize from our sample of other inventors only on indicators which measure progress to date and not on measures of current activity or likely future progress.

4 This inventor was not among the "promising" sample because he had not participated in any earlier evaluations nor had he been in touch with DOE's invention coordinators to share information about his sales with them.

Table 2.3 Analysis of Nonresponse Bias: Activity and Development Categories

Activity Category:	Targeted Followup (N=11)		Other Inventors (N=131)	
	Number of Respondents	Percent of Respondents	Number of Respondents	Percent of[a] Respondents
Actively being pursued	0	0%	68	52%
Low level of effort	0	0%	14	11%
Suspended temporarily	3	27%	9	7%
Suspended indefinitely	4	36%	30	23%
Failed	4	36%	2	2%
Chapter 11/Reorganization	0	0%	0	0%
Chapter 7/Bankruptcy	0	0%	0	0%
Missing observations	0	0%	8	6%
Development Category:	**Number of Respondents**	**Percent of Respondents**	**Number of Respondents**	**Percent of[a] Respondents**
Concept definition and development	1	9%	16	12%
Working model	2	18%	16	12%
Prototype development, testing, engineering design	4	36%	41	31%
Pre-production prototype testing	1	9%	7	5%
Production prototype	2	18%	16	12%
Limited production and marketing	1	9%	17	13%
Full production and marketing	0	0%	5	4%
Missing observations	0	0%	13	10%

[a] Percentages do not add to 100 due to rounding.

3. COMMERCIAL PROGRESS OF ERIP INVENTIONS

Each year, new ERIP technologies are introduced into the market while others are withdrawn. New licensing agreements are signed, while others expire or are terminated. Many ERIP inventions progress steadily through sequential stages of development, some fail and are shelved, while others cycle through repeated stages of technical development in response to market and user feedback.

This chapter assesses the commercial progress of ERIP inventions. It begins by describing the current status of ERIP inventions in terms of level of activity and stage of development. The chapter then documents the number of ERIP technologies that have been in the market (i.e., generating sales) during various years since 1980. This assessment draws on the full database of information on 439 ERIP technologies. The chapter further extends this analysis of commercialized inventions to assess the length of time technologies have remained in the market. Attention then turns to assessing the performance of ERIP based on the total sales of ERIP technologies relative to the program's appropriations and grants. The chapter ends with a description of royalties from licensed ERIP technologies.

3.1 CURRENT STATUS OF ERIP INVENTIONS

Analysis of the status of ERIP technologies in 1993 indicates that many (81%) of the inventions in the promising sample are either actively being developed or are being pursued at a low level of effort (Table 3.1). These results suggest a slight decline in level of activity compared to 1991, when 94% of the promising sample of inventions were under development at either an active or low level of effort. This trend is reinforced by the results for "other" inventions. In 1993 only 24% of the sample of "other" inventions were actively being developed, while in 1991, 80% of these inventions were under development.

Analysis of the stage of development indicates that few ERIP technologies were in the concept definition and development or working model stages in 1993 (4% of the promising inventions and 24% of the other inventions). Nearly one-third (31%) of the other inventors were undergoing prototype development, testing, and engineering design, which was their most frequent stage of development. This was also the modal stage for the other inventions surveyed in 1991.

More than half (54%) of the promising inventions were in limited or full production and marketing in 1993. A similar percentage (52%) characterized the sample of promising inventions in 1991. In 1993, 17% of the other inventions were in limited or full production and marketing, which is slightly less than the 25% rate in 1991. The 56 promising inventions and 22 other inventions that had reached limited or full production and marketing by 1992, based on Table 3.2, are only a subset of the population of ERIP inventions with sales. This is because only a subset of the ERIP inventions with documented sales based on previous ORNL evaluations participated in the 1993 survey.

Table 3.1 Level of Activity of ERIP Projects in 1993

Activity Category:	Promising Inventions (N=105)		Other Inventions (N=131)	
	Number of Inventions	Percent	Number of Inventions	Percent[a]
Actively being pursued	77	73%	68	52%
Low level of effort	8	8%	14	11%
Suspended temporarily	3	3%	9	7%
Suspended indefinitely	11	10%	30	23%
Failed	2	2%	2	2%
Chapter 11/Reorganization	0	0%	0	0%
Chapter 7/Bankruptcy	0	0%	0	0%
Missing	4	4%	8	6%

[a] Percentages do not add to 100 because of rounding.

Table 3.2 Stage of Development of ERIP Technologies in 1993

Development Category:	Promising Inventions (N=105)		Other Inventions (N=131)	
	Number of Inventions	Percent[a]	Number of Inventions	Percent[a]
Concept definition and development	1	1%	16	12%
Working model	3	3%	16	12%
Prototype development, testing, engineering design	13	12%	41	31%
Pre-production prototype testing	17	16%	7	5%
Production prototype	10	10%	16	12%
Limited production and marketing	27	26%	17	13%
Full production and marketing	29	28%	5	4%
Missing	5	5%	13	10%

[a] Percentages do not add to 100 because of rounding.

3.2 NUMBER OF ERIP INVENTIONS WITH SALES

Significant commercial progress has been made by ERIP inventions during each of the most recent evaluation periods. By the end of 1992, 129 ERIP inventions are known to have achieved sales. This represents 23% of the population of 557 ERIP technologies, which is probably an underestimate of the true percentage, since we were unable to collect information on all of the technologies.

This finding compares favorably with the success rates of technological 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% of new products are successfully introduced. This suggests that ERIP inventions may be at least as successful as technological innovations generally, though meaningful comparisons are difficult to make because of differences in products, technologies, and measures of success. The literature has reported success rates ranging from 1% to 85% (Cooper, 1983; Crawford, 1987).

Another way to quantify commercial success is by comparing the number of ERIP technologies that have experienced sales to the cost of the Program. Between 1978 and 1992, ERIP expended $74.3 million (in current dollars). At least 129 of the technologies it has supported have entered the market. Similar statistics are available for (1) the Gas Research Institute (GRI), which has operated an 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.

3.2.1 Market Entries and Exits

The market entries and exits of ERIP inventions over the past decade are portrayed in Fig. 3.1. A market entry in a particular year is an invention that had sales that year, but not the previous year. A market exit occurs when an invention did not have sales in the year in question, but did have sales in the previous year. Inventions "in the market" had sales during the year in question; they may or may not have had sales in the previous year.

The number of ERIP technologies in the market more than doubled from 1980 to 1984, with market entries in most years outnumbering market exits by a wide margin. Between 1985 and 1992, the numbers of ERIP technologies in the market have fluctuated between 48 and 56. Compared to other years during this nine-year period, 1985, 1987, and 1989 had large numbers of market exits. These are also the three years where exits outnumbered entries. Five of the 12 exits in 1985 were due to license agreements that had been successful for two or more years prior to 1985, but which failed to generate continuous sales. Of the 17 market exits in 1987, four are due to missing sales data for

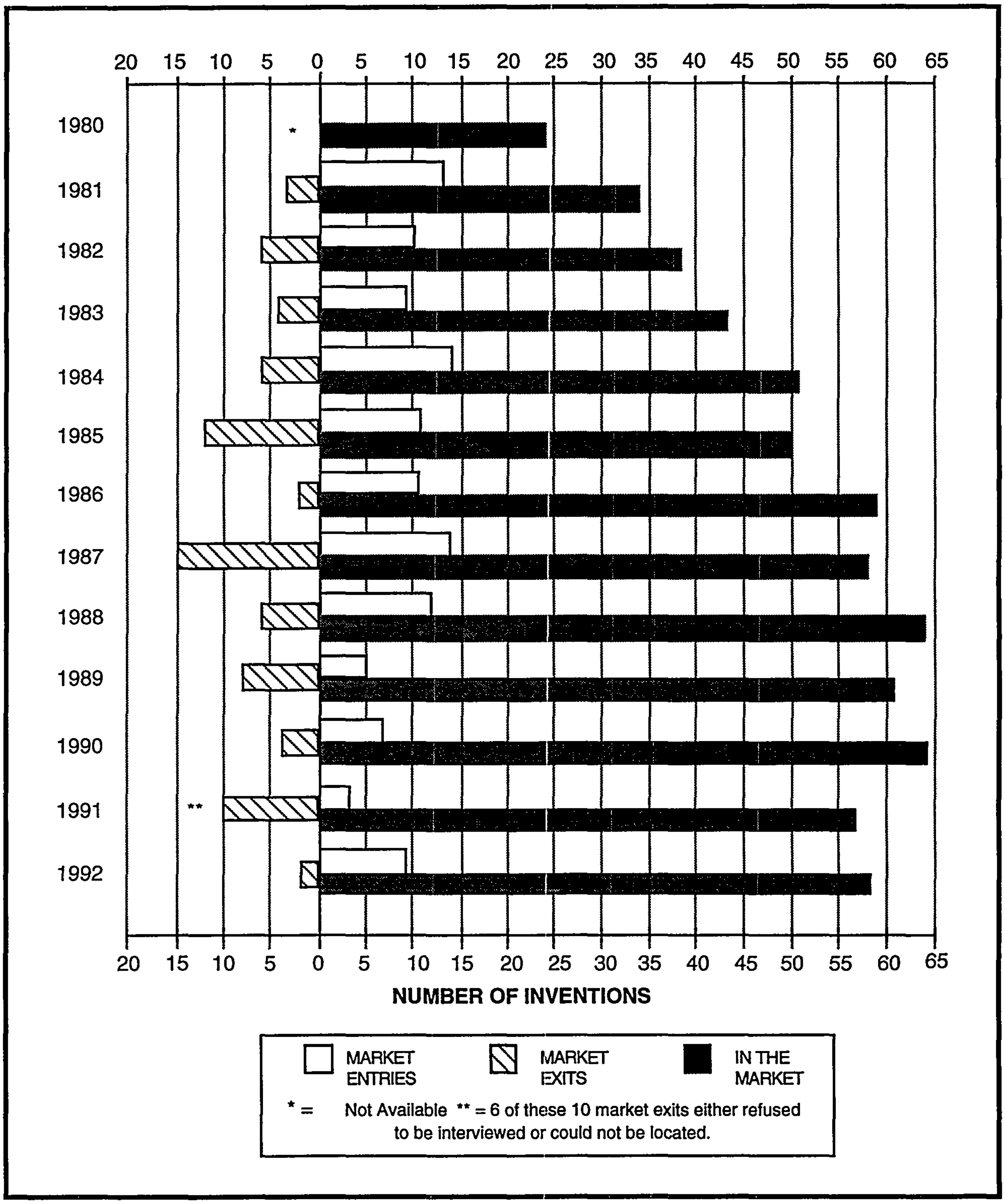


Fig. 3.1 ERIP Inventions Entering, In, and Exiting the Market, by Year

technologies that may in fact have had sales. The same is true for several of the 12 market exits in 1989. The relatively low oil prices that typified the second half of this decade also had a perverse effect on a subset of ERIP technologies. Some of the market exits during this period were technologies whose market acceptance was tightly linked to energy prices. Most recently, several market exits have been directly brought about by the nation's recession.

Just as an entry into the market does not ensure continued success, not all exits are permanent. Indeed, ERIP offers several examples of technologies that were withdrawn, redesigned based on initial market feedback, and then reintroduced. Such a pattern is unusual, however. Most of the 129 ERIP inventions with sales have sustained product life cycles. Of the 94 inventions that entered the market before 1987, between 43 and 53 were still in the market by the end of 1990, and between 31 and 37 were still in the market by the end of 1992.[1] These product longevity rates are consistent with Crawford's (1987) observation, based on a review of the literature, that around 65% of new products remain in the market for more than a few years.

3.2.2 Market Entries by Date of NIST Recommendation

Typically, it takes many years for inventions to become market-ready. As a result, one would expect low rates of commercialization among inventors who have only recently applied to ERIP and been recommended by NIST for support. One might also expect the economic downturn experienced between 1989 and 1992 to have dampened the prospects of commercial development for inventions that entered the Program in recent years. On the other hand, as the Energy-Related Inventions Program has gained experience in identifying and supporting worthwhile inventions, one might expect an increasing percentage of ERIP awardees to succeed in reaching the marketplace; assuming all other major factors were constant—quality of applicants, strength of the overall economy, energy prices, etc.

Table 3.3 illustrates that commercialization rates (i.e., percentages of inventions with sales) are fairly steady for the first 300 inventions recommended by NIST for support, with the second cohort of 100 inventions (numbered 101 to 200) achieving the highest commercialization rate, at 35%. The subsequent 257 inventions have been markedly less successful thus far, with commercialization rates that range from 14% (for the most recent 57 inventions) to 19% (for the fourth cohort of inventions numbered 301-400). It is not possible to ascertain what combination of factors has caused the lower commercialization rate experienced by the latest 257 inventions. However, insufficient development time is undoubtedly a factor for at least the most recent cohort.

1 It is not possible to provide precise numbers of inventions because some of the technologies with sales prior to 1987 did not participate in subsequent ERIP evaluation surveys. Thus, our information is incomplete.

Table 3.3 Number of ERIP Technologies with Sales by Date of NIST Recommendation

DOE Numbers	Date of NIST Recommendation	Number of[a] Inventions with Sales through 1990	Number of[b] Inventions with Sales through 1992	Percent Increase (1990 to 1992)
001 – 100	2/12/76 – 3/30/79	22	23	4.5 %
101 – 200	4/20/79 – 1/27/82	35	35	0 %
201 – 300	2/26/82 – 4/30/85	27	29	7.4 %
301 – 400	4/30/85 – 6/24/87	18	19	5.5 %
401 – 500	6/30/87 – 2/7/90	12	15	25.0 %
501 – 557	2/28/90 – 9/30/91	5	8[c]	60.0 %

[a]This column presents the number of ERIP inventions that had sales in one or more years between 1980 and 1990.
[b]This column presents the number of ERIP inventions that had sales in one or more years between 1980 and 1992.
[c]These 8 ERIP inventions represent 14% of the 57 in this cohort of inventions.

3.2.3 Market Entries by Mode of Commercialization

Three different modes of commercialization have been used by ERIP inventors to achieve sales:

- inventors have used their existing company (or their small business employer) as the business infrastructure for developing and marketing their technology (i.e., "existing companies");
- inventors have created new business ventures to launch their ERIP technologies (i.e., "new ventures"); and
- inventors have licensed or sold their ERIP technologies as a means of bringing their technologies to market (i.e., "licensing").

Inventors typically retain an instrumental role in the innovation process with either of the first two strategies. This is not usually the case when the technology is licensed or sold by the inventor.

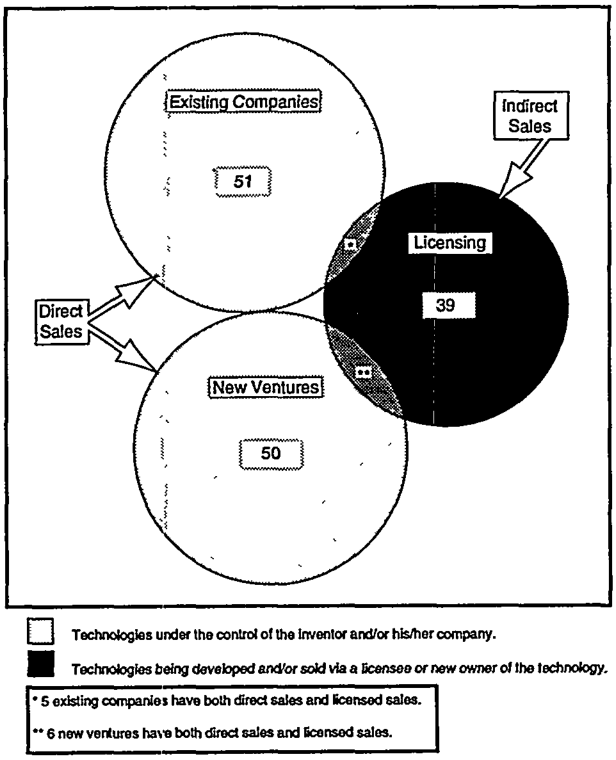


Fig. 3.2 Modes of Commercialization Used by 129 ERIP Inventions

Between 1980 and 1992, 51 inventions (or 40% of the 129 that had achieved sales) were manufactured and marketed by the inventor's existing company (Fig. 3.2). A comparable number (50 inventions) were commercialized by a new venture. Licensing was the least common mode of commercialization, being used by only 39 (or 30%) of the commercialized inventions. These percentages sum to 109% because 11 ERIP technologies have been commercialized via licensing agreements and sales through the inventor's new venture (N=6) or existing company (N=5).

The percentage of ERIP technologies commercialized via licensing has decreased slightly since 1988. Over the same period, the percentage of technologies with sales through new ventures has increased somewhat, and the percentage of technologies with sales through pre-existing companies has remained fairly steady.

3.3 SALES OF ERIP TECHNOLOGIES

It is estimated that the total cumulative sales of ERIP technologies from 1980 through 1992 is \$622.7 million in current dollars (Table 3.4). The yearly sales reported for 1980 through 1990 differ somewhat from the sales reported in previous ORNL evaluations because the current evaluation has filled in some of the missing data for the 1980 to 1990 period, and in some cases the historic data have been corrected. The net effect is to increase by \$10 million (or about 2%) the estimated sales of ERIP technologies through 1990.

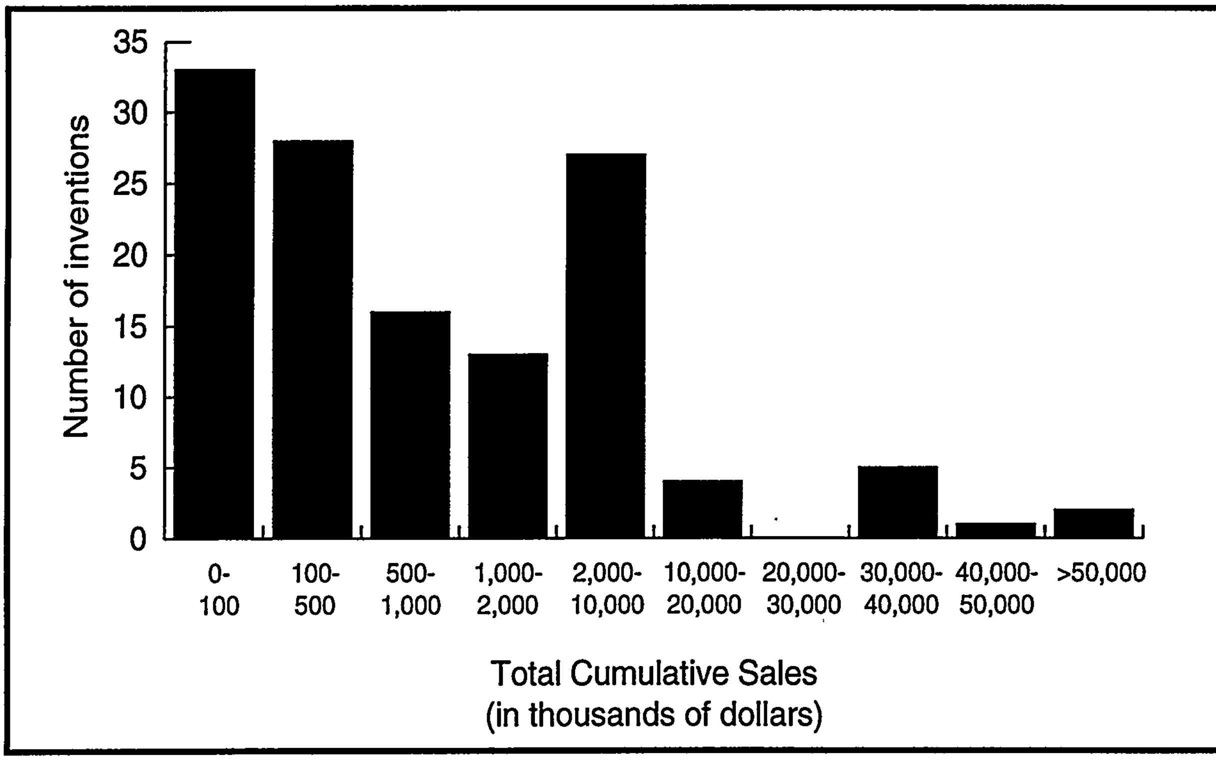
After a steady rise in annual sales of ERIP technologies between 1980 and 1983 (from \$19 million to \$38 million), annual sales leveled off at \$34 million in both 1984 and 1985. In 1986 annual sales jumped to \$61 million, bolstered significantly by several inventions that achieved substantial market shares. Between 1987 and 1990, annual sales leveled off between \$62 million and \$74 million. The \$50 million annual sales in 1991 represents a significant decrease from these historic rates, but 1992 brought annual sales up to \$60 million, which is about where they were prior to the 1991 downturn.

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 (Fig. 3.3). Cumulative sales of individual inventions range from \$2,400 to \$128 million through the end of 1992. Sixty-one (or almost half) of the inventions have had cumulative sales of less than \$500,000. The average cumulative sales of these 129 ERIP technologies is \$4.8 million, which is much larger that the median of \$565,000. The mean is much larger than the median because of the impact of a small number of highly successful technologies.

Table 3.4 Total Annual Sales of 129 ERIP Technologies (in thousands of dollars)[a]

Year	Inventor's existing company	Inventor's new venture	Licensing	Totals
1980	1,267 (N=6)	4,483 (N=11)	14,155 (N=7)	19,905 (N=24)
1981	2,450 (N=11)	7,529 (N=14)	15,826 (N=10)	25,805 (N=35)
1982	1,953 (N=14)	8,352 (N=15)	18,881 (N=10)	29,186 (N=39)
1983	3,198 (N=16)	10,999 (N=15)	23,877 (N=14)	38,074 (N=44)
1984	4,177 (N=19)	13,712 (N=17)	15,771 (N=15)	33,660 (N=51)
1985	4,478 (N=21)	14,150 (N=16)	15,523 (N=15)	34,151 (N=52)
1986	5,415 (N=28)	18,253 (N=18)	37,656 (N=15)	61,324 (N=60)
1987	5,113 (N=20)	18,492 (N=22)	39,045 (N=18)	62,650 (N=59)
1988	4,066 (N=20)	22,813 (N=24)	42,121 (N=21)	69,000 (N=64)
1989	5,497 (N=21)	23,660 (N=23)	44,789 (N=22)	73,946 (N=61)
1990	7,235 (N=23)	22,072 (N=24)	36,432 (N=22)	65,739 (N=64)
1991	7,079 (N=19)	17,842 (N=19)	24,947 (N=16)	49,868 (N=50)
1992	12,650 (N=21)	20,397 (N=24)	26,536 (N=18)	59,583 (N=58)
Grand Totals	64,405 (N=51)	202,753 (N=50)	355,560 (N=39)	622,718 (N=129)

[a]"N" represents the number of inventions. Total numbers do not equal the sum of the column numbers because 11 technologies have been sold via two commercialization modes, simultaneously. Based on current year dollars.



[a]Based on current year dollars.

Fig. 3.3 Distribution of Cumulative Sales for ERIP Technologies Through 1992

3.3.1 Sales by Year of NIST Recommendation

Table 3.3 showed that commercialization rates were highest among the first 300 inventions recommended by NIST for support. Cumulative sales by cohort also show substantial success among these first 300 inventions (Table 3.5). The fourth cohort (inventions numbered 301 through 400) is an anomaly—only 17 of these inventions have experienced sales, but their cumulative sales total $160 million. Several of the most successful ERIP technologies fall into this cohort. The levels of commercialization rates and sales are consistent for the last two cohorts of inventions. Not only do these most recent 157 ERIP recommendees have low commercialization rates, but they also have minimal cumulative sales.

3.3.2 Sales by Mode of Commercialization

In aggregate, licensed ERIP technologies have generated more sales than inventions marketed directly by the inventor's existing company or through new ventures (Table 3.4). They account for $355.5 million (or 57%) of the total cumulative sales of ERIP inventions. On an invention-by-invention basis, the difference is even more pronounced. Cumulative sales of licensed technologies have averaged $9.1 million, compared with $4.1 million for technologies commercialized through new ventures and $1.3 million for those commercialized by the inventor's existing company.

The greater sales resulting from licensing may be attributed to several factors. Licensing agreements are likely to be concluded when the licensee perceives a considerable market for the technology and the licensor finds a firm that has access to channels and markets that the inventor could not tap on his or her own. Licensees tend to be established enterprises that have already gone through the start-up phase that new ventures or recent enterprises still must experience. Licensing thus can provide an avenue for rapid market entry (Weigand, 1986).

Table 3.5 Sales of ERIP Technologies by Date of NIST Recommendation

DOE Numbers	Date of NIST Recommendation	Total Cumulative Sales Through 1990 ($ millions)	Total Cumulative Sales Through 1992 ($ millions)	Percent Increase (1990 to 1992)
001 – 100	2/12/76 – 3/30/79	185.0	227.2	22.8%
101 – 200	4/20/79 – 1/27/82	104.0	117.0	12.5%
201 – 300	2/26/82 – 4/30/85	73.8	92.7	25.6%
301 – 400	4/30/85 – 6/24/87	134.0	160.2	19.6%
401 – 500	6/30/87 – 2/7/90	7.2	14.6	102.8%
501 – 557	2/28/90 – 9/30/91	7.7	11.0	42.9%

[a]Based on current year dollars.

3.3.3 Sales Versus Appropriations

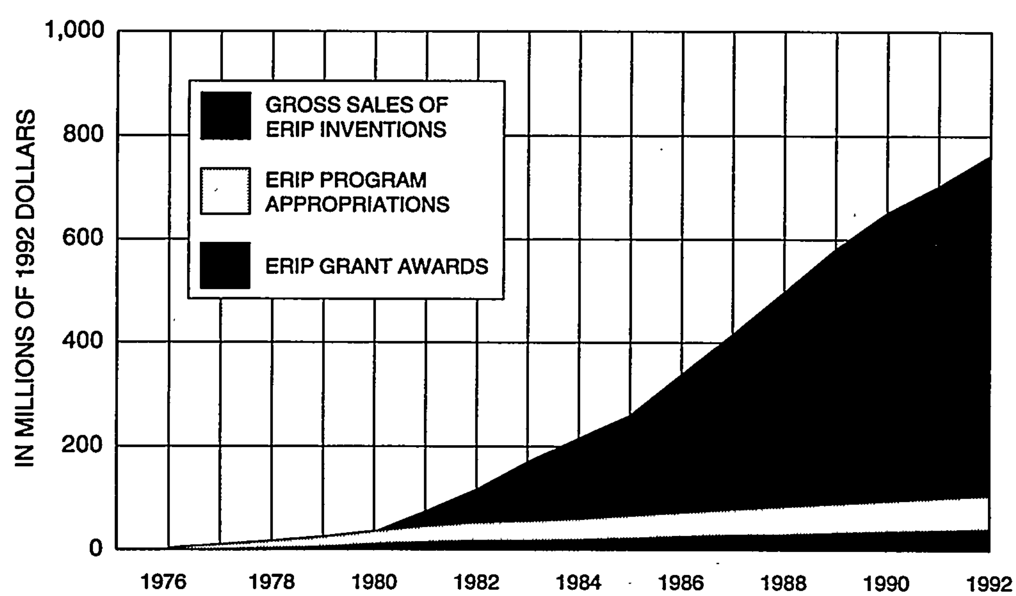
Table 3.6 compares the sales of ERIP technologies to program appropriations and grant awards, on a cumulative basis using both current and 1992 dollar values. Figure 3.4 plots just the 1992 dollar values. They both illustrate the substantial increase of invention sales over both program appropriations and grant awards.

As an indicator of the effectiveness of ERIP, the $762.7 million (in 1992-$) in cumulative sales generated by ERIP inventions can be compared with program costs. Approximately $41.1 million (in 1992-$) were awarded through 1992, and program appropriations totalled $105.7 million (in 1992-$). Thus, the ERIP program has generated a 19:1 return in terms of the value of sales to grants, and an 7:1 return in terms of sales to total program appropriations.[2] These ratios have remained remarkably steady since 1986 when they were first calculated.

2 These ratios are slightly higher—21:1 and 8:1—when current dollars are used. This is because the grants and program appropriations precede the sales of ERIP technologies and thus are more markedly inflated.

Table 3.6 Grants, Program Appropriations, and Cumulative Reported Sales (in current dollars)

Year	Cumulative ERIP Sales in Millions		Cumulative ERIP Appropriations in Millions		Cumulative ERIP Grants in Millions	
	Current Dollars	1992 Dollars	Current Dollars	1992 Dollars	Current Dollars	1992 Dollars
1976	0	0	1.5	3.7	0	0.0
1977	0	0	4.3	10.2	0.6	1.4
1978	0	0	7.6	17.3	1.5	3.3
1979	0	0	11.6	25.0	2.9	6.0
1980	19.9	33.9	18.0	35.9	6.2	11.7
1981	45.7	73.7	23.8	44.9	8.7	15.5
1982	74.9	116.2	29.0	52.4	10.7	18.4
1983	113.0	169.8	31.0	55.2	10.7	18.4
1984	146.7	215.2	34.0	59.3	12.1	20.3
1985	180.7	259.8	38.9	65.7	14.0	22.8
1986	242.0	338.3	43.7	71.8	17.1	26.8
1987	304.5	415.6	48.7	78.0	19.3	29.5
1988	375.2	497.5	53.6	83.8	20.1	30.4
1989	450.7	581.1	58.4	89.2	22.9	33.6
1990	517.7	651.7	63.1	94.3	25.7	36.6
1991	552.8	703.1	68.6	100.0	27.7	38.7
1992	622.7	762.7	74.3	105.7	30.1	41.1



[a]Based on constant 1992 dollars.

Fig. 3.4 Cumulative Grant Awards, Program Appropriations, and Sales of ERIP Technologies

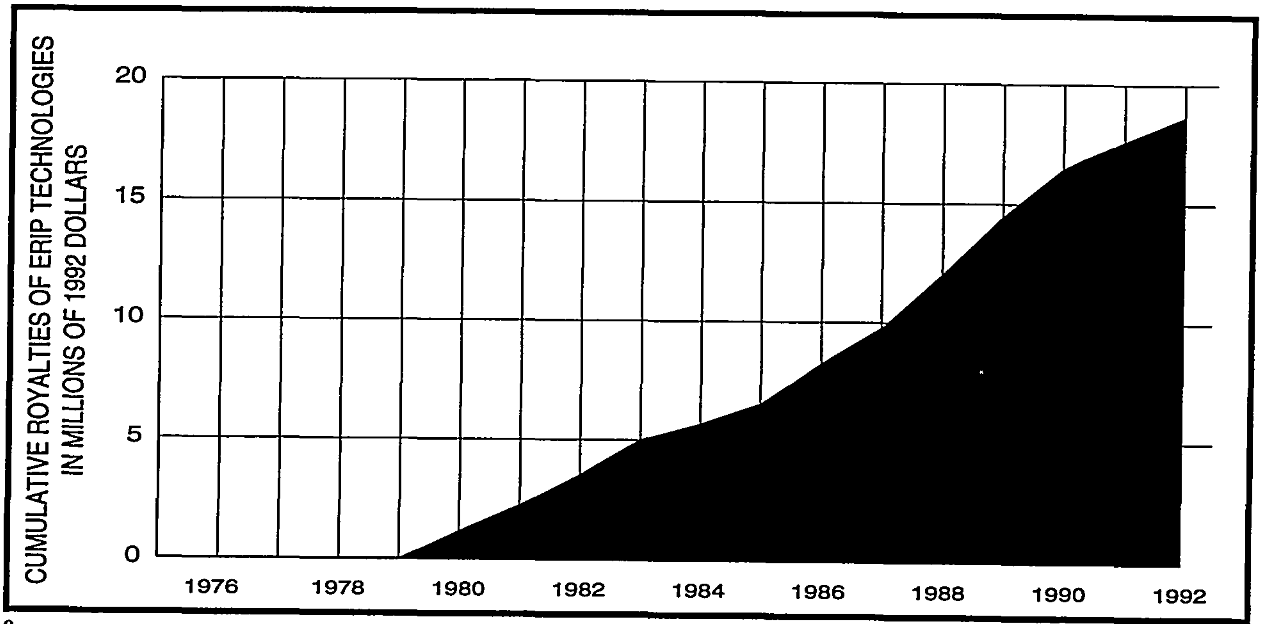
3.4 ROYALTIES FROM LICENSED ERIP TECHNOLOGIES

Estimates of royalties are available for 37 of the 39 inventions that have been sold through licensing agreements. In the remaining two cases, sales by the licensee were quite small and apparently did not involve any royalty payments to the inventor. In 21 cases, royalties were estimated by assuming a royalty rate equal to 5% of licensed sales. This estimation procedure was not applied to the three inventions with the largest estimated royalties (which account for 60% of total royalties), since these inventors provided estimates of their royalty income.

Over the duration of the Energy-Related Inventions Program, ERIP technologies have generated more than $15 million in royalties (or the equivalent of $18.6 million in 1992 dollars) for their inventors (Table 3.6). The time-line of inventions with royalties and royalty payments tracks the commercial progress of ERIP inventions, in general. Royalties were greatest between 1986 and 1990, reaching an all-time high of $2.5 million (in 1992 dollars) in 1989. In 1991 and 1992, annual royalties averaged just over $1 million.

Table 3.7 Total Annual Royalties from Sales of 37 ERIP Technologies (in thousands of dollars)

Year	Number of Inventions With Royalties	Royalties (in thousands of current dollars)	Royalties (in thousands of 1992 dollars)
1980	7	683.3	1,163.4
1981	9	703.5	1,085.8
1982	9	881.2	1,281.2
1983	13	1,049.3	1,478.1
1984	13	506.0	683.3
1985	13	656.4	855.9
1986	12	1,341.4	1,717.1
1987	13	1,205.9	1,489.3
1988	21	1,898.8	2,251.9
1989	21	2,183.2	2,470.2
1990	21	1,841.0	1,976.2
1991	15	1,122.3	1,156.1
1992	16	1,023.2	1,023.2
Grand Totals	37	15,095.4	18,631.7



[a] Based on constant 1992 dollars

Fig. 3.5 Cumulative Royalties from 37 ERIP Technologies[a]

4. COMMERCIAL PROGRESS OF SPINOFF TECHNOLOGIES

Chapter 3 documented the commercial progress of the energy conservation and supply technologies supported by ERIP. This chapter focuses on commercial activities that have resulted in part, or in total, from completion of an ERIP project, but that do not involve the ERIP technology as defined in the original invention disclosure to NIST. These spinoff activities are often serendipitous by-products—they were unplanned, unforeseen, and unintended when the ERIP project was initially conceived. Nevertheless, they represent tangible benefits that have accrued from the Program.

4.1 DEFINITION AND CLASSIFICATION OF SPINOFF TECHNOLOGIES

The term "spinoff" has acquired a number of meanings in the technology transfer literature, as reviewed by Brown and Wilson (1993). One frequently encountered use of the term refers to the creation of firms organized to pursue the private development of a technology initially supported by a government agency, a university, or a corporation (e.g., Kiesche, 1992; Parry, 1986; Gerwin, Kumar, and Pal, 1992). This use of the term focuses on the corporate control of the technology, which may pass through different business units on its way to an array of markets.

The term "spin-off" is also often used to refer to any commercialization of a government-funded R&D project (e.g., Gottinger, 1993; Herdan, 1987; Luchsinger and Van Blois, 1989). This definition is common in the context of military and space R&D, where a case can be made that any commercial product is a spinoff in that it is an alternative application of the original technology. It has also been used to describe the transfer of technologies developed at national laboratories to industry for applications different than those for which they were originally intended (Morone and Ivins, 1982).

Our definition of spinoff activities differs somewhat from both of the above concepts. For the purposes of this evaluation, a spinoff from an R&D project is "any technology development or market application that occurred as the result of the ERIP project and was not the technology or market that the original project addressed." Thus, it does not refer to the intended commercial product resulting from the ERIP project, and it may or may not involve the offshoot or creation of a new business unit.

The fact that spinoffs are distinct from the technology or market that the original project addressed forms the basis of a classification of spinoffs that distinguishes between alternative market applications and second-generation technologies.

(1) Alternative market applications occur when the results of an R&D project are subsequently applied to a market or use that differs from the originally intended application.

Whether or not an application qualifies as sufficiently different to constitute a spinoff is sometimes difficult to assess. Employing concepts from Meyer and Roberts (1986), market newness increases as one moves from **existing or intended customers** to a **new market niche,** a **new market segment,** and an entirely **new market.** Using this terminology, we would consider anything other than the "existing or intended customers" to be different enough to be a spinoff application.

(2) Second-generation technologies occur when the technology that was the subject of an R&D project is significantly altered and enhanced through subsequent R&D.

Adapting some of the concepts described in Meyer and Roberts (1986) to the measurement of technology newness, we distinguish between three different types of second-generation technologies: major enhancements, new/related technologies, and new/unrelated technologies. To apply this classification, it is first necessary to understand the concept of "core technologies" — the discrete, unique skills and techniques that embody a technology. Some of the components of this core are "key technologies" that provide the technology with its competitive edge and differentiate it from what is currently in the marketplace. Other components of the core are "base technologies" that are commonly available in the marketplace. **Major enhancements** occur through the addition of new base technologies to the core. **New/related technologies** occur through the addition or replacement of one or more key technologies, but the retention of some of the base technologies. **New/unrelated technologies** have no overlap with the key or base technologies that comprised the original technology. Minor incremental improvements are not considered here to constitute the kinds of change that herald a generational breakthrough.

4.2 ILLUSTRATIONS OF SPINOFFS FROM ERIP TECHNOLOGIES

4.2.1 Alternative Market Applications

Most of the spinoffs from the Energy-Related Inventions Program are alternative market applications. For instance, one ERIP inventor received a DOE grant to develop a thin conductive film to provide radiant heating in buildings. The film was subsequently used to create military decoys (for heat-seeking missiles) that were successfully deployed in Operation Desert Storm. Similarly, DOE provided a grant to an inventor to develop a process to recover finely crushed or powdered coal from refuse piles at coal mines. This application proved non-economic, but the technology has been successfully adapted as a belt filter press to dewater municipal wastes.

Alternative market applications may require little follow-on technical or business development to be useful in their new context. On the other hand, some technologies have required significant redesign and re-engineering to prepare them for their new uses.

Significant technology redesign has characterized instances when components of ERIP technologies have been used in whole new systems. A typical example involves microprocessor-controlled technologies. For instance, ERIP supported the development of a lightweight frame and tension form to ease production of parabolic solar reflectors. The technology included a microprocessor that allowed remote monitoring of the device's performance. The solar collector device proved difficult to sell, but the microprocessor control technology has been successfully used in building security systems. Another ERIP project focused on the development of a temperature control system for buildings. This technology and line of business failed for the ERIP participant, but as a result of ERIP funding, the inventor's start-up company gained expertise with microprocessors and was able to move into a new product area — the design and construction of microcomputers for specialized laboratory and corporate uses.

In contrast, some alternative market applications of ERIP technologies have required limited redesign, but because of their new market focus have necessitated a new business venture. This situation tends to occur when the new application involves a clear market disjuncture, requiring new sales and marketing approaches. For example, one ERIP-supported inventor developed an apparatus for mixing and deaerating drilling mud for injection into oil wells. Subsequently, the inventor experienced a leak in his basement and used the technology to mix a sealant. A new basement sealing business grew out of this experience, employing the same technology that had been developed for oil well use.

Typically, one would expect the amount of redevelopment to increase with market newness, but there are exceptions to this rule. One ERIP inventor developed a portable space heater and gas burner to prevent frost damage to orange groves. The heater draws a large volume of warm air through a duct from above the crops by means of a large blade fan; the warm air is then directed across a propane-fired flame heater where it is heated and then directed out of the apparatus at ground level into the crops to be protected. The heating system was developed (with funding from a DOE/ERIP grant) and successfully used in orchards. A subsequent use of the technology was to prevent frost damage to exotic greenhouse plants (i.e., a new "market niche"). More recently, the technology was used to heat football players at a Superbowl. Although this is an entirely new "market" for the invention, only minor redesign work was required. Figure 4.1 illustrates the development of these market application spinoffs in terms of the dimensions of market and technological newness.

Alternative market applications may emerge from technologies regardless of whether or not they were successfully applied to their originally intended use. Of course, with success comes the resources needed to explore alternative markets and to support any technical or business investments required to exploit spinoff opportunities. This case of success-breeding-success has typified the alternative market applications that have spun off from ERIP projects.

4.2.2 Second-Generation Technologies

Over the decade of experience with ERIP spinoffs, second-generation technologies have been less prevalent than alternative market applications. Where they have emerged, altered or enhanced, technologies have typically occurred after the original technology was found to be technically or economically impractical.

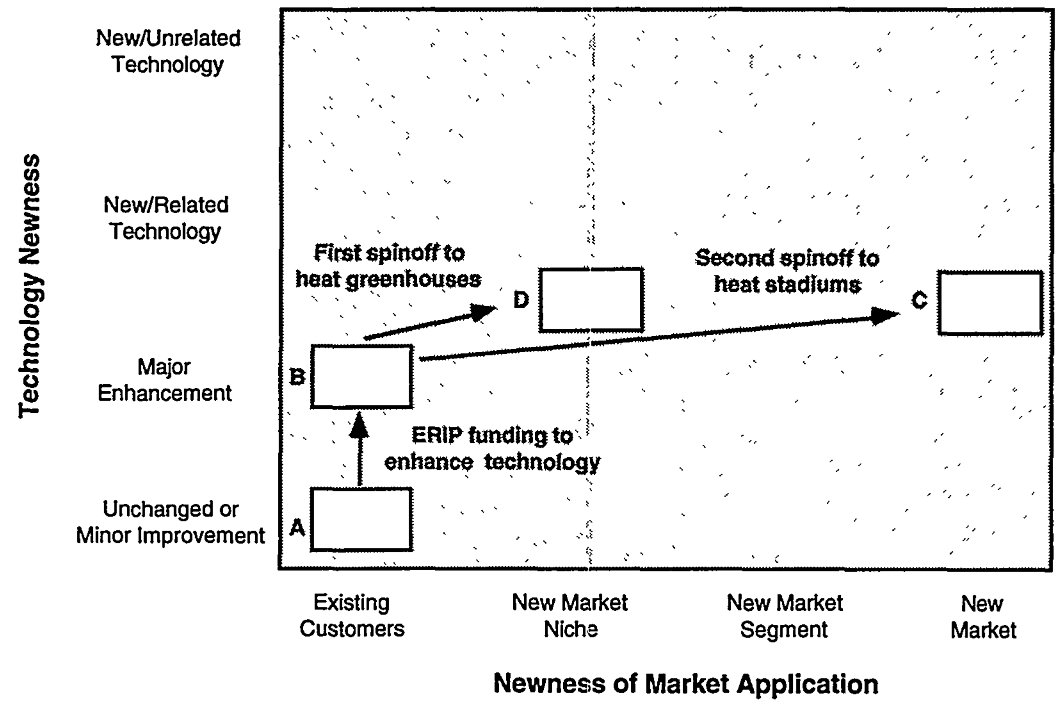


Fig. 4.1 A Market Application Spinoff of an ERIP Technology

For instance, one ERIP inventor received a grant to develop a polymerizing process for thermosetting resins that used pulsed xenon arc discharge lamps. With DOE funds in hand, the inventor imbedded the polymerization process within an electromagnetic field, significantly accelerating the curing process. This was an unanticipated technological breakthrough which significantly altered (and improved) the nature of the product, making it economically viable. Figure 4.2 illustrates the transition between first and second-generation technologies for the polymerization system described above. The ERIP grant supported the development of the initial key technology, the A-B transition illustrated in Fig. 4.2. Embedding the system in a magnetic field represented a significant technological shift that enabled the inventor to establish a new product family (Meyer and Utterback, 1993). Since this technological shift enabled the inventor to more effectively address the needs of his original market (the B-C transition in Fig. 4.2), there is no movement indicated along the market newness axis.

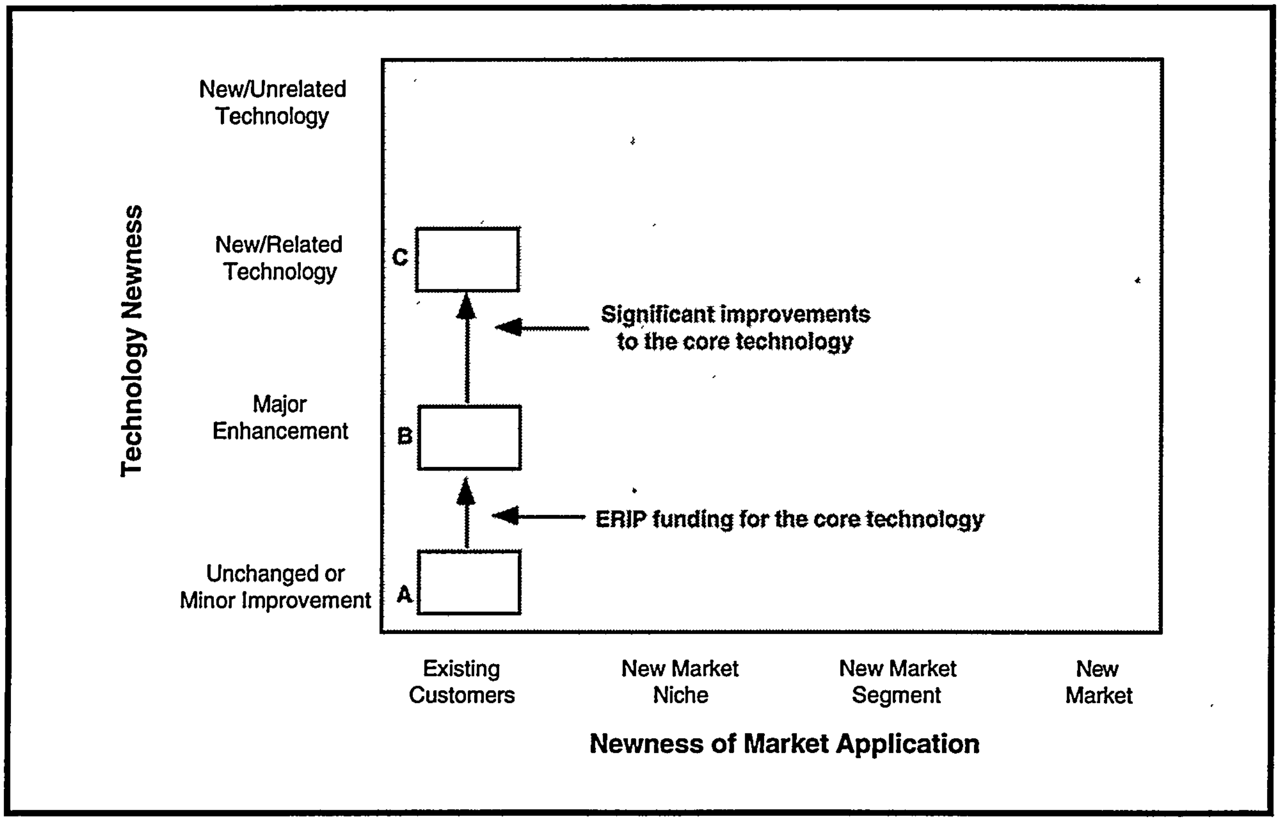


Fig. 4.2 A Second-Generation ERIP Technology Directed Toward Existing Markets

Usually these second-generation technologies build on experiences in addressing a particular market or industry-specific need. The original technology advances to the prototype development or initial market introduction stages, and it encounters limited, if any, market success. User feedback from that initial effort helps orient the next round of technology development.

This was the case with an energy conservation measure for ice rinks. The spinoff from this technology also is an example of a second-generation technology resulting from modifying the "key technologies" that comprise its core. The original technology supported by ERIP involved applying a foam directly to the ice at night, using a specially-designed machine, and then removing the foam to a storage area during the day. The "new but related" technology involves a low-cost retrofit to the standard Gamboni ice-prepping machine; it uses a similar type of foam, but the foam is created each day and disposed of each night, eliminating the additional storage space required by the original technology. ERIP enabled the inventor to develop the more marketable second-generation technology as the result of the market knowledge acquired in trying to commercialize the original technology.

Second-generation technologies sometimes result from first-generation "enabling technologies" — that is, the original R&D investment makes possible the realization of other product improvements. For instance, one ERIP participant received a grant to develop a packing process that allows fruits and vegetables to be transported without refrigeration. With this packing system successfully in place, the inventor commissioned the development of a new hybrid tomato with a particularly appealing flavor that is retained during shipment because of the unrefrigerated packing and shipping process developed during the ERIP project. In this case the original technology was transformed by replacing a "base technology" (off-the-shelf fruits and vegetables) with a newly developed "key technology" (the new hybrid tomato).

4.2.3 Linkages between ERIP Technologies and their Spinoffs

One of the most important issues in evaluating spinoffs from ERIP investments is the nature and strength of the spinoff's linkage to the original ERIP support. Linkage is easiest to establish if the connection between the original technology and its spinoff is highly visible, such as support for core technology development or specific market applications. These linkages can be readily perceived in terms of modifications in products and processes or in the adoption and use of a technology by a new set of users. Other types of substantive linkages to the original technology development effort may be much less visible, such as critical support for business development activities.

Core technology linkages are the strongest connections, because they occur when the R&D investment was instrumental in developing a core technical ensemble with multifaceted potential for further development and application. In the case of the mixing technology previously described, the mixing device developed with ERIP support was then applied to a variety of spinoff market applications. Thus, the link between the initial core technology and the subsequent market application is strong.

A similar example is illustrated in Fig. 4.3. ERIP funds were applied to the development of a metal detector, which was a key technology in the initial technical core of a materials separation technology. The detection system was initially applied to recovery of aluminum and then modified to separate iron from municipal waste (the B-C transition in Fig. 4.3). The device to separate iron is considered a market application spinoff. The success of the initial detection system suggested a dramatic revision of the technology to allow detection of metal impurities in the production of silicon wafers (the C-D transition in Fig. 4.3). This development is considered a second-generation technology, and its application will be directed to dramatically different markets.

Application linkages occur when the supported project is intended to develop an alternative application of an already well developed core technology. In these instances, the linkage between the supported application and other outgrowths of the core technology is tenuous. Such is the case of the aluminum-epoxy composite technology mentioned above. Since the inventor had developed, tested, and marketed other applications of the basic aluminum-epoxy technology before applying for ERIP funding, the ERIP technology itself is a spinoff of the original technology. Thus, additional applications of the core technology are not considered ERIP spinoffs.

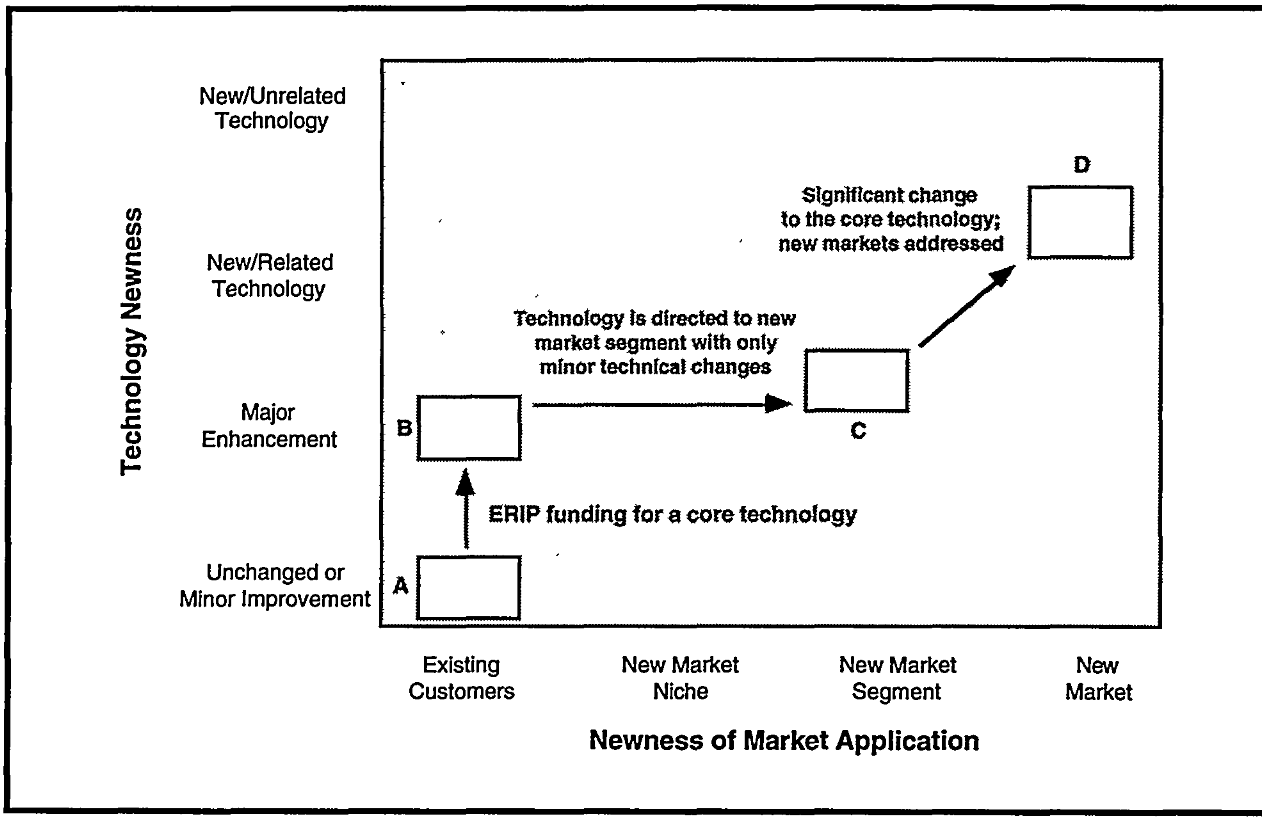


Fig. 4.3 Spinoffs Generated from a Core Technology Along Both Market and Technology Dimensions

Low visibility linkages such as the influence of R&D investment on human resources and business capabilities may have an important impact on subsequent spinoff activity. There have been several examples within the ERIP program in which ERIP funding kept an inventor active or a small business alive until it could amass the necessary resources for successful technical or business development. Governmental organizations such as the Small Business Administration whose primary mission is related to small business development would be especially interested in this sort of linkage.

4.3 SALES OF SPINOFF TECHNOLOGIES

Numerous spin-offs from ERIP projects are in early stages of development by ERIP participants—in fact, some are simply ideas that remain to be pursued. Others have already generated sales. Information on the commercial progress of spin-off technologies was first collected during the 1989 ERIP evaluation. As a result, our statistics on spin-off sales may under-represent spin-offs from

ERIP inventors who participated in the early rounds of evaluation surveying (i.e., 1985 and 1987) but who did not participate in the most recent surveys. In 1991, the data collection benefitted from greater clarity in the definition of spin-off technologies. The same definition (described in Section 4.1) was used in the 1993 survey.

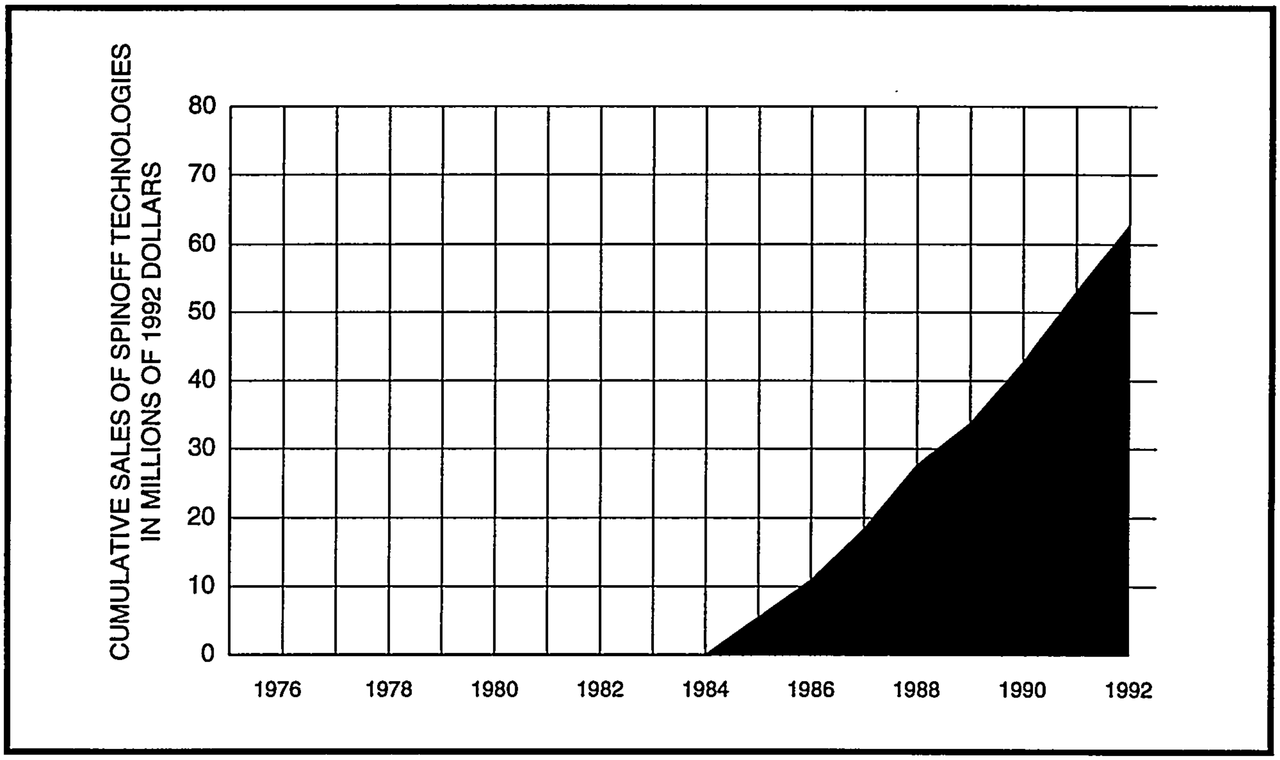
The 1993 survey identified 36 spinoff technologies that had generated sales. These technologies are offshoots of 31 different ERIP projects. These spinoffs have accumulated $56 million in sales (in current dollars, and $63 in 1992 dollars) through 1992.

Most of these 36 spinoff technologies are alternative market applications. Twenty-five of them spun off from ERIP technologies that themselves had experienced sales, and 11 spun off from ERIP technologies that had no sales.

The commercial impact of ERIP's spin-off activities has grown substantially over the lifetime of the program. Most of the spinoff technologies identified to date are fairly recent developments, with sales beginning in 1985 (see Fig. 4.4). It is likely that the role of such ERIP by-products will continue to increase as those entrepreneurs participating in ERIP strive to maximize the market potential of their inventions. One challenge for the Program is to find ways to assist less entrepreneurial ERIP inventors with robust core technologies to exploit their spinoff opportunities.

Table 4.1 Yearly Sales of Spinoff Technologies

Year	Number of ERIP Technologies with Spinoffs in the Market	Annual Sales ($000's)		Cumulative Sales ($000's)	
		Current Dollars	1992 Dollars	Current Dollars	1992 Dollars
1985	6	4,214	5,495	4,214	5,495
1986	7	4,261	5,455	8,475	10,949
1987	12	6,032	7,450	14,507	18,399
1988	13	7,818	9,272	22,325	27,671
1989	13	5,379	6,086	27,704	33,757
1990	19	8,366	8,981	36,070	42,737
1991	15	10,014	10,315	46,084	53,053
1992	15	9,777	9,777	55,861	62,830



[a] Based on constant 1992 dollars.

Fig. 4.4 Cumulative Sales of 36 Spinoff Technologies

5. EMPLOYMENT, TAX REVENUES, AND EXPORTS

Technological innovation is a major determinant of economic growth—creating jobs, tax revenues, and exports. Small businesses have been particularly successful in producing innovations for the marketplace (The Futures Group, 1984) and are seen as key players in employment and economic growth (Birley, 1987; Presidents Commission, 1984). Firms with less than 500 employees dominate job creation: the vast majority of new companies are small, and most of the jobs derived from business expansions occur within small businesses. Between 1976 and 1984, small firms accounted for 60.5% of the 17.0 million net new jobs in the United States (Kirchhoff and Phillips, 1988).

This chapter looks at the employment, tax revenues, and exports associated with ERIP technologies.

5.1 JOBS ASSOCIATED WITH ERIP TECHNOLOGIES

The employment impacts of a government investment are difficult to estimate. They include three types of effects:

- **Direct Effect:** These are the on-site jobs created by an expenditure. In the case of ERIP, the direct effect results from the jobs generated by the development, production, and marketing of ERIP technologies and their spinoffs.
- **Indirect Effect:** These are the jobs supported in a wide range of industries that provide the equipment, materials, and services needed to develop, produce, and market ERIP technologies and their spinoffs. The production of many ERIP inventions relies on subcontractors and suppliers, and the distribution and sales of final products rely on retailers, wholesalers, and others.
- **Induced Effect:** As the people who are directly and indirectly employed as a result of a government expenditure spend their weekly paychecks, they are said to "induce" other activity. Induced effects also result from lower utility bills and other costs that occur when an ERIP technology is adopted. These effects increase jobs in the industrial, retail, and service sectors that produce and distribute consumer goods and services.

The data collected by this evaluation are able to address only the direct effects of the Program. The diversity of consumer and industrial markets served by ERIP inventions argues against the use of a single multiplier to estimate the indirect and induced effects. Thus, we are excluding potentially significant employment impacts in our discussion of the jobs associated with ERIP technologies.

The 1993 survey solicited data on the number of full-time equivalent (FTE) employees working on the ERIP technologies in 1991 and 1992. Similar employment data for 1984 through 1990 were collected during previous ERIP evaluations and are presented for comparison purposes (Table 5.1). These data indicate that there are a significant number of jobs associated with the technical development, production, and sales of ERIP technologies. Previous data documented that most of this employment occurs at the production/marketing stage, although significant numbers of jobs can be generated while developing prototypes. Further, it is not until the production phase that employment can be fully supported from revenues generated by the invention itself. In prior stages, work on the technology is largely subsidized by other sources.

Table 5.1 Number of Full-Time Equivalent (FTE) Employees Supported by Sales of ERIP Inventions

Year	Known FTE's supported by direct sales	Estimated FTE's based on direct sales	Known FTE's supported by indirect sales	Estimated FTE's based on in indirect sales	FTE's supported by inventions without sales	Totals
1984	172	67	85	69	189	582
1985	229	20	77	96	48	470
1986	234	118	80	297	59	788
1987	185	138	46	173	129	671
1988	237	133	41	159	146	716
1989	282	29	160	219	78	768
1990	316	37	146	168	91	758
1991	226[a]	174	102	29	114	645
1992	289[b]	130	121	27	101	668

a 16 of these FTE's are supported by technologies that had sales both through licensing and directly by the inventor.

b 30 of these FTE's are supported by technologies that had sales both through licensing and directly by the inventor.

Employment data for 1991 and 1992 are available for most of the inventions with direct sales (since the inventors themselves tended to be interviewed), but they are available for less than half of the inventions being commercialized through license agreements (since not all of the licensees were interviewed). When sales are known, but employment data are unavailable, employment estimates are generated from ratios of ERIP sales to FTEs. (These ratios are provided in Table 5.2.) For example, in 1992, the sales-to-FTE ratio for ERIP inventions with known sales and employment, was $82,000. An additional $10.7 million of sales in 1992 is associated with an unknown number of full-time equivalent employees. Using the $82,000 ratio of sales to jobs, the estimated FTEs supported by $10.7 million of direct sales is 130. Table 5.1 shows the values of known vs. estimated FTEs, for ERIP technologies sold either directly or indirectly.

Table 5.2 Sales per FTE Employee

Year	Ratios of Sales to FTEs (in thousands of dollars): Direct Sales	Indirect Sales[a]
1984	67	119
1985	84	100
1986	67	109
1987	73	223
1988	72	266
1989	82	117
1990	72	114
1991	63	173
1992	82	165

[a] Sales through a licensee or new owner of the ERIP technology.

The ratio of sales to jobs is low for inventions sold directly by an inventor's business, with mean values ranging from $63,000 to $84,000 for the years 1984 through 1992. This is somewhat lower than the national average for small businesses with some R&D—the U.S. General Accounting Office (1984) estimated the ratio to be $107,000 (in 1982 dollars).

The dollar volume of sales per employee working on an ERIP project under a licensee is much higher, ranging from $100,000 to $266,000 over the same nine-year period. The ratios of sales to full-time equivalent employees in 1991 and 1992 are $173,000 and $165,000, respectively.

The FTEs supported by technologies for which sales have not occurred, have varied widely over the past seven years. This is partly an artifact of the different sample sizes used during the five different evaluation surveys conducted in 1984, 1987, 1989, 1991, and 1993. The 1984 sample (Brown, et al., 1987) was the largest of the four samples (N=204) and thus included a high proportion of non-commercialized inventions. It therefore documented a high number of jobs for inventions without sales. The 1985 and 1986 values (48 and 59 FTEs) are particularly low because the 1987 sample of randomly-drawn inventions was quite small (Brown and Snell, 1988), and it is the random sample which contains a disproportionate share of technologies that have not yet entered the market.

On the basis of these results, Fig. 5.1 portrays the estimated numbers of FTEs supported by ERIP technologies — 582 FTEs in 1984, 470 in 1985, 788 in 1986, 671 in 1987, 716 in 1988, 768 in 1989, 758 in 1990, 645 in 1991, and 668 in 1992. Thus, the total number of jobs associated with ERIP technologies since 1986 has remained steady, ranging from 645 to 788 FTEs.

The employment estimates presented in Table 5.1 are not equivalent to the direct employment effects of the Program. To equal the direct effects, one would have to assume that the activity associated with the ERIP project did not displace any pre-existing economic activity; therefore all of the employees working on ERIP projects would have been unemployed if it were not for the ERIP expenditure. In periods of high unemployment (such as 1991 and 1992), it is reasonable to assume that some fraction of these employees would have been without employment, but the exact number is unknown. We conclude that the estimates presented in Table 5.1 represent upper bounds for the direct effects of the Program; however, they may be underestimates of the total employment effects of ERIP since indirect and induced effects are not included.

The distribution of jobs per invention is highly skewed (Fig. 5.1). In 1992, for example, three inventions with known employment each supported more than 40 FTEs, for a total of 247 FTEs. Another four inventions with known employment each supported 20 or more FTEs for a total of 100. Thus, these seven technologies supported more than half of the total of 668 FTEs supported by all ERIP projects in 1992. This is similar to the trend documented in previous ERIP evaluations.

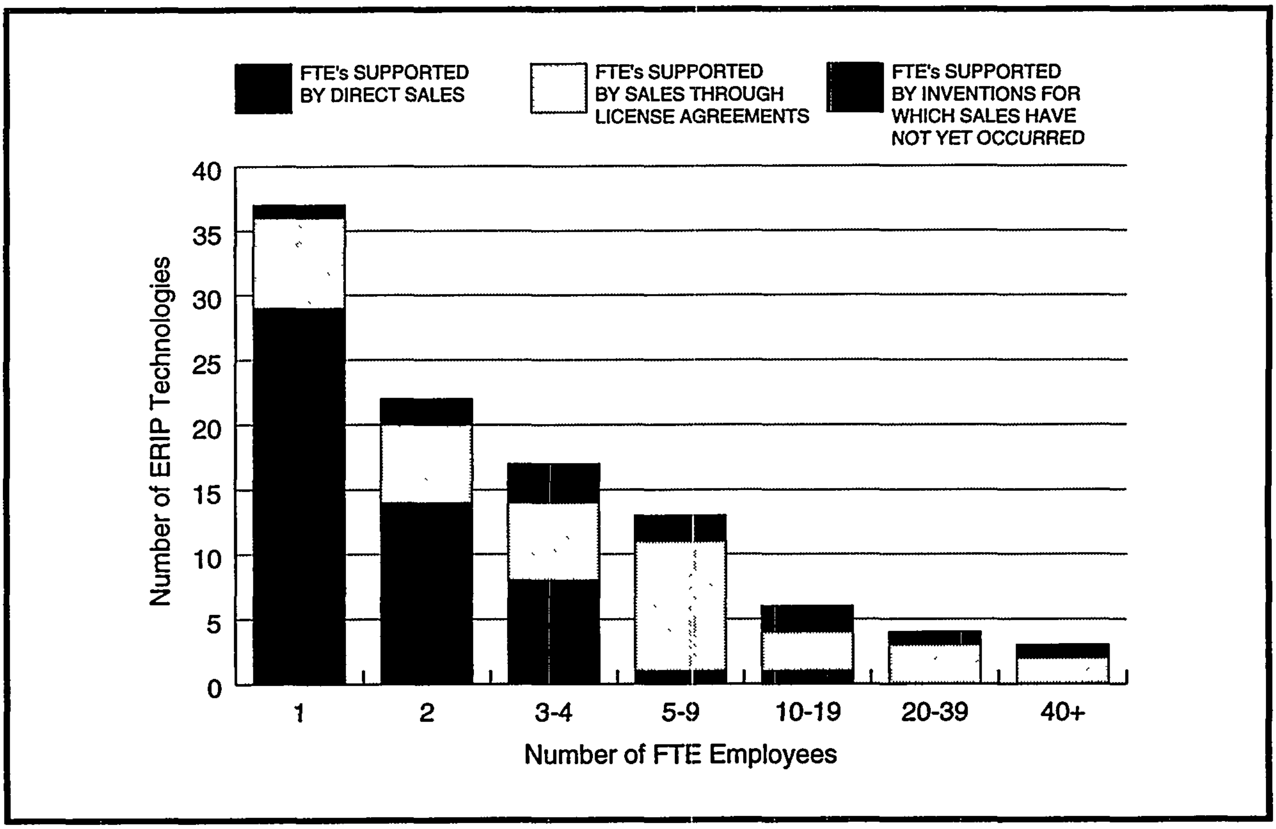


Fig. 5.1 Distribution of FTE's for 102 ERIP Technologies Supporting Jobs in 1992

Figure 5.2 indicates that during most of the years since 1984, more jobs have been supported by inventions sold directly by inventors than by licensed inventions, despite the fact that licensing has generated greater sales. This is because the ratio of sales to jobs is lower for inventions sold directly than for licensed sales.

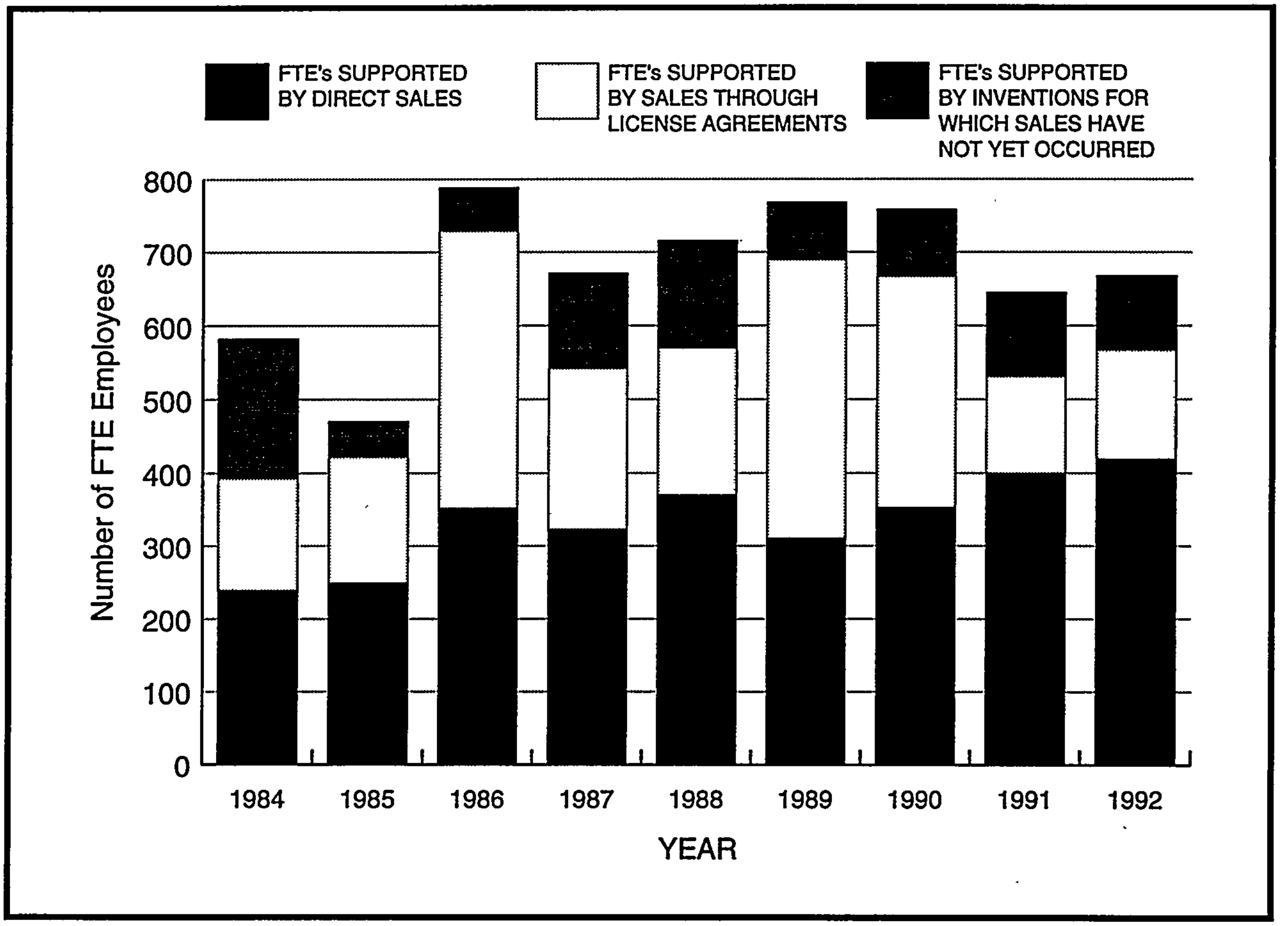


Fig. 5.2 Number of FTE Employees Supported by ERIP Technologies: 1984 to 1992

5.2 TAX REVENUES FROM ERIP-GENERATED EMPLOYMENT

This section employs a simple and conservative approach to estimating the returns to the U.S. Treasury associated with the Energy-Related Inventions Program. It uses the number of employees working on ERIP technologies, and weights this employment by the average federal individual income tax to estimate the total federal taxes that can be attributed to the Program. A similar methodology has been used in other program evaluations (Chrisman, Hoy, and Robinson, 1987).

In 1990, the average federal individual income tax per return was $4,104 (U.S. Department of Commerce, Bureau of the Census, Table No. 529, p. 341, 1992). Based on the statistics presented in the previous section, 668 FTE employees worked on ERIP technologies in 1992. Assuming that each of these employees paid $4,104 in federal individual income taxes, this amounts to a total return of $2.7 million to the U.S. Treasury in 1992. This total is more than half the 1992 ERIP appropriations.

Additional tax revenues are associated with royalty payments on ERIP inventions, corporate income taxes, state and local sales and income taxes, and personal income taxes paid by indirect employment beneficiaries of the program.

5.3 FOREIGN SALES OF ERIP TECHNOLOGIES

Information on foreign sales was not systematically collected in previous ERIP evaluations. Previous evaluations did collect data on foreign patents and identified significant activity, but the success of foreign marketing activities beyond patenting was never assessed. The 1993 survey was the first time inventors were asked to estimate the magnitude of their foreign sales.

Thirty of the respondents to the 1993 survey indicated that they have sold their ERIP technologies to customers in one or more foreign countries. This represents 23% of the 129 ERIP technologies with sales. Only 22 of these respondents estimated the magnitude of these sales. Half of these had foreign sales of less than $100,000. The remaining 11 inventors had foreign sales that ranged from $100,000 to $15,000,000. Altogether, foreign sales for these ERIP technologies totalled $19.2 million (in current dollars).

The experience of one inventor who has successfully tapped several foreign markets is described in the attached sidebar.

One ERIP participant, Karakian Bedrosian, is involved in a project in Morocco, sponsored by the U.S. Agency for International Development (AID) and the World Bank, designed to improve the quality of agricultural exports from Morocco. Four hundred million pounds of refrigerated tomatoes are shipped from Morocco to Europe annually. The cost of shipping these tomatoes currently is about $5,000 per container, including the cost of returning the empty refrigeration system back to Morocco. Nature Pak (Bedrosian's Company) may be able to reduce this cost to $2,500 if it can ship the produce in unrefrigerated, insulated vessels, or to as little as $1,500 if the vegetables can be shipped unrefrigerated and uninsulated. In addition, tomatoes can be vine ripened before shipping, which improves their taste and market value.

Bedrosian has an industrial partner in Morocco who is a tomato grower, shipper, and agricultural supply dealer. The partner will supply the tomatoes and arrange the shipping, while Bedrosian will supply the equipment and materials for 25 test shipments. After a 90-day trial, Bedrosian and his partner will evaluate whether they should develop an ongoing business relationship.

Test shipments between Morocco and France using unrefrigerated but insulated shipping containers were conducted in late 1993. Temperature probes within the pallets recorded temperatures ranging from 58-60° F, while outside temperatures varied from 45-65° F. The produce arrived with excellent results. Bedrosian is currently conducting tests using uninsulated containers to further reduce transportation costs. If successful, this system may make it feasible for Moroccan tomato growers to enter markets as far away as Canada.

The Nature Pak system has been used to ship many types of fruits and vegetables. In trial shipments, raspberries shipped from Chile to the U.S. arrived in excellent condition and at one-third to one-fifth the cost of refrigerated shipping.

6. ACQUIRING FINANCIAL SUPPORT

Small firms tend to face significant financial barriers to technological innovation. They typically have a pressing need for funds to support the testing, feasibility studies, market analysis, and business planning necessary to gain an adequate assessment in the marketplace. The small firms' internal resources to support technological innovation are rarely sufficient, and loans are difficult to obtain because of insufficient collateral and inadequate business skills. This sometimes leads to mergers or equity financing with larger firms—thereby compromising the relative advantage that the small business brings to the innovation process (Horesh and Kamin, 1983). Perhaps more often they simply are unable to secure adequate financial resources, a failure that causes premature project termination or an under-financed product that fails in the marketplace. ERIP provides several types of assistance to help participating inventors acquire the resources they need.

6.1 THE NATURE OF ERIP'S FINANCIAL ASSISTANCE

The monetary grants awarded by the Energy-Related Inventions Program are provided to meet at least some of the financial needs of small firms and individuals engaged in developing energy-related technologies. But not all ERIP inventors receive grants, and for those who do, the grants provide only a small contribution toward the total amount of capital required to bring a new technology to market. The average ERIP grant has been approximately $78,000 (in current dollars).

In addition to the direct financial assistance provided by ERIP grants, the Program can indirectly help meet the inventor's need for financing. Inventors often use their NIST evaluation and ERIP award as a source of credibility to aid them in attracting additional resources to further develop their technologies. ERIP support makes the inventor's company more credible in the eyes of potential investors. Finding a first investor when seeking capital is perhaps the most challenging part of the whole process. No one wants to be first, but if someone else is willing to participate, especially a federal agency based on an impartial evaluation of an invention's technical and commercial promise, others will follow. For example, in one instance, an inventor parlayed a $50,000 ERIP grant into a $1 million award from a private industrial research institute. Another inventor used his $75,000 award to garner $10 million in funding from a multinational corporation. In several other cases, inventors have been able to secure matching state or local grants, based on their ERIP support.

Finally, the program performs a brokering function for many of its inventors. It directs inventors to alternative sources of funding, and it disseminates information about promising inventions to potential sources of development and venture capital through the distribution of fact sheets and involvement in technology fairs.

Given the fact that very few inventors can fully develop, much less commercialize, their inventions solely on the funding provided by ERIP, it is important to study the amounts and sources of non-ERIP inventor funding.

6.2 THE COST OF TECHNOLOGICAL INNOVATION

A review of the literature indicates that ERIP inventions are typical of technological innovations at large, in terms of their development and commercialization costs. At the lowest end of the cost spectrum, Myers and Marquis (1969, p. 60) found that two-thirds of 567 surveyed innovations cost less than $100,000 (or $250,000 in 1984 dollars) for development to the point of use. They examined a broad range of innovations, mostly minor, that were named as commercially significant by firms in five manufacturing industries. Kamin, et al. (1982) found that 82% (N=18) of the 22 small-business technological innovations they studied required total technological expenditures of $1 million or less. Their innovations were sampled from two major industrial sectors—electronics and chemicals. At the more expensive extreme, a 1973 survey of innovation cost patterns for Canada found that the average cost per project was $3.3 million for a diverse sample of 83 process and product innovations. Sixty percent of the innovations cost less than $1 million to develop (Stead, 1976).

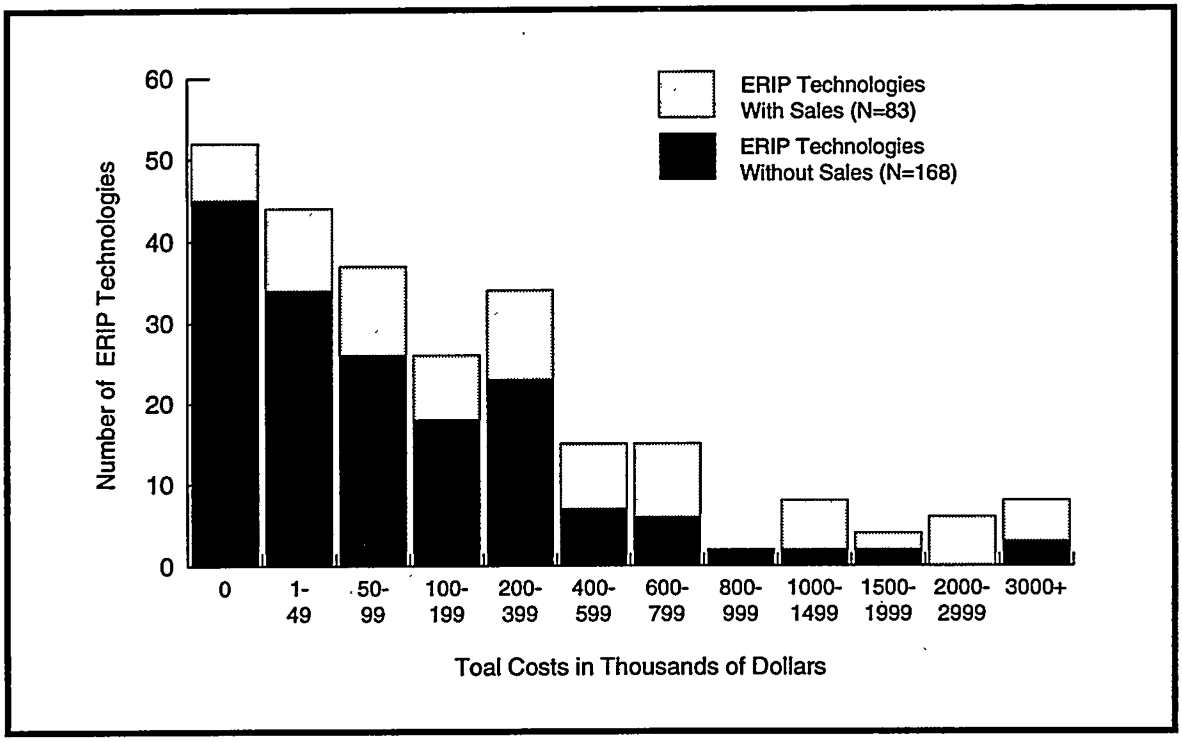
Current information on total costs of technological innovation is available for 83 of the 129 ERIP inventions with sales (i.e., those that were interviewed in 1993). Seventy-eight percent of these inventions cost less than $1 million to develop to the point of market entry or beyond (Fig. 6.1). The average total costs incurred by ERIP inventions with sales is $927,000. This high mean value reflects the skewed distribution of the cost data: 4 inventions with sales have incurred costs of more than $3 million, while 29 inventions with sales have incurred less than $100,000 in development costs. This wide variation in the cost of commercializing a new technology is due in part to industry, firm, location, and technology differences.

Some of the most successful ERIP inventions are products—simple in both their manufacture and content—with minimal capital requirements. There are several "do-it-yourself" solar technologies for homeowners, for instance. Other successful ERIP technologies require only nominal capital input for commercialization because they are simply a unique way of combining and utilizing components that are already available. These technologies frequently are assembled and distributed through subcontractors, thereby allowing the inventor to achieve considerable sales on a relatively small capital outlay

At the other extreme, several ERIP inventions with large capital requirements are process technologies in the steel and related industries. Technical problems related to testing and refining industrial processes are costly, and these technologies often require the operation of full-scale pilot plants or expensive retrofits and demonstrations in fully-operating plants.

In contrast to the average cost of $927,000 per invention with sales, the average ERIP grant is quite small. Its importance is due to its timing; the grant often arrives at a critical juncture when the inventor's funds are exhausted and other sources are unwilling to assist.

Significant levels of funding also have been acquired by inventions without sales, although those with sales have attained considerably higher levels of funding. Information on funding is available for 168 inventions that had not experienced sales by the end of 1992. The development of many ERIP inventions without sales has been retarded by lack of development capital. It is noteworthy that some 64% of these 168 inventions raised less than $100,000 above and beyond DOE's ERIP grant.



[a] Excludes the value of ERIP grants.

Fig. 6.1 Distribution of Funds Raised by 251 ERIP Inventors[a]

6.3 SOURCES OF FINANCING FOR ERIP INVENTIONS

The financing of small business innovation has been portrayed as proceeding from personal resources and other informal sources of "friendly money" to more formal sources of capital, including equity financing by venture capital firms and stock offerings. Unfortunately, there is little systematic evidence concerning when various sources of innovation financing tend to become available and when they are exhausted. "Start-up" capital has been shown to be dominated by the personal resources of the founder. However, since the start-up phase occurs early in the long process of product development, and since in any event many small business innovations are developed by existing companies, start-up capital is only one piece of the financing puzzle.

The ERIP inventors in our sample raised more funding after receipt of the ERIP grant than before (Fig. 6.2). This is true of inventors with sales (with $465,000 before the ERIP grant and $471,000 after ERIP grant), as well as those without sales (with $152,000 before the ERIP grant and $179,000 after receipt of the ERIP grant). Altogether, the ERIP technologies surveyed in 1993 were able to raise $3.88 for every ERIP grant dollar received:

- $0.93 of this was raised prior to application to the Program,
- $0.94 was raised while their application was being processed, and
- $2.01 was raised after receipt of their ERIP grant.

Strong anecdotal evidence suggests that ERIP has facilitated the acquisition of funds by program participants. Inventors often comment that participation in the program enhances their credibility with investors.

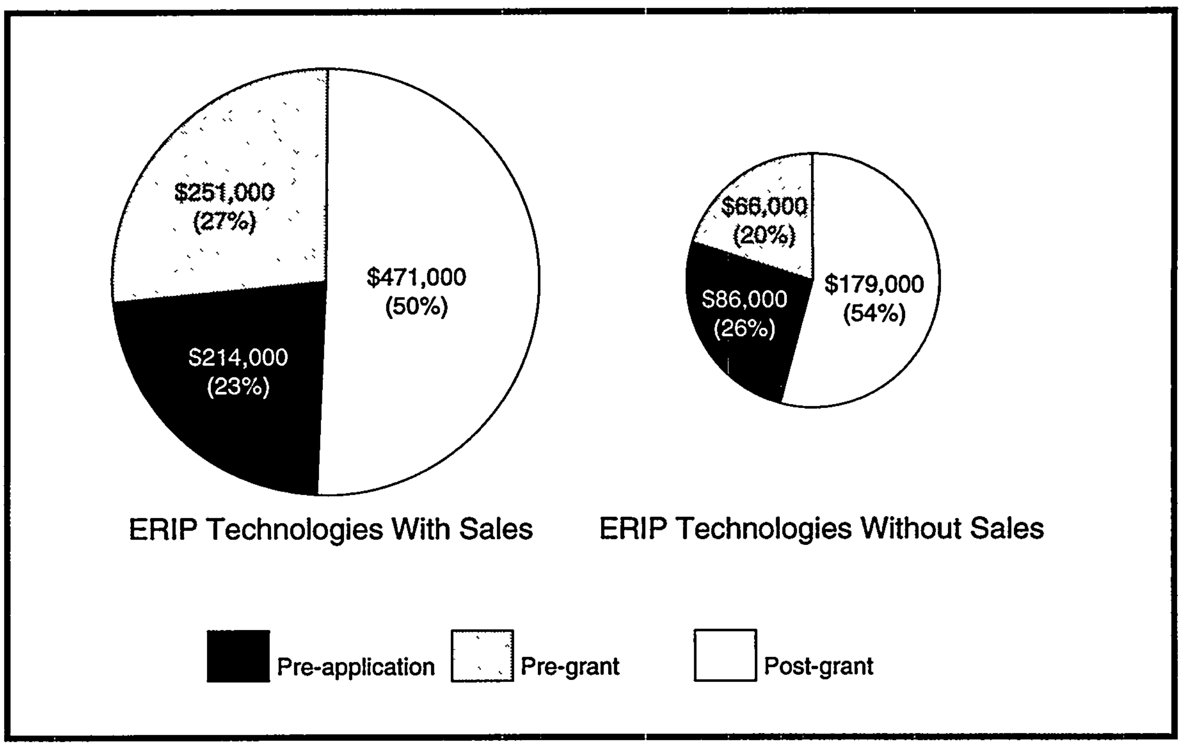


Fig. 6.2 Funds Raised Before and After the ERIP Grant

To facilitate analysis of the sources of funding for ERIP inventions, eight types of financing were studied (see Table 6.1). This classification is used in Fig. 6.3 to characterize funding for ERIP inventors before application to ERIP, during the grant approval process, and after the reception of

ERIP grants. This analysis, which was conducted for those with and without sales, excludes all ERIP grants. Table 6.2 provides the data from which Figures 6.2 and 6.3 were derived.

While the data in Fig. 6.3 are the most representative data available to date concerning funding for ERIP technologies, they are not representative of ERIP inventions as a whole. Some 40% of the participants shown in Fig. 6.3 were part of the subsample of inventions identified as having the greatest near-term sales potential. As a result, these data over-represent those inventions in the later stages of development and those that have been more successful.

Table 6.1 Classification of Funding Sources

INTERNAL SOURCES	
Personal	•inventor's own savings •friends and relatives •funds from the development team •private stock offerings
Nonfinancial	•sweat equity •in-kind contributions of customers or suppliers
Corporate	•revenue generated through sales or royalties of the ERIP technology •internal funds from other sources of revenue •loans from customers or suppliers
EXTERNAL SOURCES	
Commercial	•R&D limited partnerships •venture capital firms •other outside investors
Public Stock Offerings	•stock offering
Lending Institutions	•long-term loans to cover development costs, real estate purchases, etc. •short-term loans to cover inventory, etc.
State and Local Agencies	•state and local grants and R&D contracts •loans from state and local agencies
Federal Agencies	•federal agency R&D contracts and grants •loans from federal agencies

Figure 6.3 suggests that success in the market goes to inventors who invest personal resources and raise significant amounts of corporate and commercial money. Technologies that have entered the market have acquired considerably greater funding than those that have not yet had sales. This holds true in aggregate and for each of the eight types of funding except government support and non-financial support. ERIP inventions with no sales have, on average, received more than twice as much support from other public sources, and have absorbed as much uncompensated sweat equity as inventions with sales.

Inventions that have achieved sales have drawn upon different funding sources than inventions without sales. Before application to NIST, inventors who eventually achieved sales applied three times more personal funding (from their own funds, family and friends) than inventors who have not entered the market. What is perhaps more surprising is the level of continued reliance on personal sources of funding by both successful and unsuccessful inventors even after entry into the program. Anecdotal evidence suggests that this is due in part to the unwillingness of many ERIP inventors to relinquish control of their inventions, which is a frequent outcome of licensing and venture capital negotiations.

Table 6.2 Average Funds Raised per Inventor, by Source (in thousands of dollars)[a]

	ERIP Technologies Wthout Sales (N=168)[b]			ERIP Technologies With Sales (N=83)		
	Pre-Application	Pre-Grant	Post-Grant	Pre-Application	Pre-Grant	Post-Grant
Personal	40 (N=69)	8 (N=47)	23 (N=45)	130 (N=47)	91 (N=29)	61 (N=29)
Nonfinancial	26 (N=46)	20 (N=49)	28 (N=47)	15 (N=16)	23 (N=18)	34 (N=21)
Corporate	4 (N=9)	2 (N=7)	44 (N=15)	20 (N=9)	1 (N=16)	116 (N=20)
Commercial	10 (N=14)	25 (N=17)	26 (N=17)	24 (N=7)	73 (N=12)	146 (N=18)
Public Stock	0	0	6 (N=1)	12 (N=3)	5 (N=2)	62 (N=5)
Lending institutions	1 (N=3)	0 (N=2)	1 (N=1)	8 (N=4)	3 (N=4)	15 (N=6)
Federal Agencies	3 (N=4)	10 (N=14)	38 (N=15)	4 (N=1)	1 (N=1)	17 (N=6)
State and Local Agencies	0 (N=6)	1 (N=6)	11 (N=17)	0 (N=2)	4 (N=3)	2 (N=3)
Miscellaneous	0 (N=0)	0 (N=3)	2 (N=3)	0 (N=1)	0 (N=2)	18 (N=7)
Total	86,000 (N=99)	66,000 (N=88)	179,000 (N=86)	208,000 (N=57)	251,000 (N=47)	469,000 (N=54)

a ERIP grants are excluded from this table.

b Numbers are average amounts of funding raised by the 251 inventions for which financing data are available (168 inventions without sales and 83 inventions with sales). "N" represents the number of inventions that have attracted funding from a particular source. Thus, for instance, the 168 inventions without sales raised an average of $40,000 from personal sources before applying to the program. But only 69 of these 168 inventions actually raised personal funding.

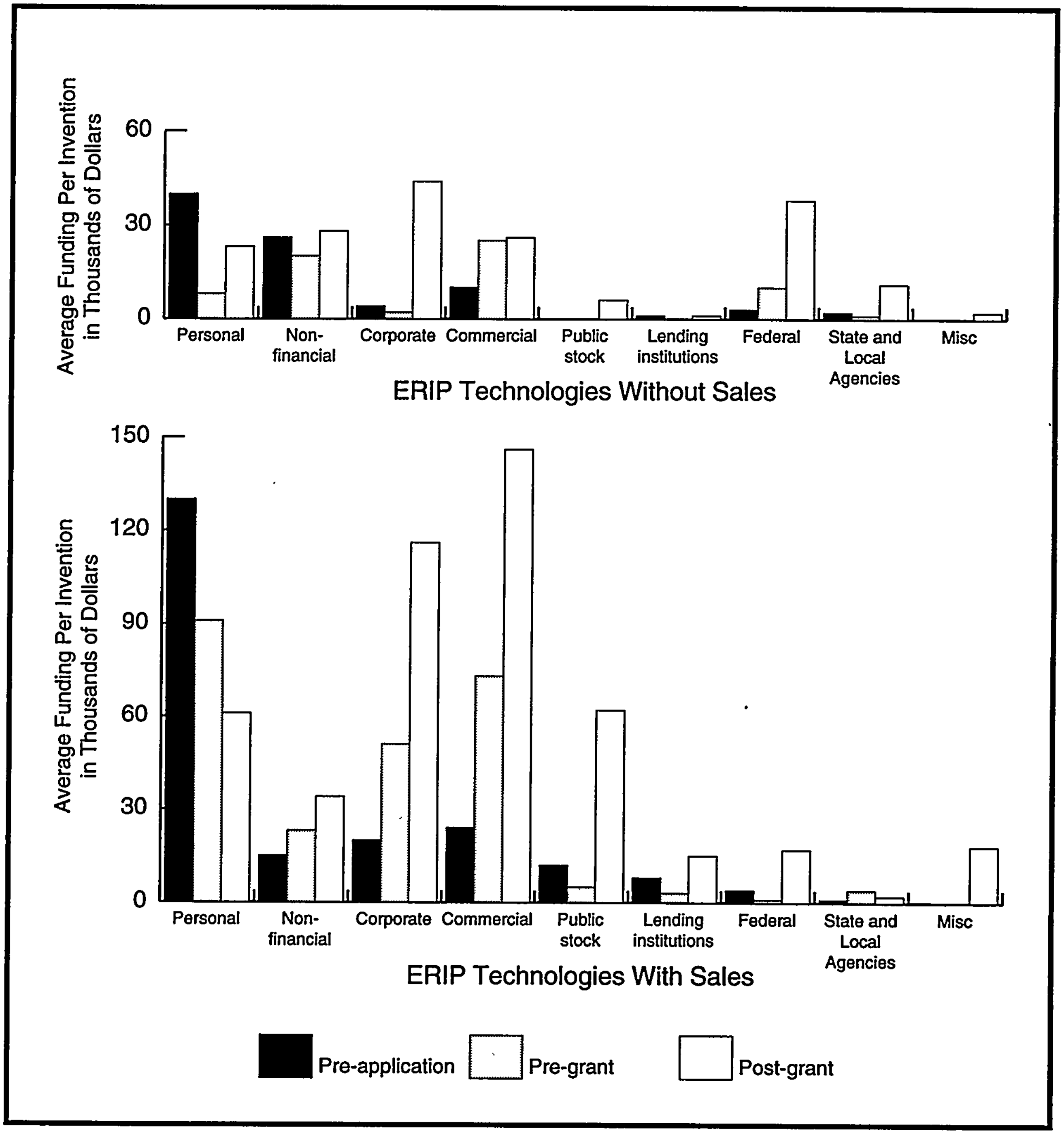


Fig. 6.3 Funding Sources for ERIP Inventions With and Without Sales

The persistence of personal sources of funding is illustrated by the fact that a quarter of the inventors without sales and over a third of those with sales invested personal funds in their ERIP technology not only before application to NIST, but also after reception of an ERIP grant. Successful inventors invested, on average, $130,000 before application to ERIP, $91,000 during the grant approval process, and $61,000 after receiving the ERIP awards.

Successful inventors invested twice as much from personal sources prior to application to ERIP than after receipt of the ERIP award. This is consistent with anecdotal evidence that personal sources of funding are consumed early in the development cycle, as well as the fact that successful ERIP inventors will have invested, on average, nearly a quarter of a million dollars from personal sources before they receive their ERIP grant.

Commercial funding (e.g., venture capital and money from other outside investors) and corporate funding (reinvestment of revenues generated by the ERIP technology and subsidies from other business operations) are, after personal funding, the two most common sources of post-award funding for inventions with sales. An average of $146,000 of commercial funding has been obtained by 22% of the successful ERIP technologies since reception of the ERIP grant. Corporate funding was acquired, after reception of ERIP grants, by 24% of the ERIP technologies with sales, averaging $116,000.

Follow-on funding from other public programs is relatively unimportant for those inventors who have successfully reached the market, but has been a valuable source of support for those not yet in the market. Seven percent of ERIP inventors who enter the market obtain other federal funding subsequent to the ERIP award; this amounts to less than 4% of overall funding after receipt of the ERIP grant. State and local funding after the ERIP grant is even less significant for inventors with sales; only four percent have received this type of funding, and it represents less than 1% of funding during this period.

For ERIP inventors without sales, however, the picture is quite different. About a tenth of ERIP inventors without sales have acquired additional funding from other federal agencies; this accounts for 22% of the funding acquired after reception of the ERIP grant. Ten percent of ERIP inventors without sales also acquired state or local funding, amounting to 6% of post-grant funding.

Other sources of funding play a less important role for ERIP inventions. Throughout the innovation development process, lending institutions are much less important sources of funds than are personal sources, internal corporate sources, or outside investors. After receipt of the ERIP grant, loans from commercial banking institutions have been utilized by 7% of the inventions with sales and only 1% of those without sales. These loans represent 3% of the total post-grant funding for inventors with sales, and less than 1% of funding for inventors without sales.

In aggregate, the 251 inventions for which financing data are available raised a total of $32M before application to ERIP, $32M during the grant approval process, and $68M after receipt of the ERIP grant. These figures are undoubtedly low estimates for the program as a whole because of the small sample size on which they are based, and the presence of a significant number of young technologies in the current sample. Technologies that have been sampled in previous years but which were not captured by the current sample design have accumulated an additional $120M before application to ERIP, $56M during the grant approval process, and $160M after receipt of the ERIP award.

In addition to financial support, ERIP participants have sustained the development of their technologies by the application of sweat equity as well as in-kind contributions from their suppliers, customers, and the communities in which they live. While the value of this sweat equity is difficult to establish, there is a considerable commitment of personal time by ERIP participants which in some cases represents several years of uncompensated labor. In addition to sweat equity, ERIP participants have received non-financial support from diverse sources. Some ERIP participants have received raw materials and advice from companies in their industries. Others have been provided access to laboratories or machine shops at universities. The dollar value of the non-financial support received is typically less than $5,000, but can come at a critical time during the development of the technology.

7. ENERGY SAVINGS AND ENVIRONMENTAL BENEFITS

The technologies supported by the Energy-Related Inventions Program offer a wide array of potential energy and environmental benefits. Some of the technologies deal with the production and distribution of energy — e.g., technologies related to oil drilling, coal mining, electricity transmission, and natural gas distribution. Others are renewable energy technologies — e.g., advances in the design of solar collectors and windmills. The majority of the technologies, however, offer potential improvements in the end-use efficiency of energy, which in turn result in reduced emissions of greenhouse gases and other environmental benefits. Energy-efficient technologies are particularly prominent among the most successful of the inventions supported by the Program.

Despite the requirement that all ERIP-supported technologies offer significant energy-related benefits, none of the previously published impact evaluations of the Energy-Related Inventions Program have assessed the energy impacts of ERIP-supported technologies. These impacts—and their associated environmental benefits—are the subject of this chapter.

7.1 THE RANGE OF ERIP TECHNOLOGY BENEFITS

Respondents to the 1993 ERIP evaluation questionnaire were asked to describe the features of their ERIP technologies that represent benefits to users or to the public. The results are summarized in Table 7.1.

Table 7.1 ERIP Technology Benefits to Users and the Public

Benefits to Users or Public	Percent of Promising Inventions	Percent of Other Inventions	Percent of All[a] ERIP Inventions
Energy savings	86.9	84.4	85.0
Energy production	32.6	40.2	38.4
Environmental benefits	72.8	75.4	74.8
Other	60.8	73.7	70.6

[a]To calculate each of these percentages, the percent of promising inventions was multiplied by 133/557, the percent of other inventions was multiplied by 424/557, and the two products were added.

Based on our surveying of inventors, 85% of the ERIP technologies save energy, 71% offer environmental benefits, and 38% contribute to the production of energy. In addition, respondents to our survey indicated that 71% of the inventions are associated with "other" benefits. In particular, many of the technologies are seen as offering quality or performance improvements and cost or resource savings.

7.2 ENERGY SAVINGS OF THREE ERIP-SUPPORTED TECHNOLOGIES[1]

7.2.1 Methodology

The amount of energy saved by the introduction of a new technology is difficult to estimate. One must consider a host of factors, including:

- the energy consumed by technologies that the new technology has displaced;
- any changes in the energy efficiency of the new technology over the lifetime of its operation; and
- any 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 1990[2], 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. This process resulted in narrowing the analysis to three technologies. It is anticipated that future research will address the energy savings of some of the remaining technologies.

The three inventions examined in this chapter are the:

- Brandon replacement packing rings for steam turbines;
- Electronic Octane® controls for automotive engines; and
- Thermefficient-100® industrial water heater.

These three technologies accounted for $144.4 million in cumulative sales through 1990, which represented 28.7% of the sales of ERIP-supported technologies accumulated to that point.

A similar set of steps was taken for each of these technologies to estimate their energy savings. First, existing documentation on the technology was reviewed, including the NIST technical evaluation and information from previous ORNL evaluations of the Program. Additional information on the technology was solicited from the inventor and/or the licensee, including recent sales of the technology, and information from secondary sources was compiled, such as statistics from the Energy Information Administration. Second, a detailed analysis of energy savings was prepared and sent to a researcher at ORNL with expertise in the field of the particular technology. The detailed analysis was then revised, based on comments by the expert. Third, the revised analysis was

1 Steve Cohn is the primary author of this section.

2 The selection of technologies for detailed analysis of energy impacts was based on historic data (i.e., sales through 1990) because this information was all that was available when the detailed analyses were intiated. Only subsequently were sales data through 1992 available.

sent to the inventor and DOE for review. The analysis was then finalized based on feedback from these reviewers.

7.2.2 Description of the Three ERIP Technologies

The three inventions examined in this chapter are described below.

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 (Fig. 7.1). 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.

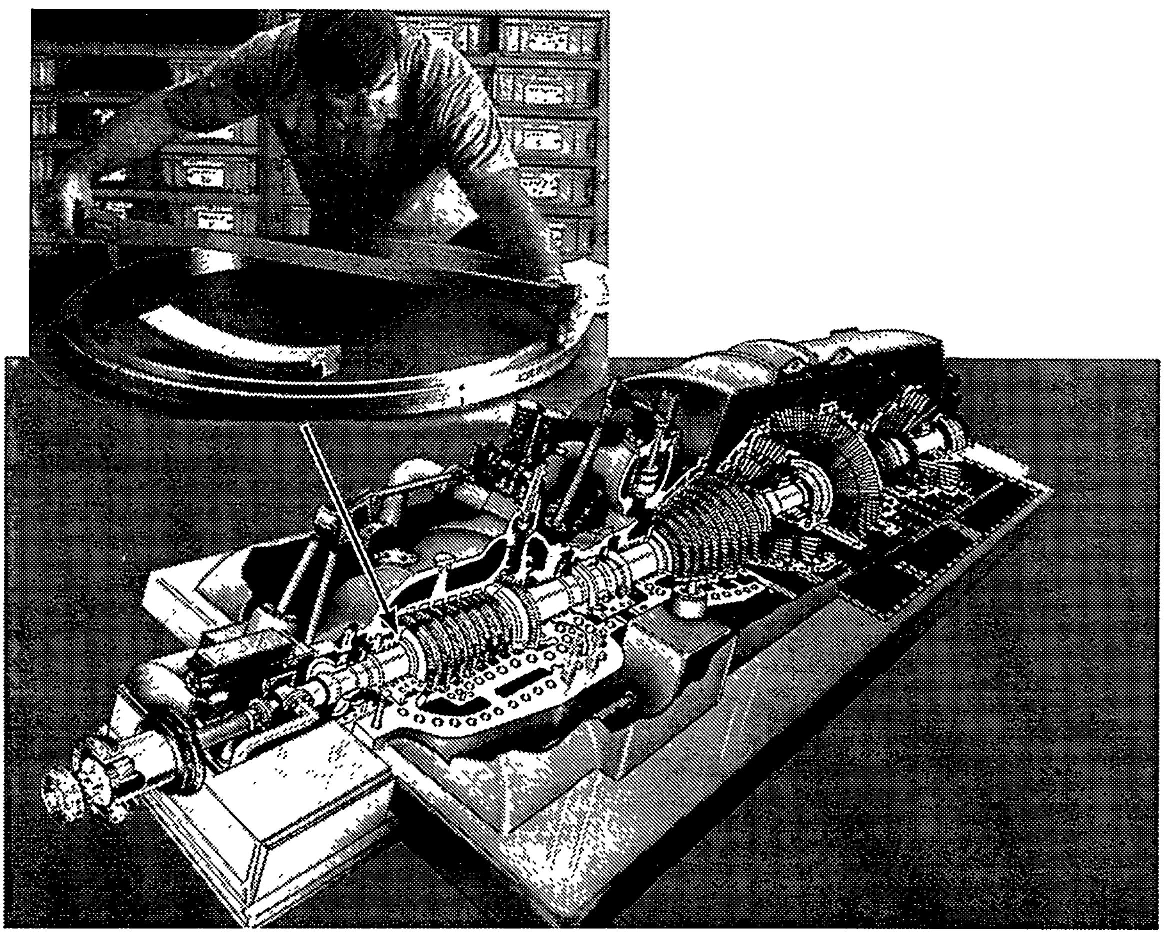


Figure 7.1 Illustration of Brandon Steam Turbine Packing Rings

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 0% to its maximum efficiency loss of 1% after 5 years. The Brandon steam packing rings prevent this gradual loss in efficiency.

Electronic Octane®. Electronic Octane®, developed by John A. McDougal, 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% 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.

Thermefficient-100®. Thermefficient-100® was developed by Harry E. Wood and is a high efficiency gas-fired water heater that allows most of the total heat of combustion of the unit to be utilized (Fig. 7.2). 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% compared to approximately 70% 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% of the floorspace of a conventional water heater of equivalent capacity.

7.2.3 Energy Consumption and Savings

The annual energy savings and cumulative savings for sales of the three technologies is shown in Table 7.2. In total, it is estimated that these technologies saved 0.14 Quads of energy between 1981 and 1993. In 1992, it is estimated that these three technologies saved 0.041 Quads of energy, and the total for 1993 is likely to have been greater.

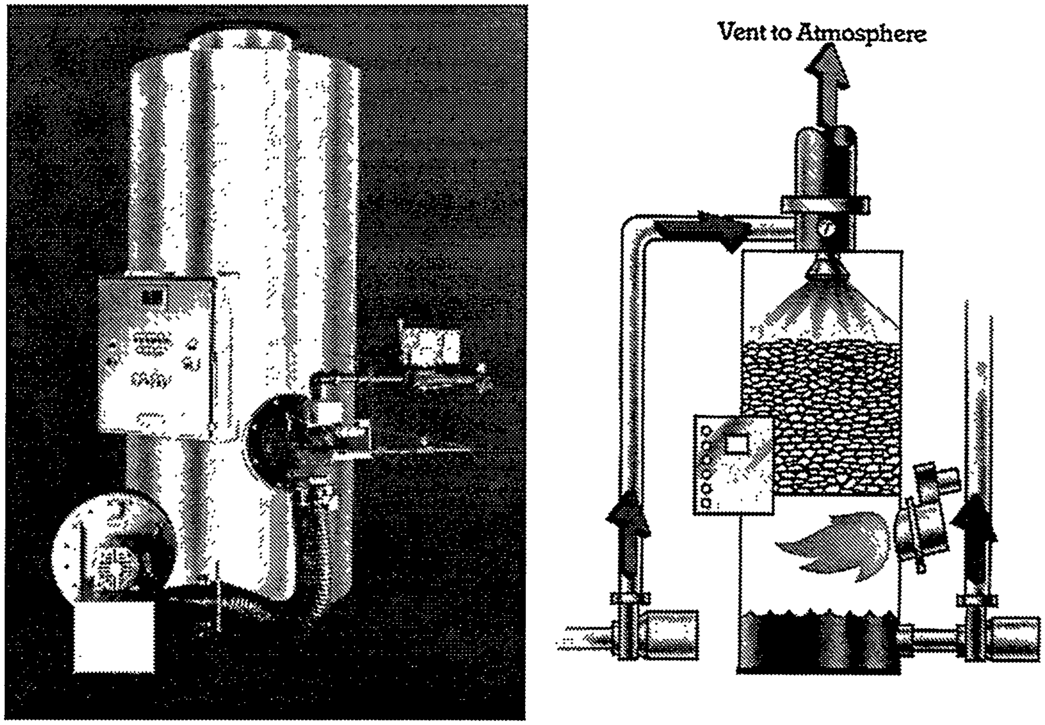


Figure 7.2 Illustration of Thermefficient-100®

The apportioning of energy savings by fuel type for the **Brandon replacement packing rings** was accomplished by using the distribution of sales of the packing rings by primary fuel of the turbines fitted. In addition, the average size of turbine capacity in the U. S. by coal, natural gas, and oil 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%
- Natural gas — 9.0%
- Oil — 12.3%

These percentages multiplied by total energy savings for the packing rings in 1992 result in the following energy savings in Btus X 10^{12}: for coal—15.9, natural gas —1.82, and oil—2.48.

The **Electronic Octane®** technology saved approximately 7.57 Btus X 10^{12} of gasoline in 1992. Approximately 2 barrels of crude oil are required to produce 1 barrel of refined gasoline. Therefore, 15.14 Btus X 10^{12} of crude oil was saved in 1992 due to this technology, which translates into 2.61 million barrels of crude oil saved.

Table 7.2 Energy Savings, in Trillions of Btu

Year	Energy Savings (Btus X 10^{12})			
	Brandon packing rings	Electronic Octane®	Thermefficient-100®	Total
1981	NS	NS	0.152	0.152
1982	NS	NS	0.328	0.328
1983	NS	NS	0.569	0.569
1984	NS	0.011	0.824	0.835
1985	NS	0.414	1.120	1.534
1986	0.023	1.492	1.484	2.999
1987	0.24	3.064	1.851	5.155
1988	1.67	4.370	2.182	8.222
1989	4.33	5.753	2.715	12.798
1990	8.66	6.775	3.417	18.852
1991	14.00	7.165	4.273	25.438
1992	20.20	7.570	5.113	32.883
1993	27.10	NA	NA	NA
Total	76.20	36.610	24.030	136.84

NS = No sales reported that year. NA = Sales data not available for that year.

The **Thermefficient-100®** technology saves 5.113 Btus X 10^{12} of natural gas in 1992. This translates into 5,113,000 thousand cubic feet of natural gas saved.

A summary of energy savings by fuel type for the three technologies is presented in Table 7.3. The equivalent energy savings in million Btu's are presented in Table 7.4.

Table 7.3 Energy Savings by Fuel Type for Three Technologies in 1992

Technology	**Coal (tons)**	**Oil (barrels)**	**Natural gas (1000 cf)**
Brandon packing rings	662,500	394,465	1,800,000
Electronic Octane®		2,610,345	
Thermefficient-100®			5,113,000
Total	662,500	3,004,810	6,913,000

Table 7.4 Energy Savings, in Trillions of Btu, in 1992

Technology	Coal	Oil	Gas	Total
Brandon Packing Rings	15.9	2.48	1.82	20.2
Electronic Octane		15.4		15.4
Thermefficient-100			5.11	5.11
Total	15.9	17.9	6.93	40.7

7.2.4 Value of Energy Savings

The value of the energy saved by each of the three technologies is dependent on the price of the particular fuel saved. The cost of energy saved by the **Brandon replacement packing rings** is priced by the cost of energy faced by electric utilities. The approximate cost of energy for an electric utility in 1993 is 1.40 $/million Btu. Therefore, the value of the cumulative energy savings for the turbine units having the Brandon rings installed is approximately $107 million 1992 dollars (0.762×10^{14} Btu X 1.40 $/million Btu = 0.1067×10^9 dollars).

The cumulative value of the energy savings for sales of autos reported to have the **Electronic Octane®** technology installed is estimated to be $327.6 million in constant dollars. This value was calculated using the estimate of energy savings in gallons times the average annual price of unleaded regular gasoline (we used regular unleaded gasoline for most auto brands and premium unleaded gasoline for those automobile brands having high compression engines). This value was in turn multiplied times the GNP deflator for each year to calculate the values in 1992 dollars.

The cumulative value of energy savings for sales of **Thermefficient-100®** units during the 1981 through the 1992 time period is $97.1 million in constant 1992 dollars. This value was calculated using the annual estimate of energy savings in Btu/yr x 10^9 times the average annual price of natural gas [we used the average natural gas price for commercial and industrial users (Energy Information Administration, 1993b)]. This calculation also takes into consideration the increase in hours of operation from 2000 hours/year in 1981 to 4000 hours/year in 1992. The values were multiplied times the GNP deflator for each year to calculate the values in 1992 dollars.

The value of energy savings and cost effectiveness (measured by payback period) for the three technologies is shown in Table 7.5. The value of the total cumulative energy savings for the technologies is $531.4 million. The payback period estimates were calculated by dividing the cost of the new technology by the annual energy savings in 1992 dollars. The payback for each of these three technologies is less than five years.

Table 7.5 Value of Energy Savings

	Brandon packing rings	Electronic Octane®	Thermefficient-100®	Total
Value of energy savings (in million 1992 $)	106.7	327.6	97.1	531.4
Payback period (yrs)	3.51	3.91	4.68	

7.3 REDUCTION OF GREENHOUSE GAS EMISSIONS[3]

Tables 7.6 and 7.7 present estimates of the reductions in emissions of carbon and methane associated with the use to date (1981-1993) of Brandon packing rings, Electronic Octane®, and Thermefficient-100®. The base data for greenhouse gas emissions come from the Energy Information Administration (1993a), and energy use data required for the estimates come from the Energy Information Administration (1992).

Table 7.6 Reduction in Carbon Emissions, in Metric Tons

	Coal	Oil	Gas	Total
Brandon Packing Rings	399,400	52,100	26,200	477,700
Electronic Octane®		369,900		369,900
Thermefficient-100®			73,600	73,600
Total	399,400	422,000	99,800	921,200

Table 7.7 Reduction in Methane Emissions, in Metric Tons (excluding emissions in associated production, transmission, and distribution)

	Coal	Oil	Gas	Total
Brandon Packing Rings	10.6		2.0	12.6
Electronic Octane®				
Thermefficient-100®			5.6	5.6
Total	10.6		7.6	18.2

3 Don Jones is the primary author of this section.

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 occur during those steps rather than during end use, and inclusion of reductions in those emissions as well would multiply the estimates in Table 7.6 by a factor of 135.

In order to have a single yardsitck by which reductions in greenhouse gas emissions can be compared, emissions of carbon and methane are often reported 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.

Table 7.8 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	921,200	3.67	3,380,804
Methane	18.2	35	637
Total	--	--	3,381,441

Through 1992, the three ERIP technologies reduced carbon emissions by an estimated 921,200 metric tons, and methane emissions by an estimated 18.2 metric tons. This results in a total reduction of the equivalent of approximately 3.4 million tons of CO_2.

8. PARTICIPANT PERCEPTIONS AND EVALUATION CONCLUSIONS

8.1 PARTICIPANT PERCEPTIONS

The last question on the 1993 ERIP evaluation questionnaire asked inventors to rate each of six types of ERIP assistance, from not at all helpful to extremely helpful using a 7-point scale. Each type of assistance was rated, based on its helpfulness to the commercialization of their technology. The average rating given to each type of assistance is presented in Table 8.1, where "not at all helpful" is given a rating of 1, and "extremely helpful" is given a rating of 7.

Table 8.1 Participant Perceptions of ERIP Assistance

Benefits to Users or Public	Average Rating by Promising Inventors	Average Rating by Other Inventors	Average[a] Rating by All ERIP Inventors
Grant[b]	6.3	6.3	6.3
Technical evaluation by NIST	4.7	5.1	5.0
Assistance with networking and and other benefits provided by DOE Invention Coordinators	4.0	4.7	4.5
Commercialization Planning Workshop	4.7	4.2	4.3
Assistance with raising funds due to the credibility associated with participation in ERIP	4.1	3.7	3.8
Assistance with sales or licensing due to the credibility associated with participation in ERIP	3.5	2.8	3.0
Other	5.0[c]	5.0[d]	5.0

[a]To calculate each of these weighted averages, the percent of promising inventions was multiplied by 133/557, the percent of other inventions was multiplied by 424/557, and the two products were added.
[b]Respondents were asked to skip this question if no DOE grant was received.
[c]8 promising inventors rated other types of assistance.
[d]17 other inventors rated other types of assistance.

Four of the six types of ERIP assistance listed in the survey (and in Table 8.1) have average ratings that exceed 4.0, the midpoint of the 7-point scale. Assistance with raising funds and with sales or licensing, due to the credibility associated with participation in ERIP, are the two types of assistance that received the lowest ratings. While the average ERIP participant does not appear to benefit substantially from these two types of assistance, we know from testimonials that the credibility associated with participation in the Program has opened doors to increased funding and other opportunities for at least some inventors.

Inventors indicated that the grant was by far the most valuable type of assistance provided by ERIP. The next most highly rated type of assistance was the technical evaluation provided by NIST. Assistance with networking and other benefits provided by DOE Invention Coordinators was the third most valued form of assistance, followed closely by the Commercialization Planning Workshop.

8.2 INTERNAL AND EXTERNAL VALIDITY OF THE EVALUATION

Program evaluations are often judged in terms of their internal and external validity (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? Each of these types of validity is discussed below.

8.2.1 Internal Validity

Program evaluators typically employ comparison groups as a defense against threats to the internal validity of their evaluations. Internal validity is threatened when extraneous variables are able to produce effects that cannot be disentangled from effects of the program. Extraneous variables that are particularly relevant to evaluations of technology innovation programs include: changing economic conditions that might affect access to capital and demand for products; progress that would have occurred in the absence of program participation simply due to the sustained efforts of inventors and product champions; and selection biases resulting in differences between program participants and comparison groups.

The evaluation design employed in this evaluation and all of the subsequent ERIP evaluations does not involve a comparison or control group against which the progress of ERIP inventions can be compared. Rather, the literature at large is relied upon to provide insight into the invention and innovation process as it occurs without government intervention. Thus, as is true of most evaluations of innovation programs (Roessner, 1989), a precise assessment of the net benefits of the Energy-Related Inventions Program is beyond the reach of this evaluation.

In order to address the issue of internal validity, a comparison group assessment of ERIP was recently completed (Brown, et al., 1994). The purpose of the comparison group analysis was to isolate the effects of ERIP from the host of other factors that influence the commercialization of inventions. The analysis was based on the results of the 1991 ERIP evaluation supplemented by a 1992 survey of 79 "program referrals." Program referrals are ERIP applicants that were found by

NIST to be technically feasible and commercially competitive, but appear not to offer sufficient energy benefits for program participation. They are labeled "program referrals" because NIST refers them to other programs for support, such as the Small Business Administration's Small Business Development Centers located across the U.S. The advantage of using program referrals as a comparison group is that overall their technologies and inventors appear to be well matched to the population of ERIP participants.

Program referrals and ERIP participants were found to differ significantly in terms of several indicators of commercial success.

- Only four of the 28 program referrals who did not have sales before they applied to the program were able to achieve commercial success afterwards.
- Only one of the four program referrals that did experience initial commercial success after rejection from the program was able to remain viable for more than a few years.
- Average dollar sales by ERIP participants are an order of magnitude greater than the program referral group.
- A higher percentage of ERIP inventions are protected by patents (90%), compared with program referrals (72%).
- Only 6% of the program referrals were associated with employment in recent years, compared with 58% of the ERIP participants.
- ERIP participants raised twice as much funding, per invention, as program referrals.
- Program referrals relied mainly on personal funding to develop their inventions, while ERIP participants received much of their funding from non-personal sources such as corporate profits, banks, stock offerings, and government programs in addition to the ERIP.

These results provide strong evidence that ERIP-supported technologies achieved their considerable commercial success, at least in part because of the support provided by the Energy-Related Inventions Program.

8.2.2 External Validity

The external validity of this evaluation of ERIP is difficult to assess. Our analysis of nonresponse bias indicates that respondents tend to be more actively involved in the development of their ERIP technology than nonrespondents, who tend to have suspended work on their ERIP technologies. But the progress made by respondents is no greater than that of nonrespondents in terms of the advancement of their technologies through the stages of development and into the marketplace.

One indicator of external validity is that all five evaluations of ERIP have produced remarkably similar indicators of commercial progress. For example, consider the various rates of market entry that have been produced by the five evaluations, each based on different samples and an ever-growing population of ERIP inventors. The first evaluation of ERIP based on a sample of 204 inventors and a population of 305 estimated that 18% of the ERIP technologies had entered the market by the end of 1984 (Brown, et al., 1987, p. 22). This rose to 26% based on a sample of 181 inventors out of a population of 373, and data through the end of 1986 (Brown and Snell, 1988, p. 14). By the end of 1988, an evaluation based on a sample of 176 inventors estimated that 25% of 444 technologies had entered the market (Brown and Wilson, 1990, p. 10). The most recent evaluation based on a sample of 183 inventors out of a population of 486, estimated the same rate of market entry—25% (Brown, Wilson, and Franchuk, 1991, p. 3.5). The current evaluation's estimate (based on a sample of 253 inventors and a population of 557) is a rate of 23%.

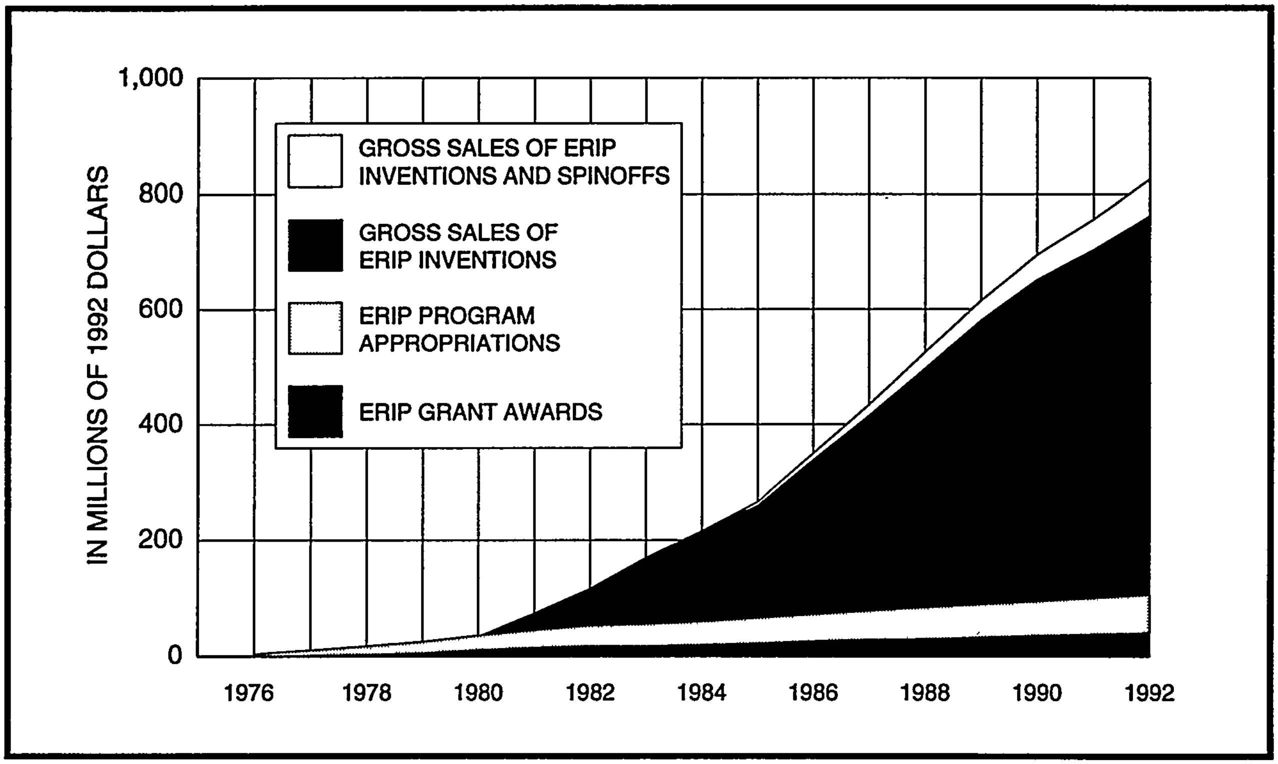
The constancy of these rates and other key evaluation findings suggests that the evaluation designs have been sufficiently robust to enable extrapolation to the population of ERIP inventors at large, and to future cohorts of participants, as well.

8.3 EVALUATION CONCLUSIONS

This evaluation reveals that 1991-92 was a successful period for many ERIP technologies. By the end of 1992, at least 129 ERIP inventions had entered the market, generating total cumulative sales of $763 million (in 1992 dollars). The success of ERIP inventors is also shown in their licensing revenues. It is estimated that in 1992 ERIP inventors earned royalties of $1.0 million, and over the lifetime of the program, royalties total $18.6 million. With $41 million in grants awarded from 1975 through 1992, and $106 million in program appropriations over the same period, ERIP has generated a 19:1 return in terms of sales values to grants, and a 7:1 return in sales versus program appropriations. It is estimated that 23% of the 557 ERIP inventions had achieved sales by the end of 1992. An analysis of sources of funding provides additional evidence of positive program impacts. While it is difficult to make exact comparisons between these percentages and other indicators of the success rates of technological innovations as a whole, the ERIP figures remain impressive.

The commercial progress of spinoff technologies is also documented. Altogether, 36 spinoff technologies have generated sales of $63 million. Most of these involve alternative market applications, but some of them are second-generation technologies. Figure 8.1 portrays the cumulative sales of ERIP's inventions and spinoff technologies over the lifetime of the program and compares these values to ERIP program appropriations and grant awards.

The employment and tax benefits associated with ERIP technologies are also significant. It is estimated that at least 668 full-time equivalent employees were working on ERIP technologies in 1992. This employment is associated with a return of approximately $2.7 million in individual income taxes to the U.S. Treasury.



[a]Based on constant 1992 dollars.

Fig. 8.1 Cumulative Sales of ERIP Inventions and Spinoff Technologies[a]

Finally, this evaluation assessed the energy and environmental benefits associated with ERIP technologies. It documents that more than $531 million of energy expenditures has been saved over the past decade as a result of the commercial success of three ERIP projects. These energy savings have resulted in reduced emissions of nearly one million metric tons of carbon.

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APPENDIX A
QUESTIONNAIRE

1993 ERIP Evaluation Questionnaire

Project Number:

TECHNOLOGY DESCRIPTION

The following title and description are based on the status of the technology when ERIP support was initially requested. Please revise the title and description if they are no longer correct.

TITLE
BRIEF DESCRIPTION
DOE Invention Coordinator:

Project Number:

CONTACT INFORMATION

To be sure that we have up-to-date contact information, please complete or correct the following data.

CONTACT		Additions or changes?
Name		
Company		
Address		
City & State		
Zip code		
Phone: Home Business FAX		
INVENTOR		**Additions or changes?**
Name		
Company		
Address		
City & State		
Zip code		
Phone: Home Business FAX		

CONTACT'S ASSOCIATION WITH THIS PROJECT

We would like to know how you are related to this ERIP technology. Please check one or more boxes below. If your circumstance does not fit any of the listed categories, please describe it in the space provided.

- Inventor ☐
- Applicant ☐
- Licensee ☐
- Owner of technology ☐
- Designated contact ☐
- Developer of technology ☐
- Other (Describe below) ☐

Project Number:

CONTACT'S EMPLOYMENT HISTORY

Please update the employment data below.

Contact's Current Employment, if different from below				Additions or changes?			
Company							
Your position or job role							
Number of employees in company	1-15			500-999			
	16-49			1000-9999			
	50-99			10000+			
	100-499						
Years there	First		Last	First		Last	
Contact's Most Recent Employment				**Additions or changes?**			
Company							
Your position or job role							
Number of employees in company	1-15			500-999			
	16-49			1000-9999			
	50-99			10000+			
	100-499						
Years there	First	0	Last 0	First		Last	
Contact's Previous Employment				**Additions or changes?**			
Company							
Your position or job role							
Number of employees in company	1-15			500-999			
	16-49			1000-9999			
	50-99			10000+			
	100-499						
Years there	First	0	Last 0	First		Last	

Project Number:

CONTACT'S EDUCATIONAL BACKGROUND

Please check the boxes next to those categories that apply to your educational background.

High School		Trade School		In-Service Training		Junior College Degree	
BS		BA		MS		MA	
MBA		JD		MD		PhD	

Please make any necessary additions or corrections to the information in the table below.

Type of Study	Course of Study	Additions or corrections?
Trade school/High school		
Undergraduate Major		
Graduate Major		
Other certifications or educational experience		

DEMOGRAPHICS

Please make any necessary additions or corrections to your year of birth noted below.

CONTACT DEMOGRAPHICS	Year of Birth	Additions or corrections?
In what year were you born?		

INVENTOR'S POSITION AT TIME OF CONCEPTUALIZATION

Please make any necessary additions or corrections to the information in the table below.

INVENTOR'S BACKGROUND		Additions or corrections?
Inventor's Name		
Company in which inventor worked during the initial period of conceptualization		
Inventor's position at time of conceptualization		

Number of employees in company								
	1-15		50-99		500-999		10000+	
	16-49		100-499		1000-9999			

Project Number:

PATENTING ACTIVITY

We are interested in understanding the degree to which your ERIP technology has patent protection.

In most cases, our contact is the original inventor, and patenting activity should go in the first column below. Occasionally a technology is further developed by individuals other than the original inventor. If you are not the initial inventor, but you or your company have received patents, please record this in the second or third columns below.

Please change or update the table below as necessary.

PATENTS ISSUED TO

RELATIONSHIP to ERIP	The inventor		The contact, if different from inventor		Company developing the ERIP-sponsored technology	
	U.S. Patents	Foreign Patents	U.S. Patents	Foreign Patents	U.S. Patents	Foreign Patents
Related to ERIP technology						
Unrelated to ERIP technology						

DISTRIBUTION STRATEGY

How do you (or how do you intend to) distribute your ERIP technology? Please check one or more of the boxes below. If your intended distribution strategy falls outside of the categories below, please describe it briefly in the space provided.

☐ Direct Sales	Direct sales from contact's company to end users.
☐ Distributors/Resellers	Distributors or resellers outside the company will be used to reach end users.
☐ Indirect Sales	This technology will either be licensed or sold, and the licensee or new owner will manage distribution.
☐ Services	The primary product is a technical service that this company provides to end users.
☐ Other	Please describe.

Project Number:

ACTIVITY AND DEVELOPMENT STATUS OF THIS TECHNOLOGY

This information helps us track the chronological development and activity status of the ERIP technology. Please use the following activity and development status categories to update the table below.

ACTIVITY CATEGORIES

0 = Active development begins

1 = Actively being pursued

2 = Low level of effort

3 = Suspended temporarily

4 = Suspended indefinitely

5 = Failed

6 = Chapter 11/Reorganization

7 = Chapter 7/Bankruptcy

DEVELOPMENT CATEGORIES

0 = Technology originally conceptualized

1 = Concept definition and development

2 = Working model

3 = Prototype development, testing, engineering design

4 = Pre-production prototype testing

5 = Production prototype

6 = Limited production and marketing

7 = Full production and marketing

HISTORY OF ACTIVITY LEVEL AND DEVELOPMENT STATUS

YEAR	ACTIVITY LEVEL	DEVELOPMENT STATUS	Changes or comments?
1980			
1981			
1982			
1983			
1984			
1985			
1986			
1987			
1988			
1989			
1990			
1991			
1992			

1993 ERIP Evaluation Questionnaire

Project Number:

FIELD TESTS AND DEMONSTRATIONS OF THE TECHNOLOGY

We are interested in collecting information on the roles played by field tests and demonstrations in the commercialization of ERIP technologies. Please keep in mind the following definitions when answering the questions on this page:

FIELD TESTS are tests of full-sized prototypes in real-life situations, conducted to determine the workability of an innovation under operating conditions. Field tests are smaller in scale than demonstrations, are generally characterized by lower visibility, and involve limited outside dissemination of results.

DEMONSTRATIONS are applications of full-sized prototypes, installed to demonstrate market readiness, not to test for it. The aim is to inform and persuade potential adopters by providing them with an opportunity to examine and assess the technology's performance.

1. Has your technology ever been the subject of a field test or demonstration? Please check the appropriate box(es) below:

☐ Field Test (Please describe) ______________________________

____

☐ Demonstration (Please describe) ______________________________

____

☐ Neither (Skip to Question 7)

2. When did the field test/demonstration take place? Year(s): ______________

3. Did the field test/demonstration involve an industrial partner? ☐ NO ☐ YES

(Please describe) ______________________________

4. Did the industrial partner, a government agency, a supplier, or any other organization help pay for the field test/demonstration? (Please include in-kind costs.)

☐ NO ☐ YES (Please describe) ______________________________

____

5. Was a neutral and credible outside organization involved in monitoring the performance of the technology during the field test/demonstration?

☐ NO ☐ YES (Please describe) ______________________________

____

6. Were the results of the field test/demonstration disseminated or otherwise used to promote sales?

☐ NO ☐ YES (Please describe) ______________________________

____

7. Do you believe that a field test or demonstration of your technology (could have) significantly improved the sales of your technology? Please check the appropriate box(es) below:

☐ YES - Field test ☐ YES - Demonstration ☐ Neither (would have) helped

Please explain your answer: ______________________________

____

Project Number:

SALES DATA

Information on sales of your ERIP technology is essential to our assessment of the assistance provided by ERIP. Information on sales of your company helps us understand the relationship between technical development and the growth of small business.

Direct sales: Direct sales are sales of the ERIP technology that are taking place out of your company.

Indirect sales: If other organizations that are not your customers are selling the ERIP technology, these sales are indirect sales. For example, this would include sales by a licensee or a company that has purchased the technology.

Please make any appropriate additions or changes to the table below.

First year of sales of the ERIP technology:				
	SALES CATEGORY			
Year of sales	Number of units sold	Direct Sales of the ERIP technology to end users or distributors —($)—	Indirect Sales of the ERIP technology —($)—	Gross Sales of your company across all product lines —($)—
1980				
1981				
1982				
1983				
1984				
1985				
1986				
1987				
1988				
1989				
1990				
1991				
1992				

Has your ERIP technology been sold outside of the U.S.? ☐ YES ☐ NO

If yes, please estimate your total foreign sales to date. $ ____________________

(These sales should also be included in the above table.)

Project Number:

LICENSING REVENUE

Information about licensing helps us examine the relative success of different approaches to commercialization. If your ERIP technology has not been licensed and its patent has not been sold, proceed to the next page.

Please make any appropriate additions or changes to the tables below.

LICENSE AND PURCHASE AGREEMENTS

YEAR	LICENSE/PURCHASE	With or from whom?	Did sales of the ERIP technology result? (Y/N)

LICENSING REVENUES

YEAR	ROYALTIES (-$-) Royalties received or paid out based on actual sales of the ERIP technology.	ROYALTY RATE (XX.X%) The average royalty percentage rate. If multiple royalty rates are in use, please give us a weighted average.	OTHER LICENSING PAYMENTS (-$-) Includes up-front payments, bonuses, or other licensing revenues not tied to actual sales.
1980			
1981			
1982			
1983			
1984			
1985			
1986			
1987			
1988			
1989			
1990			
1991			
1992			

Project Number:

EMPLOYMENT

Information about employment generated by the ERIP technology helps us examine the degree to which the ERIP program has been successful in generating jobs.

Direct ERIP employment: This is the number of employees of your company that can be directly attributed to the technology sponsored by the ERIP program.

Indirect ERIP employment: These are employees of other organizations whose jobs are related to the production, marketing, or distribution of the ERIP technology. Indirect ERIP employees could include suppliers, subcontractors, retailers, licensees, or others whom you do not directly employ. Please estimate these numbers and provide descriptions in the table below.

Please make any appropriate additions or changes to the table below.

EMPLOYMENT ASSOCIATED WITH THE ERIP TECHNOLOGY			
YEAR	DIRECT EMPLOYMENT Number of FTE employees **	INDIRECT EMPLOYMENT Number of FTE employees **	COMMENTS
1980			
1981			
1982			
1983			
1984			
1985			
1986			
1987			
1988			
1989			
1990			
1991			
1992			

** Use Full-Time Equivalents (FTE) (2 Half Time = 1 FTE)

Project Number:

'SPINOFF' TECHNOLOGIES

There are several ways in which 'spinoff technologies' can arise.

1. Development of an initial technology results in new product characteristics that adapt the product for new markets.

2. Efforts to solve a problem with an initial technology fail, so a different approach is used to resolve the same problem and a new technology results.

3. A new application is found for a component of an initial product.

If any of the criteria above apply to your ERIP technology, please describe below the two most promising or successful spinoff technologies that you have developed as a result of your ERIP project.

DESCRIPTION OF SPINOFF TECHNOLOGY #1

	1985	1986	1987	1988	1989	1990	1991	1992
Sales ($)								
Licensing Royalties ($)								

DESCRIPTION OF SPINOFF TECHNOLOGY #2

	1985	1986	1987	1988	1989	1990	1991	1992
Sales ($)								
Licensing Royalties ($)								

DEFINITIONS OF CATEGORIES OF FUNDING

Please use the following funding types when describing your sources of funding on the next page.

Category	EQUITY INVESTMENTS
Sweat Equity	Estimated value of uncompensated labor.
Personal/Mgt Team	Personal funds and those from the development team.
Informal Equity Investment by friends and family	Equity investment from friends and relatives who are not associated with formal investment organizations and who are not professional private investors. May involve distribution of private stock.
Venture Capital	Equity investments from formal venture capital organizations. This includes funding from SBDICs and venture partnerships developed to invest in the technology, as well as professional or sophisticated private investors.
Public Stock	Public stock offerings.
Federal R&D Contracts & Grants other than the ERIP grant	Federal R&D contracts and grants, such as SBIR, DOE, DOD etc. This does not include the grant you got from the Energy-Related Inventions Program.
State & Local Grants & R&D Contracts	Grants and R&D contracts from State and local agencies.
Retained Earnings from Sales	Reinvested profits from sales. This is that portion of profits from sales that is reinvested in the company.
Other Equity	Equity funding from other sources, e.g., preferred stock subordinated debentures.
Category	**DEBT INVESTMENTS**
Supplier and Customer Credit	Trade credit from suppliers and Work-in-Progress payments from customers.
Banks	Commercial bank loans. This would include long-term loans to cover development costs, real estate purchases, etc., as well as short-term loans to cover inventory, etc.
Federal, State, & Local Guaranteed Loans	Loans guaranteed by State, local, and Federal agencies, including loans guaranteed by the Small Business Administration.
Informal Debt Investment	Debt investment from friends and relatives who are not associated with formal investment organizations.
Other Debt	Debt funding from any other source, e.g. operating or capitalized leases.

Project Number:

SOURCES OF FUNDING
FOR YOUR ERIP TECHNOLOGY

This information helps us understand the nature of the funding that goes into the development of ERIP technologies. Please update the funding table below using the Funding Categories in the left column of the table on the previous page.

ERIP Application Date		Award Date		ERIP Grant ($)	

HISTORY OF FUNDING FOR YOUR ERIP TECHNOLOGY

YEAR	Amount -($)-	Funding Category	Comments

Project Number:

CONTACT'S EXPERIENCE WITH STARTUP COMPANIES

Please give us some information about startup companies with which you have been involved.

How many startup companies have you been personally involved with?	ERIP related	Not ERIP related

Please describe your involvement with startup companies in the table below.

MOST RECENT STARTUP		Additions or changes?
Company Name		
Location		
Year company started		
Your job role		
Business type (e.g. Sole proprietorship, Partnership, Joint Venture, S Corp., Other Corp.)		
What connection, if any, was there between this startup company and the ERIP technology?		
PREVIOUS STARTUP		**Additions or changes?**
Company Name		
Location		
Year company started		
Your job role		
Business type (e.g. Sole proprietorship, Partnership, Joint Venture, S Corp., Other Corp.)		
What connection, if any, was there between this startup company and the ERIP technology?		

1993 ERIP Evaluation Questionnaire

Project Number:

TECHNOLOGY CHARACTERISTICS

We are interested in knowing about the features of your ERIP technology that you believe represent benefits to users or to the public. Please check all the boxes below that are applicable to your technology and provide a brief description for all those you check.

☐ Energy savings. Explain: ______________________________

____

____

☐ Energy production. Explain: ______________________________

____

____

☐ Environmental benefits. Explain: ______________________________

____

____

☐ Other quality or performance improvements or cost or resource savings. Explain: ______________________________

____

____

____

ERIP ASSISTANCE

ERIP seeks to accelerate the commercialization of energy-related inventions by offering several kinds of assistance. Please rate each of the following types of assistance, from not at all helpful to extremely helpful, based on helpfulness to the commercialization of your technology.

	Not at all helpful 1	2	3	Somewhat helpful 4	5	6	Extremely helpful 7
Technical evaluation by NIST	☐	☐	☐	☐	☐	☐	☐
Grant (Skip if no DOE grant has been received)	☐	☐	☐	☐	☐	☐	☐
Commercialization Planning Workshop	☐	☐	☐	☐	☐	☐	☐
Assistance with networking and other benefits provided by DOE Invention Coordinators	☐	☐	☐	☐	☐	☐	☐
Assistance with raising funds due to the credibility associated with participation in ERIP	☐	☐	☐	☐	☐	☐	☐
Assistance with sales or licensing due to the credibility associated with participation in ERIP	☐	☐	☐	☐	☐	☐	☐
Other (Describe):	☐	☐	☐	☐	☐	☐	☐

Did (or do) you have any needs that were not met? ______________________________

____

Project Number:

ADDITIONAL COMMENTS

INTERNAL DISTRIBUTION

1. T. D. Anderson
2. R. A. Balzer
3. L. G. Berry
4. L. Baxter
5. M. A. Brown
6. J. B. Cannon
7. R. S. Carlsmith
8. T. R. Curlee
9. J. R. Ferguson
10. C. A. Franchuck
11. W. Fulkerson
12. S. W. Hadley
13. E. L. Hillsman
14. E. Hirst
15. R. B. Honea
16. D. W. Jones
17. C. H. Kerley
18. M. A. Kuliasha
19. E. Lapsa
20. P. N. Leiby
21. D. E. Reichle
22. C. G. Rizy
23. A. C. Schaffhauser
24. R. B. Shelton
25. E. J. Soderstrom
26. D. L. White
27. T. J. Wilbanks
28. C. R. Wilson
29. Central Research Library
30. Document Reference Section

31-32. Laboratory Records

33. Laboratory Records-RC
34. ORNL Patent Office

EXTERNAL DISTRIBUTION

35-70. P. M. Hayes, Inventions and Innovation Programs, U.S. Department of Energy, EE-521, 5E-052, 1000 Independence Ave., SW, Washington, DC 20585.

71. D. R. Bohi, Director, Energy and Natural Resources Division, Resources for the Future, 1616 P Street, N.W., Washington, DC 20036.
72. T. E. Drabek, Professor, Department of Sociology, University of Denver, Denver, Colorado 80208-0209
73. T. M. Levinson, Inventions and Innovation Programs, U.S. Department of Energy, EE-12, 5E-052, 1000 Independence Ave., SW, Washington, DC 20585.
74. M. A. Fowler, U.S. Department of Energy, 5G-023, EE-532, 1000 Independence Avenue, S.W., Washington, DC 20585.
75. H. C. Livesay, 1401 Riverstone Court, College Station, TX 77840
76. D. S. Lux, 30 Card Street, Coventry, RI 02816
77. C. D. MacCracken, President, Calmac Manufacturing Corporation, 101 West Sheffield Avenue, P.O. Box 710, Englewood, NJ 07631
78. R. Nader, P.O. Box 19367, Washington, DC 20036
79. Office of the Assistant Manager, Energy Research and Development, Department of Energy, P.O. Box 2008, DOE Field Office, Oak Ridge, TN 37831-6269.

80-81. OSTI, U.S. Department of Energy, P.O. Box 62, Oak Ridge, TN 37831.

82. R. W. Peplies, Department of Geography, East Tennessee State University, Johnson City, TN 37814.

83-84. M. Rorke, Mohawk Research Corp., 915 Willowleaf Way, Rockville, MD 20854-317.

85. J. B. Shrago, Director, Office of Technology Transfer, 405 Kirkland Hall, Vanderbilt University, Nashville, TN 37240

86-350. Energy Program Planning and Evaluation Distribution List, Marilyn A. Brown, Oak Ridge National Laboratory, P.O. Box 2008, 4500N, MS 6206, Oak Ridge, TN 37831-6206.