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**OAK RIDGE  
NATIONAL  
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**MARTIN MARIETTA**

**Commercializing  
Government-Sponsored Innovations:  
Twelve Successful Buildings  
Case Studies**

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OPERATED BY  
MARTIN MARIETTA ENERGY SYSTEMS, INC.  
FOR THE UNITED STATES  
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## COMMERCIALIZING GOVERNMENT-SPONSORED INNOVATIONS: TWELVE SUCCESSFUL BUILDINGS CASE STUDIES

by

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## EXECUTIVE SUMMARY

### FOCUS AND GOALS

This report examines the commercialization and use of R&D results funded by DOE's Office of Buildings and Community Systems (OBCS), an office dedicated to improving the energy efficiency of the nation's buildings. Three goals guided the research described herein:

- to improve understanding of the factors that hinder or facilitate the transfer of OBCS R&D results,
- to determine which technology transfer strategies are most effective and under what circumstances each is appropriate, and
- to document the market penetration and energy savings achieved by successfully-commercialized innovations that were developed with OBCS support.

### RESEARCH DESIGN

Our overall research approach was to conduct case studies of successful OBCS-supported innovations in order to examine the technology transfer activities leading to commercialization. Five fully-commercialized innovations and seven semi-commercialized innovations were examined. Market penetration of at least 4% characterizes the former; lower levels of market penetration characterize the semi-commercialized innovations. The fully-commercialized innovations are:

- solid-state ballasts for fluorescent lighting,
- low-emissivity coatings for windows,
- unequal parallel compressor systems for supermarket refrigeration,
- flame retention head oil burner, and
- DOE-2.

The semi-commercialized innovations are:

- dielectric coatings,
- heat pump water heater,
- radiant barriers,
- Wisconsin audit,



- Computerized, Instrumented, Residential Audit (CIRA),
- hotbox method for testing heat transfer through walls, and
- tracer gas testing.

Each of the case studies provides background information on the technology, a summary of the steps in its development and deployment, and an assessment of the importance of the DOE role. Estimates of the market penetration and energy savings achieved by an innovation are reported whenever it was possible to obtain this information. For several of the innovations we also offer recommendations for future technology transfer activities that would accelerate their market penetration and use.

#### **DATA COLLECTION METHODS**

The 12 successful case studies were identified through interviews with OBCS program managers and a review of relevant literature. The next step was to document the commercialization process. This was initiated by reviewing the available literature, which consisted mainly of technical reports and trade publications. We then contacted OBCS and national laboratory project managers as well as industry and trade association representatives. Telephone and personal interviews were conducted with these technical managers and industry representatives. Data from secondary sources, such as trade associations and the Census of Manufacturers were also used to obtain an accurate picture of the extent of commercialization.

#### **ALTERNATIVE TECHNOLOGY TRANSFER STRATEGIES**

A review of the literature suggests that there are at least six broad technology transfer strategies available to OBCS:

- contracting R&D to industrial partners,
- working with industry consortia,
- influencing key decision-makers,
- working with broker organizations,

- generating end-user demand, and
- licensing to industry.

In addition to describing each of these strategies in general terms, the case studies are characterized according to which of these strategies was used to achieve commercialization, and conclusions are drawn concerning the usefulness and appropriateness of each strategy.

## **RESULTS**

### **Market Penetration and Energy Savings**

The level of market penetration achieved to date by the 12 innovations ranges from less than 1% for radiant barriers, heat pump water heaters, and dielectric coatings to complete saturation (100% of new residential units) for the flame retention head oil burner. The fully-commercialized innovations were found to be technically mature and without major problems related to acceptance and use. The semi-commercialized innovations, on the other hand, tend to have major unresolved technical or market-related problems.

Energy savings could not be estimated for all of the innovations. However, for the three innovations with the highest predicted levels of energy savings (i.e., the flame retention head oil burner, low-E windows, and solid-state ballasts), combined cumulative savings by the year 2,000 are likely to approach 2 quads. To date the energy savings for these three innovations are about 0.2 quads.

### **Technology Transfer Strategies**

Of the six generic technology transfer strategies available to OBCS, one dominates as a route to successful commercialization, in our small sample of case studies. Contracting R&D to industrial partners is the most commonly used strategy among the innovations studied here. A typical sequence of events (illustrated by the heat pump water heater, the supermarket refrigeration

compressor system, low-E windows, and the solid-state ballast) is for a national laboratory to issue a Request for Proposals for prototype development in hope of attracting a major manufacturer who will cost share. Only small firms respond. Through a subcontracting arrangement to the national laboratory, the selected small company is supported (with some cost-sharing) to develop a prototype. The national laboratory evaluates the prototype and either the laboratory or the small firm completes a market study. Field tests and demonstrations are conducted jointly by the laboratory and the small firm.

At this point the DOE involvement typically ends. The small firm that developed the prototype begins commercial production. After a few years, the innovation is then added to the product line of one or more major manufacturers, either through the purchase of patent rights or through imitation.

In each of the four case studies that followed this pattern, interviews with industry spokespersons indicate that the DOE role was significant. Either the technology would not have been developed without DOE support, or at the very least, the pace of technology development, market entry, and market penetration would have been significantly slower.

Despite the dominance of this one technology transfer strategy, three of the other strategies were shown in the case studies to be effective in specific situations: working with broker organizations, influencing key decision-makers, and generating end-user demand. DOE's valuable role as a source of information about the performance of new technologies is illustrated throughout our case studies in conjunction with efforts to promote technological change via these audiences.

DOE's ability to stimulate commercialization through a training program for service personnel was vividly illustrated in one case study. Examination of

several other innovations suggests that inadequate training is a common and critical barrier to technological change in the buildings industry.

None of the case studies involved an industry consortium or licensing from a national laboratory to industry. The cost of establishing industry consortia is probably a major deterrent to the industrial consortium strategy. Patent policies and procedures, in turn, have made it difficult for DOE laboratories to obtain patent waivers and thereby license technologies.

There are many factors that affect the appropriateness of one technology transfer strategy over another, including: the nature of the R&D results being transferred, the potential applications, the producer and consumer markets, and DOE's goals and resources. The role of each of these factors is discussed.

The report also suggests specific activities that are appropriate to stimulate the further penetration of several of the case study innovations. For instance, a consumer information program is recommended for radiant barriers and the heat pump water heater. Further technical development is needed before tracer gas testing will gain widespread use. A less expensive version of the Wisconsin audit is required to enable widespread adoption. Dielectric coatings, low-E windows, solid-state ballasts, DOE-2, CIRA, the new supermarket refrigeration system, and the flame retention head oil burner have all achieved self-generating growth rates and do not, at this point, require further government support.

## CONCLUSIONS

Energy-saving innovations for buildings have a major potential role to play in improving the nation's energy security and international competitiveness. We have examined the processes by which 12 technologies sponsored by the U.S. Department of Energy were successfully commercialized,

and have suggested strategies for promoting future successes. The tentative lessons offered here provide insight into the complex innovation process and the importance of public support for R&D and technology transfer.

## ABSTRACT

This report examines the commercialization and use of R&D results funded by DOE's Office of Buildings and Community Systems (OBCS), an office that is dedicated to improving the energy efficiency of the nation's buildings. Three goals guided the research described in this report:

- to improve understanding of the factors that hinder or facilitate the transfer of OBCS R&D results,
- to determine which technology transfer strategies are most effective and under what circumstances each is appropriate, and
- to document the market penetration and energy savings achieved by successfully-commercialized innovations that have received OBCS support.

Twelve successfully-commercialized innovations are discussed here. The methodology employed involved a review of the literature, interviews with innovation program managers and industry personnel, and data collection from secondary sources. Six generic technology transfer strategies are also described. Of these, contracting R&D to industrial partners is found to be the most commonly used strategy in our case studies.

The market penetration achieved to date by the innovations studied ranges from less than 1% to 100%. For the three innovations with the highest predicted levels of energy savings (i.e., the flame retention head oil burner, low-E windows, and solid-state ballasts), combined cumulative savings by the year 2,000 are likely to approach 2 quads. To date the energy savings for these three innovations have been about 0.2 quads. Our case studies illustrate the important role federal agencies can play in commercializing new technologies.

# 1. INTRODUCTION

## 1.1 BACKGROUND AND PURPOSE

Over the past decade, federal policy makers have expressed a growing desire to obtain a better return on federal research and development (R&D) investments through improved technology transfer. The nation's future economic productivity, trade balance, and foreign indebtedness depend in large part on how well new technologies are put to use. Since nearly one-half of the nation's R&D is federally-supported, much can be gained by improving the translation of publicly-sponsored research results into private-sector products and practices. The commercialization of energy-efficient innovations can play a particularly important role in improving our economic competitiveness because of its multiple benefits: it can enhance the productivity of our economy, reduce our dependence on oil, and create products for export (U.S. Department of Energy, 1988a).

Although improved technology transfer is clearly a high national priority, many dimensions of the technology transfer process are poorly understood. Transferring products from producers to consumers, the realm of market research, is fairly well understood, but moving ideas from the laboratory bench to the producer (when they are part of different organizations) is another matter entirely, relatively ignored as a generic research question. As a special case, technology transfer from the public to the private sector has been especially neglected.

"In the rush to bring technology down from the federal shelf to industry's bench, only limited attention has been given to assessment of particular approaches and local effects....For the most part, opinions about the success of technology transfer policies is more a result of casual observation than of systematic inquiry" (Bozeman and Fellows, 1988).

This report examines the processes by which R&D results funded by one federal program have generated successful commercial applications. In particular, it focuses upon the process by which R&D results funded by the Office of Buildings and Community Systems (OBCS) of the U.S. Department of Energy (DOE) have been put to use by various public- and private-sector "beneficiaries."

Our examination of these processes is designed to accomplish three goals:

- to improve understanding of the factors that hinder or facilitate the transfer of OBCS R&D results;
- to determine which technology transfer strategies are most effective and under what circumstances each is appropriate; and
- to document the market penetration and energy savings achieved by successfully-commercialized innovations that have received OBCS support.

Through its R&D programs and regulatory activities, the federal government has an important role to play in efforts to design, construct, manage, and operate more energy-efficient buildings. Rapid increases in the energy-efficiency of buildings can be enhanced by carefully designed technology transfer efforts aimed at moving OBCS innovations into the marketplace. This study contributes to the improvement of such technology transfer efforts by focusing on the lessons to be learned from 12 case studies of the commercialization process. These case studies highlight some of the complexities inherent in developing strategies to transfer publicly-sponsored research results.

## 1.2 THE TECHNOLOGY TRANSFER PROCESS

Broadly defined, technology transfer is the application of available knowledge or technology by a new user and, in some cases, to a new use (Glaser et al., 1983). In the context of this report, it is more specifically



defined as the application of government-supported R&D by the private sector and state and local government users.

The term "technology transfer" is somewhat misleading because it implies that a technology can be picked up from one place and set down in another, as if the transfer process is simply the final step in an R&D project. Indeed, many government programs do start to encourage utilization of research only after the R&D results have been generated. Unfortunately, this "technology push" approach is usually unsuccessful. The most effective approaches to increased research utilization begin much earlier in the innovation process - as far back as when ideas are generated and selected for development (Roberts and Frohman, 1979). All too often, technology transfer is blamed for failures in commercialization when the real problem is mistakes in selecting the technologies for development.

Successful technology transfer and utilization require close attention to market needs - a clear identification of the user, his or her needs, and the user's reaction to types of technical solutions (Myers and Marquis, 1969). This is accomplished most effectively through close government-industry collaboration. The OBCS R&D program exemplifies this approach to technology transfer.

There are many ways in which close public-private cooperation can occur, and an appropriate partnership arrangement in one instance may not work well in another. No single mold or model fits because of the complexity of the technology transfer process. While useful "rules of thumb" exist, there is a great deal of variety in the ways that successful technology transfer unfolds. Figure 1.1 characterizes some of the reasons for this diversity.

Technologies originate from many sources - universities, company laboratories, independent inventors, government laboratories, and foreign

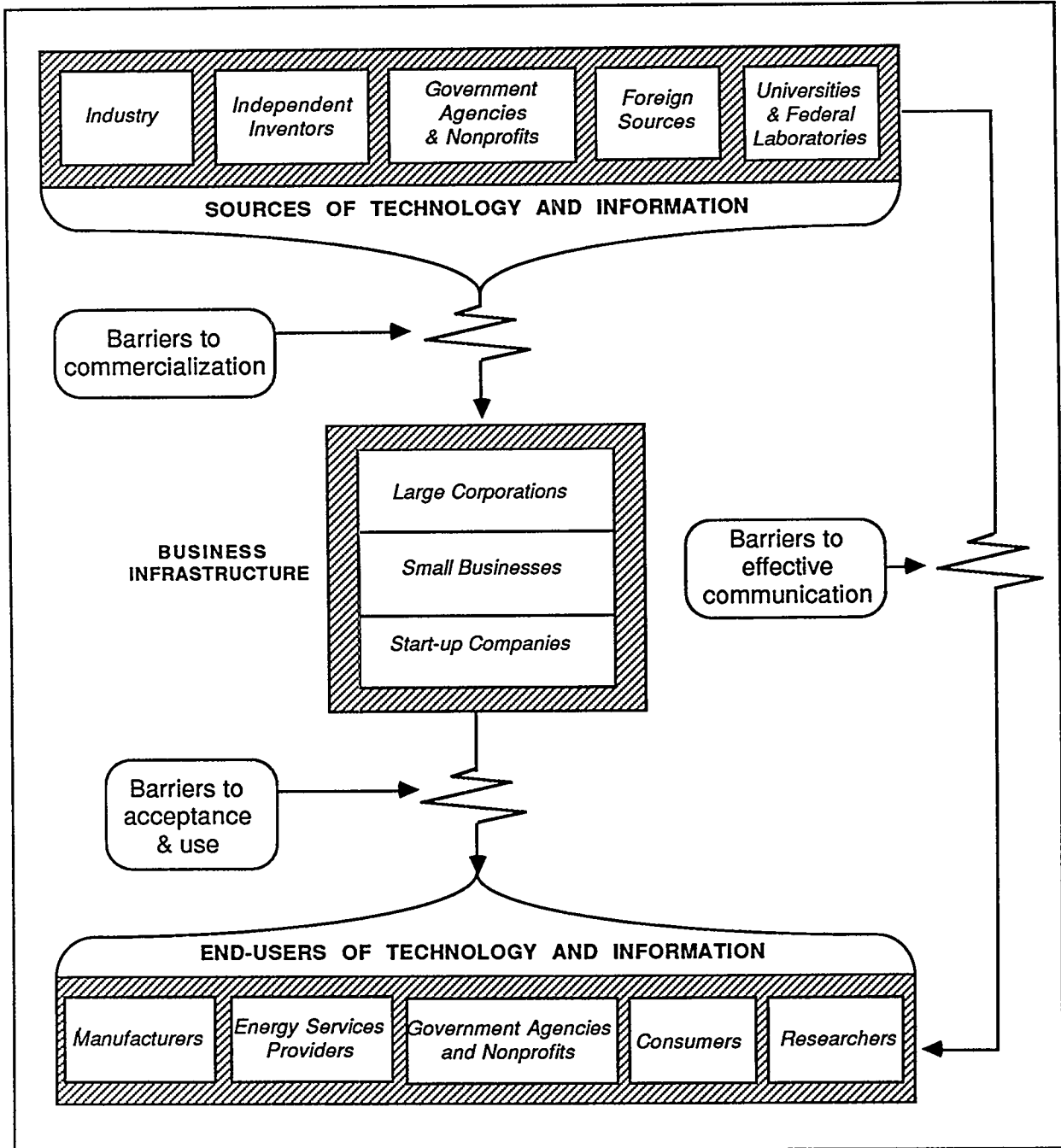


Fig. 1.1. The technology and information transfer process.

R&D. These points of origin differ dramatically in terms of the types of barriers that must be overcome to achieve commercial success and widespread use.

The technology and research findings to be transferred are also diverse and greatly determine the steps needed to ensure their use. Types of findings include:

- scientific knowledge,
- physical technologies (devices and prototypes),
- technological processes,
- test results,
- performance data,
- cost/benefit information, and
- patents and copyrights.

The channels and audiences appropriate to these different types of results differ dramatically and lead to vastly divergent technology transfer activities. For instance, among the end-users of OBCS-generated technologies and information are manufacturers, utilities, government agencies, nonprofit organizations, consumers, and researchers.

### **1.3 OVERVIEW OF THE REPORT**

To place the 12 case studies into a broader conceptual framework, barriers to innovation in the buildings industry are discussed (Section 1.4) and six generic types of technology transfer strategies are described (Section 2). The portfolio of strategies recognizes that, at a minimum, the technology transfer process varies according to the nature of the R&D result and the industry and end-user audiences being addressed.

Section 3 describes the research design used here, including the case study selection criteria and the data collection methods. We then trace the processes by which each innovation was developed and deployed. The DOE role is described, barriers and facilitating factors are documented, and the market

penetration and energy savings of innovations are estimated (Sections 4 and 5).

Section 4 discusses five innovations that are judged to be fully-commercialized:

- solid-state ballasts for fluorescent lighting,
- low-emissivity coatings for windows,
- microprocessor-controlled unequal parallel compressor systems for supermarket refrigeration,
- the flame retention head oil burner (FRHOB), and
- DOE-2.

Section 5 covers seven semi-commercialized innovations, ones that have entered the market but have relatively low levels of market penetration:

- dialectic coatings for lighting fixtures,
- heat pump water heaters (HPWHs),
- radiant barriers,
- Wisconsin audit,
- Computerized, Instrumented, Residential Audit (CIRA),
- Hotbox method for testing heat transfer through walls, and
- tracer gas testing.

Section 6 presents lessons from the case studies and prior research concerning which technology transfer strategies are most effective and under what circumstances each strategy is most appropriate. These lessons are tentative given our small sample size.

#### 1.4 BARRIERS TO INNOVATION IN THE BUILDINGS INDUSTRY

The rate of innovation adoption in the buildings industry is unusually slow as indicated by its lethargic gains in productivity relative to other sectors of the U.S. economy (Nelson and Winter, 1977; Abernathy, 1983). The construction industry, in particular, has been identified as a "laggard" industry by the federal government (Roessner, 1984).

Innovation in the buildings industry is plagued by many barriers. At each stage of the innovation process (including research and development, entry into the marketplace, and widespread adoption), there are significant barriers. A variety of barriers to innovation in the buildings industry are

discussed below, including barriers to initial R&D, barriers to market entry and penetration, and barriers related to regulatory and legal issues.

#### 1.4.1 Barriers to Research and Development

The buildings industry supports very little R&D. Manufacturers of building components and equipment conduct some proprietary research but they usually focus on down-stream issues of product performance and not on basic research leading to the development of new product lines (Moavenzadeh, 1985; Brown et al., 1986). This disinterest in R&D activity is often attributable to a situation in which innovations can be copied by competitors for less cost and risk than is paid by the developer. In addition, product line economics often make investments in energy-related R&D unattractive. While an innovation may represent a major breakthrough in performance or energy efficiency, it may also reduce the profitability of an existing product line. Companies offering the more profitable products that might be displaced will not invest in developing the innovation. They also may oppose the efforts of other companies to introduce the innovation. The solid-state ballast and radiant barrier (Section 4.2 and 5.3) illustrate<sup>5</sup> this type of problem.

The ability of the buildings industry to conduct R&D is also inhibited by its fragmentation and decentralization. Decentralized industries are characterized by low rates of R&D spending and strong resistance to technological change (Nelson and Winter, 1977). The buildings industry is fragmented along many dimensions, inhibiting the flow of information among its members and reducing its ability to conduct research (Achenbach, 1982; Moavenzadeh, 1985; Brown et al., 1986). The industry's fragmentation is indicated by:

- the large number of small- and medium-sized firms (i.e., low concentration ratios);

- the limited use of mass production and standardized practices;
- the numerous decision-makers involved in construction projects and the ad hoc nature of project teams; and
- the lack of coordination between sectors: commercial, residential, and industrial (The Business Roundtable, 1982).

#### **1.4.2 Barriers to Market Entry and Penetration**

Several characteristics of the buildings industry slow the market entry and penetration of energy-efficient technologies. One relevant characteristic is the large number of decision-makers involved. Consider, for example, the implications of having numerous, different parties engaged in the design and construction of buildings. The design of many large buildings involves an architect for the building envelope and mechanical engineers for the heating, ventilation, and air conditioning (HVAC) system. Poor coordination between envelope and equipment decisions often results, as when energy-efficient approaches to envelope design do not result in down-sized HVAC equipment. Often the decisions made by architects and mechanical engineers are based on minimizing first costs to stay within a construction budget. This is a deterrent to new energy-efficient products which tend to have higher first costs, but lower life-cycle costs than standard products.

The tendency to minimize first costs and to ignore life-cycle costs is widespread because of misplaced incentives and imperfect information about the performance of new technologies. Incentives to reduce life-cycle costs are usually relevant only to the building owners, owner-occupants or tenants who pay the energy bills. Yet it is builders, without direction from the eventual owners and occupants, who typically decide how energy-efficient a new structure's envelope will be. They also usually select and purchase large numbers of furnaces, water heaters, and other appliances without the

participation of building occupants or tenants. These "imposed choices" limit or eliminate the ultimate consumer's role in decision making (Quelch, 1980). Because builders are sensitive primarily to first costs, the exclusion of the owner/occupant from decision making results in less energy-efficient choices and higher life-cycle costs.

Even when builders are willing to install energy-efficient equipment, there is usually no mechanism that allows them to recover the higher initial investment. Much commercial space, for example, is leased under agreements that do not allow pass-through of investment costs or savings from energy-efficient equipment replacement or building modifications. Similarly, master metering of apartment buildings and other multi-occupancy structures leads to misplaced incentives in much of the U.S. building stock.

Although some owner/occupants might choose more efficient buildings and equipment if the choice were in their hands, many are unaware of the energy characteristics of common appliances and building components. Owner/occupants also may have high discount rates or prefer to invest capital in options other than improved energy efficiency. Uncertainties associated with the cost of energy, as indicated by the wide fluctuations in energy prices over the last two decades, reduce end-user interest in energy-efficient technologies as well.

The lack of adequately trained service and maintenance personnel to support new products is often another important barrier to their adoption. This barrier was significant in two of our case studies: the heat pump water heater and the microprocessor-controlled compressor train for supermarket refrigeration (Section 4.3).

The entry of new firms can be delayed and sometimes denied by market practices such as high advertising costs, predatory pricing, and long-term

contracts. High advertising costs may be unaffordable to new entrants who typically have limited resources. Predatory pricing can make a particular product unprofitable for potential entrants. Finally, when incumbents are tied into long-term contracts with buyers, new firms face difficulties in selling their products even when their prices are competitive.

#### **1.4.3 Regulatory and Legal Barriers**

Federal income tax depreciation allowances encourage substandard building construction and discourage investment in energy conservation renovations. Building construction and short-term ownership is often motivated by acquiring income tax write-offs against business income rather than by long-term or life-cycle economics (Science Applications, Inc., 1983).

Design and product liability requirements also may slow the adoption of innovations. These requirements sometimes inhibit the adoption of new products because of a lack of product validation procedures and facilities (Science Applications, Inc., 1983). Even when traditional methods are used, there are considerable fears about liability within the buildings industry (Moavenzadeh, 1983).

Codes and standards covering building materials and equipment could be used to encourage the implementation of energy-efficient options. But, this approach has limited effectiveness for several reasons: (1) codes are often mostly concerned with safety and reliability rather than energy efficiency, and (2) industry consensus standards take a long time to adopt and modify (Achenbach, 1982). In addition, codes and regulations often specify obsolete technologies, thereby inhibiting innovation (Quelch, 1980; Goldstein, 1983; Brown et al., 1985; Moavenzadeh, 1985; Rollin and Beyea, 1985).



The length of patent protection is sometimes insufficient to attract potential inventors. Patent waivers from DOE are also often difficult and costly to obtain, thereby hindering commercialization. Failure to discourage monopolies through antitrust regulation also discourages innovation, since monopolies lack incentives to perform aggressive R&D.

### **1.5 POTENTIAL FOR ENERGY SAVINGS IN BUILDINGS**

Although there are many barriers to innovation in the buildings industry, the potential payoff is significant. Buildings consume 40% of all forms of energy, and 75% of U.S. electricity production. A recent study (Rosenfeld and Hafemeister, 1988) estimates that technologies and policies for energy-efficient buildings could reduce energy consumption by \$50 billion per year. Without a major technology transfer effort, however, less than half of the energy savings achievable by cost-effective investments in buildings will occur (Office of Technology Assessment, 1982).

## 2. ALTERNATIVE TECHNOLOGY TRANSFER STRATEGIES

In 1985 a technology transfer assessment identified five strategies that appeared to have particular promise for overcoming the barriers inherent in transferring energy-conserving building technologies developed with support from the Office of Buildings and Community Systems (Brown et al., 1985). Due to limited resources, however, the previous study was unable to determine how often (if at all) each strategy was actually used by OBCS and under what circumstances each was most successful.

The five strategies provide a point of departure for this report, and include:

- contracting R&D to industrial partners,
- conducting R&D through industry consortia,
- influencing key decision-makers,
- working with broker organizations, and
- generating end-user demand.

Since that earlier assessment, licensing to industry has been actively debated as a technology transfer strategy (U.S. Department of Energy, 1988b). Changes in federal patent laws and policies have enhanced the ability of DOE's national laboratories to license their technologies to users. Thus, licensing is added to the list of alternative strategies discussed here.

These strategies are not mutually exclusive. For instance, DOE may support workshops to inform manufacturers of a new product opportunity that has energy-conservation advantages (i.e., "influencing key intermediaries"), while at the same time, end-user demand is being generated by informing consumers of the product's advantages (as was the case with low-emissivity coatings for windows - Section 4.1).

Each of these six strategies is briefly described below. A detailed description of the original five is provided in the prior report, including step-by-step information on how each has been used by government agencies in the past. Much of this information is summarized in Fig. 2.1 which lists the pros and cons of each strategy and also suggests appropriate situations for use.

## **2.1 CONTRACTING R&D TO INDUSTRIAL PARTNERS**

In this strategy, an R&D product is commercialized as the result of a DOE-supported R&D subcontract to an innovative firm. The firm acts as an industrial partner in the technology transfer process. With this approach the firm is given the support to reduce its risk and the incentive it needs to develop and vigorously market a technology. Cost-sharing from the industrial partner is encouraged, both as evidence that the firm is committed to the commercialization process and as a way of enhancing the R&D effort. Since the potential manufacturer is an integral part of the development of the technology, the chances for its commercialization are improved.

## **2.2 INDUSTRY CONSORTIUM APPROACH**

This approach involves DOE managers and laboratory scientists working closely with groups of firms to develop a particular innovation or R&D area. In a typical consortium arrangement, each company contributes only a portion of the cost of the research, but receives information on all of the work conducted. The consortium may retain patent rights on any new technologies, with member companies usually receiving nonexclusive, royalty free licenses. Nonparticipating firms may also be licensed, and royalties from them are shared based on annual firm contributions. Known as leveraging, this pooling of small investment justifies high-risk research by minimizing the

	CONTRACTING R&D TO INDUSTRIAL PARTNERS	WORKING WITH INDUSTRIAL CONSORTIA	LICENSING TO INDUSTRY	INFLUENCING KEY DECISION-MAKERS	WORKING WITH BROKER ORGANIZATIONS	GENERATING END-USER DEMAND
ADVANTAGES	<ul style="list-style-type: none"> <li>•carries technically feasible inventions into commercial production</li> <li>•overcomes "not invented here" syndrome</li> <li>•allows protection of proprietary information</li> <li>•potentially reduces tech transfer costs</li> <li>•enhances resources through cost sharing</li> </ul>	<ul style="list-style-type: none"> <li>•focuses on market needs leading to more transferable technologies</li> <li>•gains access to enhanced resources through sharing of equipment, funds and expertise</li> <li>•disseminates information quickly to industry</li> </ul>	<ul style="list-style-type: none"> <li>•provides reward for effective technology transfer</li> <li>•allows many firms to benefit when the market is large</li> </ul>	<ul style="list-style-type: none"> <li>•can achieve greater impact than broadcasting untailored information</li> <li>•provides logic for designing specific marketing approaches</li> </ul>	<ul style="list-style-type: none"> <li>•often provides an effective channel for assessing the needs of the industry and sharing OBRS R&amp;D results</li> <li>•can be inexpensive</li> <li>•enhances resources through cost sharing</li> </ul>	<ul style="list-style-type: none"> <li>•consumer education can achieve long-term behavioral change</li> <li>•some consumer education activities are low cost</li> </ul>
DISADVANTAGES	<ul style="list-style-type: none"> <li>•may be difficult to choose a partner</li> <li>•risk and equitability problems associated with reliance on a single firm or partner</li> </ul>	<ul style="list-style-type: none"> <li>•may require special organizational units to be established which may be expensive to coordinate</li> <li>•proprietary interests may discourage the sharing of information</li> <li>•the nonproprietary dissemination of information may discourage product development</li> </ul>	<ul style="list-style-type: none"> <li>•may select inappropriate licensees</li> </ul>	<ul style="list-style-type: none"> <li>•may be expensive to conduct necessary background research</li> <li>•may be expensive to implement</li> </ul>	<ul style="list-style-type: none"> <li>•may be ineffective or inequitable if organization's membership is limited</li> <li>•"vested interests" of the organization may distort or limit information transfer</li> <li>•loss of control over information transfer</li> </ul>	<ul style="list-style-type: none"> <li>•direct market interference can create unintended distortions</li> <li>•some consumer education activities are ineffective</li> <li>•wide variability in effectiveness</li> </ul>
APPROPRIATE SITUATIONS	<ul style="list-style-type: none"> <li>•product oriented R&amp;D</li> <li>•potentially useful at all stages of the R&amp;D process but particularly appropriate during development of basic technology for products and product development</li> </ul>	<ul style="list-style-type: none"> <li>•when a group of firms faces a generic R&amp;D problem critical to their international competitiveness</li> <li>•when the risks and capital requirements are too great for a single firm to "go it alone"</li> </ul>	<ul style="list-style-type: none"> <li>•with spin-off technologies</li> <li>•later stages of technology development</li> <li>•with small or large potential markets</li> </ul>	<ul style="list-style-type: none"> <li>•when specific groups of decision-makers hinder diffusion</li> <li>•when R&amp;D findings are technically intricate or difficult to communicate</li> <li>•when R&amp;D findings need to be targeted for use by diverse audience segments</li> </ul>	<ul style="list-style-type: none"> <li>•when an effective communication network already exists within an industry's associations</li> <li>•at all stages of the R&amp;D process, but particularly for long-range, utilization, application and impacts research</li> <li>•when limited resources are available for technology transfer</li> </ul>	<ul style="list-style-type: none"> <li>•when rapid changes in consumer behavior are required</li> <li>•when products are technically difficult to understand</li> <li>•when actual energy savings are difficult to observe</li> <li>•when R&amp;D relate to utilization, application or impacts</li> </ul>

Fig. 2.1. Technology transfer strategies: pros, cons, and appropriate situations for use.

cost to each member. It also reduces R&D duplication because companies share information on common problems.

### **2.3 LICENSING TO INDUSTRY**

Licensing technologies developed at national laboratories and universities to industry has increased in frequency as a method of transferring publicly-developed R&D. In order to license a technology and preserve its commercial value, it must first be protected as a patented invention, copyrighted material, or technical data. All of the DOE laboratories conducting OBCS-supported research have their own technology transfer programs and have the capability to license once a patent or copyright waiver is obtained from DOE. The choice between exclusive and nonexclusive licensing must be made and appropriate licensee(s) found. Exclusive licensing is often necessary to interest private industry. Nonexclusive licensing is more appropriate when the potential market for a technology is large enough to accommodate many firms, or when there are many potential direct or spinoff applications of a technology.

### **2.4 INFLUENCING KEY DECISION-MAKERS**

The goal of this strategy is to increase the application and adoption of R&D results by carefully identifying key industry decision-makers. Targeting information and incentives for key decision-makers has the potential advantage of a higher response rate relative to an untargeted approach.

This strategy involves: (1) identifying the key decision-makers who are inhibiting the use of a particular technology, (2) conducting market research to determine why there is resistance and how to reduce it, and (3) implementing a technology transfer program aimed at influencing these key decision-makers. In the buildings industry where there are so many

intermediaries, there tend to be many decision-makers who can thwart an innovation's progress, including energy service companies, builders, service personnel, architects, and others who may require additional information or convincing. This strategy may not be applicable where there are no identifiable key decision-makers or the number of decision-makers is too large to obtain consensus on issues.

## **2.5 WORKING WITH BROKER ORGANIZATIONS**

This strategy uses trade, professional, and regulatory organizations to represent various building industry interests and act as "brokers" throughout the technology transfer process. Since many of these organizations have continuing contact with their members, have their members' confidence, and speak their language, they provide DOE with a useful information exchange system. Through it, user needs can often be assessed, innovations evaluated, and commercialization promoted at a relatively low level of transaction cost. On the other hand, the membership of any particular trade or professional organization may be limited, and its communication network may not be effective.

## **2.6 GENERATING END-USER DEMAND**

In order to promote an innovation, it is often necessary to enlarge demand for the innovation and improve implementation techniques. Information programs - including the development of standardized testing procedures, rating systems, and performance standards and guidelines - can help end-users make more informed choices between energy alternatives, thereby enlarging demand. Providing adoption incentives and reducing barriers to appropriate use are alternative ways of enlarging demand. It is

necessary to keep in mind, however, that market interference can create unintended distortions, and many information and education programs are questionable in terms of cost effectiveness.

Sometimes the introduction of a new technology hinges on a success story by a prominent user - an adopter whose patronage would be widely considered an important endorsement of a new technology. Public agencies themselves can sometimes play this role in that their use of some new technology may be considered a trend-setting event by end-users or even other potential manufacturers and sellers. Indeed, some states and counties are known to be particularly innovative, and their technology choices are closely watched. Stimulating adoption by such prominent users can be an effective road to success.

### 3. RESEARCH DESIGN

#### 3.1 CASE STUDY SELECTION CRITERIA

Our overall research strategy was to conduct case studies of a wide range of successful OBCS-supported innovations in order to examine the technology transfer activities leading to commercialization and use. Several criteria were used to select innovations for the case studies.

First, and most importantly, we wanted to examine successful innovations. For this report, the definition of success was that market entry or initial use of the technology or practice had been achieved. For the fully-commercialized cases, a market penetration of at least 4% was considered necessary.

Second, we sought representation of different types of building technologies and practices supported by OBCS. OBCS funds research on: lighting and windows; HVAC equipment and appliances; building materials; software; and testing procedures. Figure 3.1 shows the range of the case studies along these lines.

Third, we wanted to include a diversity of technology transfer approaches that would represent the spectrum of OBCS roles from exploratory R&D to support for market acceptance. Figure 3.2 classifies the 12 innovations according to the stage at which OBCS support was initiated. For six of the 12 innovations, support for the innovation was first initiated in the exploratory R&D stage. Four innovations first received support in the technology development stage, and two at the applied and information-based R&D stage. None of the innovations was first supported by OBCS during the market acceptance stage.



	Lighting and Windows	HVAC and Appliances	Materials	Software	Testing Procedures
<b>Fully- Commercialized</b>	Low-E Windows  Solid-State Ballasts	Flame Retention Head Oil Burner  Supermarket Refrigeration Compressor Systems		DOE-2	
<b>Semi- Commercialized</b>	Dielectric Coating	Heat Pump Water Heater	Radiant Barriers	CIRA  Wisconsin Audit	Hot Box  Tracer Gas Testing

**Fig. 3.1. Case study innovations by type of technology and level of commercialization.**

### 3.2 DATA COLLECTION METHODS

Investigation of an innovation began with a review of the available literature, consisting mainly of technical reports and trade publications. The next step was to identify and contact OBCS and national laboratory project managers as well as industry and trade association representatives. Telephone and personal interviews were conducted with these technical managers and industry representatives to determine the chronology of events leading to commercialization, and the current market standing of the innovation.

	Lighting and Windows	HVAC and Appliances	Materials	Software	Testing Procedures
Exploratory R&D	Low-E Windows  Solid-State Ballasts	Heat Pump Water Heater		DOE-2  Wisconsin Audit  CIRA	
Technology Development	Dielectric Coating	Supermarket Refrigeration Compressor Systems			Hot Box  Tracer Gas Testing
Applied & Information Based R&D		Flame Retention Head Oil Burner	Radiant Barriers		
Support For Market Acceptance					

Fig. 3.2. Case study innovations by type of technology and development stage when first supported by OBCS.

### 3.2.1 The Use of Aggregate Statistics

Data from secondary sources providing industry-wide statistics such as the Census of Manufacturers were also used. Statistics were sought for three commonly employed measures of market structure that influence an industry's ability to innovate:

- industry concentration ratios,
- R&D expenditures, and
- advertising expenditures.

Each of these is discussed below.

Industry Concentration Ratios. Industrial concentration is studied to identify market power - the power of a firm(s) to influence the industry-wide price of a product and/or the entry of new firms. It is traditionally measured by concentration ratios, the value of shipments contributed by the largest four, eight, ten (and so on) firms. For example, a four-firm concentration ratio gives the value of industry output produced by the largest four firms. If there is only one producer in an industry, then the one-firm concentration is 100% since all the output is produced by a single producer (Scherer, 1980).<sup>1</sup>

**Table 3.1 Concentration ratios for the OBCS case study innovations**

4-digit SIC Code	Industry (and related innovation)	4-Firm Concentration Ratio, 1982
3211	Flat glass (Low-E coatings)	85%
3433	Heating equipment except electrical (FRHOB)	15%
3497	Metal foil and leaf (Radiant barrier)	56%
3567	Industrial furnaces and ovens (FRHOB)	24%
3585	Refrigeration and heating equipment (HPWH)	34%
3632	Household refrigerators and freezers (Supermarket refrigeration compressor systems)	94%
3645	Residential lighting fixtures (Solid-state ballasts)	19%
3646	Commercial lighting fixtures (Solid-state ballasts)	35%

It is difficult to obtain concentration ratios for narrowly defined industry groups. Besides being a tremendous data gathering exercise, such ratios are not likely to be very meaningful due to the presence of multiproduct firms and the threat of potential entry. We tried to relate the OBCS case studies to the available concentration ratios at the four digit SIC levels which is the finest classification on which data are available (Table 3.1). These numbers are less than ideal descriptors of the industries we are studying because they are not well matched to the 12 innovations. Nevertheless, they do not suggest high levels of industrial concentration related to low-E windows and supermarket refrigeration systems.

R&D Expenditures. Data on R&D expenditures help gauge an industry's research potential. Industries with high research expenditures are able to undertake ambitious projects and to innovate more easily. However, data on R&D expenditures are quite scarce. There are several reasons for the lack of data: (1) firms often do not wish to disclose their R&D expenditures lest their rivals benefit from such information, and (2) the appropriation of commonly used assets to R&D versus other uses is problematic. Hence, firms do not like to disclose their research budgets and in some cases they are genuinely unaware of the true resources devoted to research. The use of patents as the outcome of a research undertaking is also problematic. It fails to consider the research that goes unpatented and does not weigh patents of varying importance (Comanor and Scherer, 1969).

Due to the problems noted above, we did not attempt to gather data on industry R&D expenditures. However, the managers and technical people we interviewed often commented on the low level of R&D effort in the lighting, window, heating equipment, refrigeration, and insulation industries.

Advertising Expenditures. Advertising by firms is said to create barriers to the entry of new firms by enabling incumbent firms to build up brand followings. However, advertising can also promote competition by facilitating the entry of new firms (Comanor and Wilson, 1979).<sup>2</sup>

The effect (intensity) of advertising is difficult to measure because advertising has a lingering effect on the public. The problem of allocation of expenses between advertising and other inputs poses measurement problems, as well. Besides being scarce, aggregate data are not generally appropriate to our case studies; disaggregated firm level and sub-industry data are required to study firm behavior.<sup>3</sup>

### **3.2.2 The Use of Statistics from Manufacturers, Trade Associations, and the Trade Press**

Information from manufacturers on sales and market shares were often difficult to obtain and contradictory. We attempted to arrive at the best estimates of market penetration by using multiple sources, including trade and professional associations and publications. Some particularly useful sources were a statistical panorama of the air conditioning, heating, and refrigeration industries published in the April 8, 1985 issue of Air Conditioning, Heating and Refrigeration News and a series of articles on low-E windows in Glass Digest, Builder, and Building Design and Construction. Technical reports from national laboratories and their contractors often provided a good deal of useful market information, too.

References to market penetration numbers are often not provided because they are the result of syntheses from multiple sources. All of the sources of information are listed at the end of each case study.

### 3.3 PRESENTATION OF CASE STUDY RESULTS

Each of the 12 case studies presented in Sections 4 and Section 5 includes background information concerning the technology, a summary of the steps in its development and deployment, and an assessment of the importance of the DOE role. Estimates of the market penetration and energy savings of the innovation also are presented whenever possible. For several of the case studies we are able to offer recommendations for future technology transfer activities to promote their further commercialization and use.

### 3.4 FOOTNOTES TO SECTION 3

<sup>1</sup>Another measure of concentration called the Herfindahl Index is obtained by summing the square of market share of each producer in an industry. For example, if there are two producers in the market with 50% market share each, then the Herfindahl Index is  $(50)^2 + (50)^2 = 5,000$ . Note that the highest value that the Herfindahl Index can take is 100,000. The Herfindahl index is inversely related to the number of firms.

Under recent Reagan administration guidelines, the Justice Department will not challenge any merger that does not raise the Herfindahl Index above 1,000 (Business Week, 1982).

There is no direct one-to-one correspondence between the concentration ratios and Herfindahl indices. One major drawback of the Herfindahl Index is that in industries with a large number of firms it is very difficult to obtain market shares of all. Also, an error in allocating market shares to the largest and smallest firms can lead to large variations in Herfindahl Indices (Pautler, 1982).

<sup>2</sup>Advertising costs for the buildings industry are quite high. For example, the costs of preparing 15,000 copies of a two-page color advertising brochure can range from \$3,500 to \$5,000. A full-page color ad in a leading magazine can cost anywhere from \$12,000 to \$21,000 per run, and is typically run three times. These costs are prohibitive to small firms attempting to enter the market with new technologies (Akers, 1988).

<sup>3</sup>For certain kinds of goods, industry data may be appropriate, as when the innovation is a nondistinguishable good and the consumer cannot discriminate one product from the other. The incentives to advertise are not present at the firm level under these circumstances, so industry-wide expenditures are more relevant.

## 4. CASE STUDIES OF FULLY-COMMERCIALIZED INNOVATIONS

### 4.1 LOW-EMISSIVITY COATINGS FOR WINDOWS

#### 4.1.1 The Innovation

In 1976 the U.S. Department of Energy initiated a research program at Lawrence Berkeley Laboratory (LBL) to develop new energy-efficient window technologies. After an LBL review of potential window research projects, low-emissivity (low-E) coatings were selected as the major DOE program emphasis. At that time, the principle behind low-E coatings was understood, but no low-E windows were commercially available in the United States.

Low-E coatings offer high energy savings potential by reducing a major component of winter heat loss in buildings - the transfer of long-wave infrared radiation between glazing elements. Low-E coatings reflect a large fraction of the invisible, near infrared energy back to its source while remaining transparent to visible light. They provide an insulating value equivalent to a triple-glazed window (R-2 to R-3) but transmit 70-80% of the sun's light (Greer, 1987). Since low-E windows reflect radiant heat back to its source, heat stays inside in winter and outside in summer (Rush, 1987). Thus, windows with low-E coatings admit light and useful solar heat gain, but behave thermally more like an insulated wall (American Council for an Energy-Efficient Economy and Energy Conservation Coalition, 1986).

#### 4.1.2 The DOE Role

During the late 1970's, a series of parallel research projects was undertaken by LBL with DOE support. Several small research firms received subcontracts to investigate suitable coating systems and deposition processes (Selkowitz, 1986). Extensive conversations and meetings were held with glass



and window manufacturers, and limited market studies were conducted to improve the fit between the complex structure of the industry and various window designs with low-E coatings. These market studies were important because the coatings were likely to be developed and sold by glass companies or specialized fabricators, while the windows would ultimately be sold to specifiers and homebuilders by the window manufacturers, who, as a group, did not have experience with or confidence in the coating technology (Selkowitz, 1986).

After several years of DOE research support, one of the small firms developed an attractive enough coating technology to obtain venture capital for construction of a major production facility. By 1980, Southwall Technologies, Inc. (formerly Suntek Research Associates), was working closely with several window manufacturers to develop and refine a fabrication technology that incorporated a low-E film in window units.

In the early 1980's, LBL staff attempted to influence key decision-makers by giving presentations at industry association meetings and trade shows, and by meeting privately with research and marketing staff from a number of major window manufacturers. The process of building interest and confidence in the new low-E coatings was also advanced by their widespread use in several European countries and by their use in a small test building at MIT, along with other innovative energy technologies. The MIT test building originally used prototype windows incorporating the Southwall coated plastic film. Later a coated glass product, produced with the Airco Plating Company, Inc., magnetron sputtering process, (Airco is the major U.S. producer of large sputtering systems), replaced the Southwall windows. The MIT building offered the first view of a low-E product to many interested parties (American

Council for an Energy-Efficient Economy and Energy Conservation Coalition, 1986).

A major market breakthrough occurred in 1983 when Airco installed a large sputtering plant for low-E coatings for Cardinal Glass Company, the firm that supplies the sealed insulating glass units for the largest window manufacturer in the U.S. - Andersen Corporation (American Council for an Energy-Efficient Economy and Energy Conservation Coalition, 1986). After Andersen began offering a low-E window, the product gained new acceptability and credibility for consumers, builders, and specifiers. The availability of the Andersen low-E window placed competitive pressure on other window manufacturers. By the mid-1980's industry investment in facilities that could produce the new generation of low-E coatings exceeded \$150 million and virtually every major glass and window company offered a low-E product (Selkowitz, 1986).

#### **4.1.3 Importance of the LBL/DOE Role**

When the LBL/DOE effort to support research and development for low-E windows began, industry was too concerned with rising fuel costs and with responding to building codes limiting window areas to put much effort into a speculative new technology. Some manufacturers were aware of the potential of low-E coatings, but they doubted that durable products could be produced at low cost and high volume. The window industry essentially ignored low-E coatings (American Council for an Energy-Efficient Economy and Energy Conservation Coalition, 1986). It was only after the LBL/DOE program developed and demonstrated the technology, that the window industry began to acquire and market low-E products.

Market response to low-E products, growing at an annual rate of about 5% of total sales, has been excellent. Representatives of Cardinal IG and Southwall Technology have indicated the importance of the DOE role in the development of low-E products. Stephen Selkowitz of Lawrence Berkeley Laboratory believes that the development and commercialization of low-E windows is one of the most successful undertakings of the Office of Buildings and Community Systems (Selkowitz, 1987).

#### 4.1.4 Market Penetration

Low-E windows were first introduced by Andersen in 1983. In 1983 and 1984 sales of low-E windows were between 1 and 3% of total sales (Fig. 4.1). By 1985 about 50 million square feet or over 5% of total sales had been captured. In 1986 over 20 manufacturers sold more than 70 million square feet of low-E windows - nearly 10% of total sales (Selkowitz, 1987). By 1987 about 15% of total residential windows sold had low-E coatings (Braun, 1987). Industry marketing and sales representatives estimate that 20% of the annual sales in 1988 will be of low-E windows (PPG, 1988). Andersen is now assembling more products with low-E than without, and a few Andersen distributors carry nothing but low-E products (Andrews, 1986). Marketing directors at several major glass companies estimate that penetration will reach 25-50% in 1990 (Brody, 1987).

Manufacturers agree that growth of the market so far has been solid, and that sales are likely to accelerate a great deal in the next few years. A marketing manager with PPG Industries Glass Group and an Executive Vice President with AFG Industries, Inc., both expect that the product life cycle of low-E windows will follow a path similar to that of double-glazed insulating (Swanson, 1986). Within ten years, low-E will be the industry standard (Hayes, 1987).

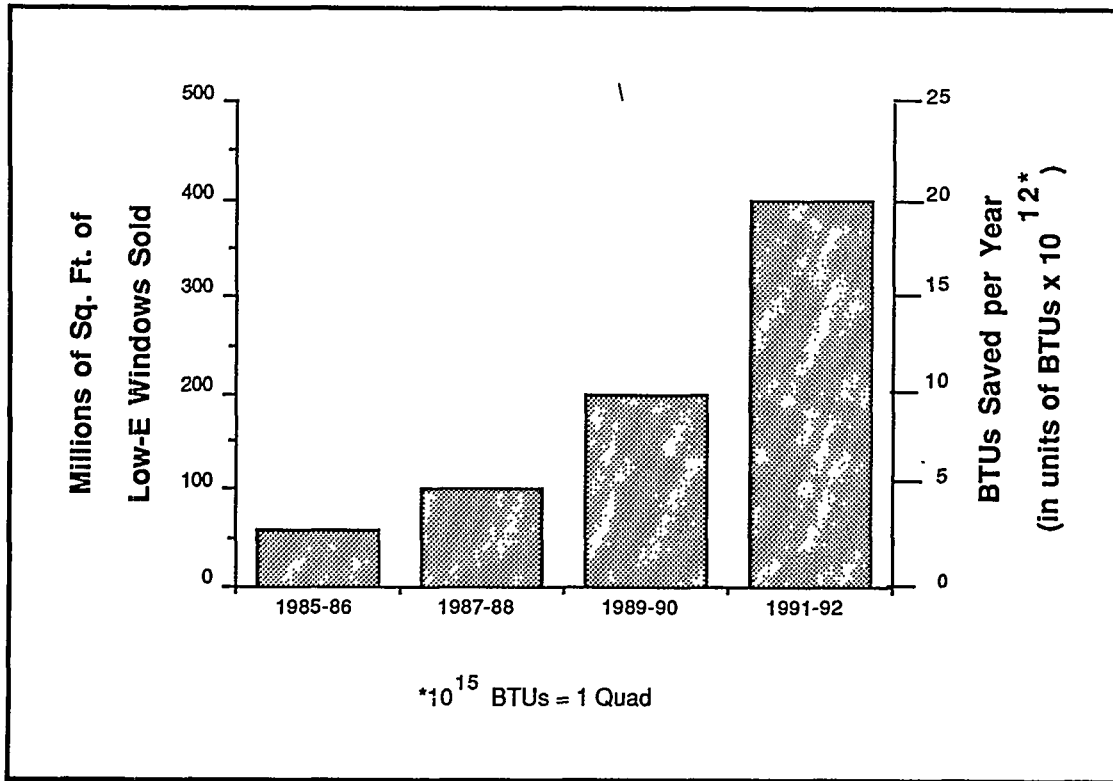


Fig. 4.1. Market penetration and energy savings of low-E windows.

#### 4.1.5 Energy Savings

One quarter of all the energy used to heat and cool U.S. buildings is required to compensate for unwanted heat flow through windows. Low-E windows can reduce the heating, cooling, and lighting requirements associated with windows by 20-40%.

LBL estimated that annual heating energy savings from the penetration of about half of the residential market (i.e., capturing about half of the annual window sales for new construction, additions, and renovations) would probably exceed \$120 million. Cumulative savings by the year 2000 would be more than \$3 billion (American Council for an Energy-Efficient Economy and Energy Conservation Coalition, 1986). This estimate assumes annual sales of about 400

million square feet of low-E windows. It does not include the residential retrofit market, the commercial sector, or potential cooling load savings in the sunbelt. The variety of new low-E products and the diversity of their potential applications make it difficult to predict their total energy savings potential. It is clear, however, that the estimates given above are conservative because they include only part of the potential applications. The amount of energy savings associated with the estimated sales of low-E windows between 1985 and 1992 are shown in Fig. 4.1. Cumulative savings for this time period could approach 0.1 quad.

#### 4.1.6 Return on the DOE Investment

The U.S. Department of Energy invested about \$2 million in the development of low-E windows. This investment leveraged private sector investments in new deposition systems and in the development of new window product lines that exceeded \$100 million. By 1985 windows with low-E coatings were saving consumers \$14 million per year on their energy bills. By 1995 annual heating savings should be over \$120 million, and by the year 2,000, cumulative savings should exceed three billion dollars (American Council for an Energy-Efficient Economy and Energy Conservation Coalition, 1986).

There are a variety of other benefits from this DOE-sponsored research in addition to the savings on fuel bills. The fenestration industry benefits from the development of a new production technology, increased employment, and new value-added products that are competitive internationally. The nation benefits from decreased dependence on imported fuel and from an improved balance of payments (American Council for an Energy-Efficient Economy and Energy Conservation Coalition, 1986).

#### 4.1.7 Future Directions

Current DOE-sponsored research is building upon the foundation of the already successful low-E window commercialization efforts to develop further technological breakthroughs in window design. A new generation of "superwindows" will outperform the best insulated roof or wall. New "smart windows" will automatically adjust in response to changing climate conditions and occupant needs. These smart windows will minimize cooling needs, maximize daylighting benefits, and provide glare control, thermal comfort, and privacy for building occupants. With these new technological developments and their optimal use, windows and skylights can become a net source of energy in buildings, instead of a cause of heat loss as they have been in the past (American Council for an Energy-Efficient Economy and Energy Conservation Coalition, 1986). The amount of market penetration that has already occurred for the current generation of low-E windows suggests that commercialization of the developing window technology options should be rapid once performance and cost goals are met.

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## 4.2 SOLID-STATE BALLASTS FOR FLUORESCENT LIGHTING

### 4.2.1 The Innovation

Solid-state ballasts use 15-30% less energy to produce the same light output as standard core ballasts for fluorescent bulbs. High-frequency solid-state ballasts also can be used to reduce electricity demand with sophisticated lighting control systems. The flexible dimming capabilities of solid-state ballasts make it possible to implement a variety of demand control strategies

including task lighting, daylight capture, and load-shedding (American Council for an Energy-Efficient Economy and Energy Conservation Coalition, 1986).

#### 4.2.2 The DOE Role

In 1976 the U.S. Department of Energy established a lighting research program at the Lawrence Berkeley Laboratory to accelerate the entry of new energy-efficient lighting technologies into the marketplace. Solid-state ballasts were selected for development, testing, and technology transfer efforts in the first year of the LBL program. LBL's role was to cost-share the development of solid-state ballast prototypes, to test and establish the characteristics of the prototypes, and to identify any technical or economic obstacles to the development of a reliable, efficient, and cost-effective ballast. When the program began, no ballast manufacturers were involved in such development efforts (Verderber, 1988).

A public Request for Proposals (RFP) was issued by LBL to solicit the participation of companies interested in cost-sharing prototype development. None of the major ballast manufacturers responded. However, several small entrepreneurial firms submitted proposals. In 1977 LBL selected two contractors to develop prototypes: IOTA Engineering, and Stevens Electronics. IOTA Engineering developed a low-cost, non-dimmable design and Stevens Electronics developed a sophisticated, high-performance design that was more efficient and could dim fluorescent lamps to 10% of full light output. LBL's testing of the prototypes covered the issues of energy efficiency and failure rates. Energy efficiency was 25% higher than for traditional ballasts. Greater reliability was needed, however, so a second prototype was developed.



The second, more reliable prototype was installed as part of a joint LBL and Pacific Gas and Electric (PG&E) demonstration project. Five hundred IOTA ballasts, 500 Stevens ballasts, and 500 electromagnetic ballasts were installed on three respective floors of PG&E's main office building in San Francisco. LBL monitored the energy use and reliability of the ballasts. The demonstration data confirmed the earlier laboratory testing result of a 25% reduction in energy consumption with the solid-state ballasts. The demonstration also led to the identification of some design faults that produced a considerable number of ballast failures. These faults were corrected, and in 1979 the much improved solid-state ballasts captured the interest of several companies. Beatrice Foods, Inc., purchased IOTA's concept and patent rights and formed a division, E Tech, to produce the ballasts. Stevens Electronics sold their exclusive rights to Luminoptics, a company established to produce the Stevens design (Verderber, 1988).

A second demonstration project (sponsored by DOE and a Veterans Administration medical facility) began in 1979. In this demonstration over 400 prototypes of an advanced dimmable ballast were installed and monitored. As a result of the demonstration, the Veterans Administration Office of Construction became the first federal agency to specify the use of solid-state ballasts in its facilities.

All of the major firms in the ballast industry had considered and rejected the possibility of introducing a solid-state ballast either before or approximately when the DOE Lighting Program came into existence. The ballast industry is very similar in structure to other sectors of the lighting industry. It is a mature, stable industry dominated by four to six large companies with many small companies that account for a very small percentage of sales. Although Census data are not available and

manufacturers do not wish to divulge market share information, interviews conducted by Johnson, Marcus, Campbell, Sommers, Skumatz, Berk, Petty, and Eschbach (1981) suggest that two manufacturers, Universal Manufacturing Corporation and Advance Transformer Company, control almost 90% of the fluorescent lighting ballast market. Because of the structure of the industry, it is difficult for small companies to enter the marketplace and be competitive. There is also little incentive for the major companies to develop new technologies, especially if the innovation will require large capital investments. Innovations are likely to be duplicated by competitors at less cost than was paid by the original developer and market shares are unlikely to change significantly (Lawrence Berkeley Laboratory, 1981).

The major manufacturers continued to reject the idea of adding the solid-state ballast to their product line throughout the 1970's. One reason for their resistance was that for each solid-state ballast sold, one traditional ballast would not be sold. Facilities for the production of traditional ballasts were already built and paid for. Production of the solid-state ballasts required new capital investment that could be used more profitably in other ways. Thus, major manufacturers had no financial incentive, but they did have some disincentives to begin production of solid-state ballasts. Many of the major firms expressed their belief in the nonviability of the product during the period (1977-1981) when the LBL prototype development, testing, and demonstration efforts took place. Given the disinterest, nonparticipation, and even hostility to the product development efforts shown by the major manufacturers, the solid-state ballast clearly would not have reached its present level of market penetration without DOE-sponsorship of the LBL effort.

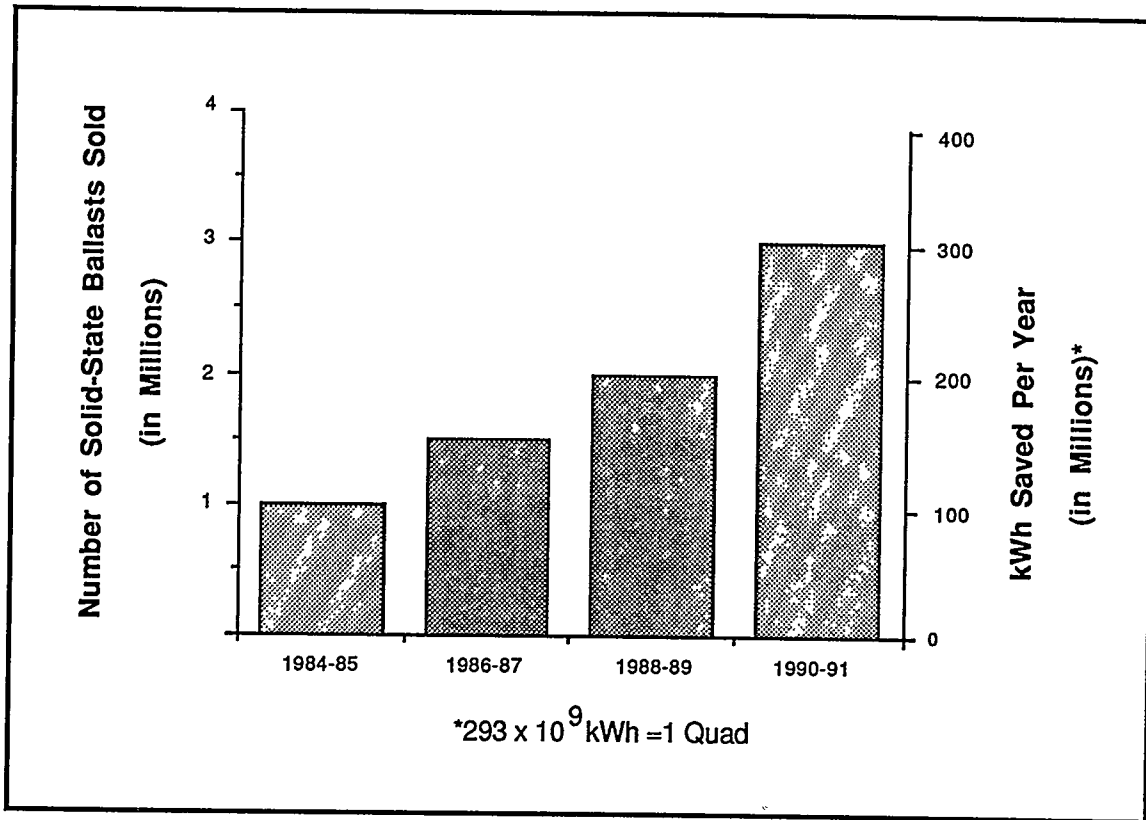
The LBL/DOE program was highly successful because it forced the industry to adopt an innovation by contracting development work to small

outsider companies. While the LBL/DOE program developed, tested, and demonstrated the reliability, safety, and energy efficiency of solid-state ballasts, major ballast manufacturers published many statements concerning the infeasibility of the technology. As a result of the LBL/DOE program, Beatrice Foods, a newcomer to the ballast industry, purchased rights to the new design in 1979. This was a major breakthrough because Beatrice Foods had the funds to impact market shares in the ballast industry, forcing the major manufacturers to reevaluate their rejection of the technology (Lawrence Berkeley Laboratory, 1981).

Today all major U.S. manufacturers offer a solid-state ballast as part of their product line and the ballasts are available from all electrical wholesalers. Without the DOE program, current levels of market penetration by U.S. companies could have been delayed many years or perhaps never have occurred. Introduction of the technology by Japanese firms (which began selling the product in Japan in 1980) and their eventual dominance in the market would be much more likely without the stimulus to U.S. manufacturers provided by the DOE program. Major U.S. manufacturers are not marketing the product aggressively, but they are slowly expanding levels of production and sales (Verderber, 1988).

#### **4.2.3 Market Penetration**

In 1980 E Tech of Beatrice Foods introduced the first U.S. manufactured solid-state ballast into the market. Luminoptics had a product on the market in late 1981. In 1982 Luminoptics was purchased by Universal Manufacturing, a major ballast manufacturer with 40% of the ballast market. In 1984 Advance Transformer, the largest U.S. ballast manufacturer, introduced a solid-state ballast to operate a compact fluorescent lamp. By the end of 1984, one



**Fig. 4.2. Market penetration and energy savings of solid-state ballasts.**

million solid-state ballasts for the F40, 40-watt lamp had been sold in the United States. Although the number of solid-state ballasts was small in comparison to total annual sales of 70 million units, the DOE support for R&D, demonstrations, and technology transfer activities had clearly brought the solid-state ballast to the brink of commercial success (American Council for an Energy-Efficient Economy and Energy Conservation Coalition, 1986). By 1985 several more U.S. manufacturers offered solid-state ballasts, and annual sales reached one million units (representing one and one-half percent of the total sales of all types of ballasts). Today the demand for solid-state ballasts exceeds

the supply. The market for solid-state ballasts is expected to expand rapidly. Penetration of 30-50% is projected within the next 10 years (American Council for an Energy-Efficient Economy and Energy Conservation Coalition, 1986). Figure 4.2 describes the market penetration of solid-state ballasts thru 1987 and estimates future sales levels thru 1991.

#### 4.2.4 Energy Savings

In terms of national energy goals this DOE program has been highly successful. LBL estimated, in 1985, that with two million solid-state ballasts in operation, each one saving 25 watts for 4,000 hours annually, annual savings would be 200 million kWhs. At an average energy cost of \$0.075 per kWh, this would be an annual savings of \$15 million. If solid-state ballasts saturate the market, savings worth up to \$5 billion per year could be achieved by reducing electricity demand by an amount equal to the output of ten large (1,000 MW) power plants (American Council for an Energy-Efficient Economy and Energy Conservation Coalition, 1986).

#### 4.2.5 Return on the DOE Investment

For a total investment by DOE of \$2.7 million, two major achievements have occurred. First, the major U.S. manufacturers are now producing solid-state ballasts and the product is widely available. It is unlikely that U.S. companies would have begun producing this product without the stimulus of the DOE program. Foreign manufacturers might well have introduced the technology to the market instead, as occurred in the case of compact fluorescent lights. Secondly, substantial energy savings have resulted because of the entry of solid-state ballasts into the marketplace (Fig. 4.2). With annual energy savings worth over \$15 million already occurring, the DOE investment has been returned five fold. With full market penetration, future savings

could produce returns worth several thousand times the value of the original investment.

#### 4.2.6 Barriers to Further Penetration

In spite of the successful development and introduction into the market of solid-state ballasts, their share of the total ballast market is still very small. The major barrier to more rapid penetration is their high initial cost. Manufacturer's costs for solid-state ballasts are about \$23 compared to a cost of \$10 for standard core coil ballast designs.

Solid-state ballasts reach end users in two ways: (1) as replacements for existing ballasts; or (2) as components of new lighting fixtures. Census Bureau figures published in 1979 and interviews with manufacturers conducted by Johnson et al. (1981) suggested that 60-75% of the solid-state ballasts being manufactured were installed in new lighting fixtures and that 25-40% were replacement ballasts. Recent interviews with industry representatives (Mullins, 1988) suggest that sales are now more evenly divided between new installations and retrofits.

Building owner/occupants typically give attention to energy-saving alternatives only when a ballast needs to be replaced. Because an investment in conservation must compete with other capital investment decisions, a return on investment as high as 15% may be required (Johnson et al., 1981). Returns on solid-state ballasts typically do not meet this criterion. Builders and contractors are more concerned with first costs than life-cycle costs, and are, therefore, even more resistant to installing the more expensive solid-state ballasts than owner/occupants.

#### 4.2.7 Future Directions

Johnson et al. (1981) offer several recommendations for increasing the market penetration of solid-state ballasts which are still relevant today:

- (1) fund research that would produce a complete lighting system (including fixture, solid-state ballast, and tubes) that is lighter weight and less expensive than current options;
- (2) encourage utility officials to include solid-state ballasts in their commercial and industrial conservation programs;
- (3) conduct a direct mail campaign to energy managers; and
- (4) advertise the technology in trade publications that reach architects, engineers and builders, and the specifying community. Solid-state ballasts have been promoted by several utility rebate programs, and industry representatives believe that the rebates have promoted the product (Mullins, 1988).

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### **4.3 UNEQUAL PARALLEL COMPRESSOR SYSTEMS FOR SUPERMARKET REFRIGERATION**

#### **4.3.1 The Innovation**

The innovation examined here is a highly energy-efficient supermarket refrigeration system. It features unequal parallel compressors, microprocessor suction pressure control, and floating head pressure control. Energy savings are achieved by employing the principle of capacity modulation. The system is better able to match compressor capacity with the required refrigeration load, and thereby can operate at the lowest possible condenser pressure. The combined effect of highest possible suction pressure and lowest possible condensing pressure substantially increases the energy efficiency ratio (EER) of the refrigeration system.

Most of the system elements of the design had been in use for some time prior to DOE's involvement and involved off-the-shelf hardware, including:

- unequal parallel compressor trains;
- floating head pressure; and
- floating suction pressure.

The use of familiar components whose reliability and service requirements were widely known was important in the eventual acceptance of this innovation.



The only new component was a microprocessor control system. The control system developed in this project was a modification of a patented control system originally developed by Friedrich Air Conditioning and Refrigeration Systems to supply twin compressor systems.

Standard supermarket refrigeration systems employ paired compressors of equal size, which operate intermittently. Considerable energy consumption is involved in the initiation of the cycle. A compressor train composed of units of unequal size can more closely match the demand and can avoid energy losses associated with the cycling of larger compressors. In the unequal design, two to six compressors of unequal horsepowers are controlled by an integrated circuit and software. This system is a replacement for a pair of 25 hp compressors.

There are several ways that the multiple uneven capacity parallel compressors with microprocessor control can save money for a supermarket:

- computer controlled cycles can be optimized for the demand patterns of an individual store;
- a wider range of defrost cycles is made possible by a microprocessor; and
- maintaining suction pressure within a narrow band extends compressor life by reducing the frequency of cycling.

Laboratory testing estimated that the system with R-12 refrigerants consumes 16.6% less than the same system operating with mechanical control and ambient subcooling. In tests with R-502 refrigerants, the energy savings was only 4.3% (Toscano, Walker, and Tetreault, 1983).

A minimal increase in first costs is associated with this technology, and this has promoted adoption. The payback period is two years in larger stores (with 60,000 or more sq. ft.) and three years in medium-sized stores (with 45,000-60,000 sq. ft.).

#### 4.3.2 The DOE Role

In 1978 ORNL issued a broad, nonspecific Request for Proposals directed towards refrigeration technology, in general. The proposal by Foster-Miller, Inc., to conduct R&D on compressors was selected. ORNL managed the project from its inception in 1979 to completion in 1983. ORNL staff analyzed determinants of performance and communicated the results to Foster-Miller personnel. ORNL also participated along with DOE personnel in periodic project review meetings.

Foster-Miller first performed a market study under contract to ORNL to help ORNL select the type of refrigeration technology development most likely to have an impact on energy consumption. Foster-Miller then undertook engineering design and prototype development. The final phase was laboratory and field testing. OBCS funding totalled \$1 million and was distributed across the project phases as follows:

1980	\$250K	Phase 1	Marketing Study
1981	\$550K	Phase 2	Engineering Design and Prototype Development
1982	\$250K	Phase 3	Laboratory and Field Tests

Bill Toscano, an engineering PhD with an MBA, was the initial Foster-Miller director. He is credited with being an excellent marketer for his product, serving as a project champion from 1979 until he left the company in 1983.

Friedrich became involved at the end of the design phase, as subcontractors for Foster-Miller, helping to develop the compressor assembly. They also cost-shared and contributed equipment and frozen food to the project, for a total cost sharing of \$250,000.

In the field test, Foster-Miller compared two adjacent stores in Corpus Christi, Texas, which had identical climates but very different system

configurations. Thus, it was difficult to interpret the results. To further complicate the situation, the comparison units in the test program did not run side-by-side, but ran in alternating weeks. As a result, local fluctuation in climate and usage patterns could explain the apparent energy savings of the new system. Nevertheless, the research was influential.

Five hundred copies of the project report were distributed; every major supermarket chain was sent a copy and presumably had it available to its engineering staff. It was the first research report on the technology. By making supermarket engineering staff aware of the favorable performance of the technology, the OBCS project generated end-user demand. According to one engineer at Hussman, "the industry picked up the technology because of the positive evaluation in the ORNL report."

The Energy Committee of the Food Marketing Institute (FMI) also played an important role. The primary function of the Energy Committee was to screen and guide technical developments. Its members represent both technical and managerial functions within the supermarket industry. Technical members tend to be engineers by training and have direct supervisory responsibility over energy-related technology. Managerial personnel are those with overall responsibility for store development, including decisions concerning energy use. These managers typically have minimal appreciation of the engineering issues raised by new technologies.

Researchers come to the FMI Energy Committee for feedback on their technologies, giving presentations on new technologies and learning about possible opportunities and potential problems.

Annual meetings of the FMI Committee in 1982, 1983, and 1984 provided retailers and others with exposure to the new technology. At these meetings, the Energy Committee put Foster-Miller or a store member employing the

technology on the podium to describe developments in the project. This gave 70-80 retailers a chance to give their perceptions and suggestions, and gave Foster-Miller some insight about the likely reception of the project.

Exposure was also provided by articles in the trade press. Supermarket News is by far the most important trade publication, and it carried several stories about the DOE project. In addition, there were articles in other periodicals covering various aspects of the project, including:

ASHRAE Journal - design and laboratory testing;

Air Conditioning News - field test results; and

Energy User News - field test results.

Early experimentation with the technology by Safeway Stores, Inc., also provided excellent publicity. In 1981, Safeway bought the experimental compressor skids and installed them in one of four refrigeration systems which cooled display cases in one store. When satisfied with its performance, they bought the equipment for other Safeway stores.

#### **4.3.3 Market Penetration**

According to data provided by the Underwriters Laboratories and the Thomas Register, 43 companies manufacture supermarket refrigeration systems. Of these, only seven companies manufacture units that use the unequal parallel design of compressor arrangement, but all seven of these serve national markets, and they include the largest manufacturers of supermarket refrigeration systems. By talking with these manufacturers, we identified two small, locally-producing companies that also manufacture the technology. The companies that do not use the design are mainly manufacturers of specialty cases such as beverage dispensers.

Hussman, Inc., is the dominant company with approximately half of the market for supermarket refrigeration systems. Other companies offering the innovation are:

- Tyler Refrigeration Corporation, Michigan;
- Friedrich Air Conditioning and Refrigeration Systems, Texas;
- Hill Refrigeration Corporation, New Jersey;
- Warren/Sherer Company, Georgia;
- Kimmel-Molts Refrigeration, California; and
- Engineered Refrigeration Systems, Inc., Georgia.

Several of the industry contacts interviewed alleged that Hussman has resisted and fought the technology. It had the lion's share of the market with the old equipment. Less than half of the equipment currently manufactured by Hussman uses the technology.

It is estimated that 2,130 supermarket refrigerated display cases were sold in 1987, and that 1,160 or (54%) of these had unequal parallel designs. The primary market for the new technology is the large supermarkets (i.e., stores over 12,000 sq. ft.) and supermarket chains. Independently-owned stores have also been receptive to the product, but these stores represent a smaller portion of the market. The systems are also being sold for use in refrigerated warehouses.

Retrofits are limited to major remodeling projects; otherwise new construction dominates. There is no obvious geographic bias to the market, but stores in areas with high electricity costs are more likely to incorporate the energy-saving technology.

In addition, at least one U.S. company, Tyler, is manufacturing the new technology in Europe for European markets. Hussman exports its software and related parts to their subsidiary in the U.K.

#### 4.3.4 Barriers to Further Penetration

Servicing is a major deterrent to increased adoption. Service personnel are generally unfamiliar with these systems and are hesitant to maintain or overhaul them. The new system requires more maintenance, more care, and more skillful servicing than the traditional system.

Manufacturers typically train their own service personnel, but most installed systems are maintained and serviced (optimized) by in-house personnel or their subcontractors. As a result of inadequate training, the microprocessor is often improperly tuned. When a supermarket has no control over the training of its service personnel, it has a strong incentive to stick with traditional technologies or adopt equipment requiring little maintenance.

The level of engineering expertise in supermarket refrigeration is minimal. There are few "refrigeration engineers" because no university offers a degree in refrigeration engineering. Those who call themselves engineers may be engineers originally trained in other specialties. Or they may be limited in breadth of exposure to academic engineering. They are unlikely to be sophisticated in the design of refrigeration systems, even though they may have years of experience with installing or servicing them. A "refrigeration engineer" may be competent with traditional technology but unfamiliar with the principles underlying new technologies.

Another problem noted by some, but not all of the manufacturers interviewed, is the higher first cost associated with the technology. During the planning stage of a new grocery store, the A/E firm typically receives a 6% commission on its fixed, competitive bid. The bid package usually includes the cost of buying and installing refrigeration equipment, but may or may not specify a particular supplier or technology. To win the job, the A/E firms bid

low, and then attempt to keep costs below the bid. They are not motivated to voluntarily suggest the purchase of more expensive, nonconventional technologies. First costs are the critical factor; life-cycle costs are not.

To add to this problem, saving energy is a low priority in the supermarket industry. While energy is the second highest operating cost after labor, it constitutes only 3% of the total.

Another problem is that supermarkets run on low profit margins. The industry has a narrow margin for risk and little reward for experimentation. The required payback is between two and three years. Payback and reliability are both important, as are capital costs.

There is very little R&D in the supermarket refrigeration business. Product development tends to be gradual and incremental, due to:

- the reticence of supermarkets to take risks in the purchase of equipment;
- the significant retooling costs of a major change in manufacturing; and
- the difficulty of retraining service personnel.

Residential air conditioning dominates commercial refrigeration (including supermarket systems) both in terms of sales and R&D effort.

The Food Marketing Institute is the main source of R&D funding for the industry. Most of its R&D, however, is directed at boosting labor productivity. Only a small fraction of the Institute's R&D funds is directed towards grocery store energy use. The Electric Power Research Institute (EPRI) also has a refrigeration R&D effort and it is much larger than the refrigeration research programs of FMI or DOE.

Patents are not highly valued in this industry because competitors rapidly design around them. But a headstart in the market place is valued. Nevertheless, concern over disclosure of competitive information did not present a problem in this case study.

#### 4.3.5 Spinoff Applications and Future Directions

Through the ASHRAE journal article and the ASHRAE meetings, DOE's efforts to develop the unequal parallel supermarket refrigeration system appear to have promoted the development and use of variable speed compressors for supermarket refrigeration and for air conditioning systems in shopping centers. As a more advanced application of the capacity modulation principle, it is likely that variable speed compressor systems will soon replace the unequal parallel system for supermarket refrigeration, because of advantages in cost and reliability. DOE can take some credit for the energy-savings that will thereby result, because of the early role they played in promoting applications of the capacity modulation principle.

The computer design model sponsored by OBCS is currently being used by EPRI. Safeway has teamed up with EPRI in Oakland to test unequal parallel systems in California, and provide a more solid basis of comparison between the competing systems. Advances being built into the improved design by EPRI include better condensers and subcooling.

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## 4.4 FLAME RETENTION HEAD OIL BURNER

### 4.4.1 The Innovation

The flame retention head oil burner (FRHOB) was invented in the early 1970's. It consists of: (1) a slotted metal cone that enhances mixing of combustion air with fuel oil and dramatically reduces drafting, and (2) a higher capacity blower. The more powerful blower is required because of the air-flow restriction caused by the shape of the burner head.

The pre-existing oil burner technology is easy to use and service, but has a "seasonal efficiency" of only 65%. The FHROB provides an 11-22% improvement over the pre-existing technology. It reduces oil consumption by an average of 18% for boilers and 11% for furnaces (Hoppe and Graves, 1982). It is also inexpensive - the incremental cost to retrofit an oil burner is small (\$200-\$400), yet the savings are substantial (\$150-200 annually), and the payback is short (0.5 to 3.7 years). The FRHOB is a low-tech, standard item, easily installed and serviced.

#### 4.4.2 Initial Barriers to Adoption

Although the technology was commercially available as an energy-saving device in the mid-1970's, it had not achieved significant market penetration. By the late 1970's there were a few manufacturers producing the product, but their volumes were small. There was little awareness of the technology among the public or the industry, and the product was not "taking off."

The fuel oil industry is highly fragmented and very competitive. Local dealers have no control over margins. Prices are set by producers, and dealers take a standard markup for the service provided. Oil producers are only distantly associated with users and have little incentive to pursue fuel oil conservation.

Equipment manufacturers producing oil furnaces and boilers also represent a highly competitive and fragmented industry that lacks vertical integration. Furnaces are assembled by "box manufacturers" using components produced by numerous other manufacturers. Minor incompatibilities between components are dealt with by the use of relatively standard adaptors. Flanges allow interchangeability between most burners

and boilers or furnaces. Manufacturers of furnace components tend to restrict themselves to a limited range of components. Major manufacturers are R.W. Beckett Corporation of Elyria, Ohio; The Carlin Company of Windsor, Connecticut; and the Wayne Home Equipment Division of Fort Wayne, Indiana. These manufacturers do not support any significant amount of R&D.

Service personnel for oil furnaces and boilers are not technically sophisticated and are generally slow to adopt new technologies. Consumers tend to be poorly informed about alternative technologies, and there was little public awareness of the FRHOB at the time the OBCS effort at Brookhaven was conceived in 1976.

#### 4.4.3 The DOE Role

DOE supported three phases of R&D: laboratory testing, field testing, and a marketing program. The project began in 1979 and ended in 1982; total project costs were \$250,000. An industry committee was formed to advise the project, and was headed by John Mellow of the Hydronics Institute.

The DOE role began with the identification of possible intervention points in the fuel oil residential heating industry. Brookhaven National Laboratory (BNL) investigated several possible energy saving techniques in the laboratory and selected the FRHOB for further work. BNL then supervised a carefully controlled field test to establish and demonstrate the energy conservation benefit of the technology. Fuel oil dealers were paid to install and maintain the burners as part of this Fuel Oil Marketing Program. A training program for service personnel was also operated in conjunction with the field test.

As part of the marketing program, 70,000 copies of a consumer-oriented information booklet and fact sheet on "Upgrading your Oil-Hot Water Home

Heating System," were produced. They were distributed to the public through state energy offices and other state and local agencies, DOE regional offices, trade organizations (e.g., Hydronics Institute), and real estate offices.

Northern and northeastern states were the primary target. Information was then picked up by the media, with articles in newspapers and popular trade and science magazines.

The DOE program succeeded by generating end-user demand and by training service personnel who are key decision-makers regarding the adoption of this technology. No attempt was made to reach furnace or burner manufacturers.

#### 4.4.4 Market Penetration and Energy Savings

The FRHOB technology is now accepted as the standard burner technology for residential oil-burning heating systems. As of 1986, the three major manufacturers of oil burners manufacture and sell only FRHOBs. The three major manufacturers' primary market is to "original equipment manufacturers" (OEMs), although they also have a large retrofit market.

The number of high efficiency FRHOB's in use increased from 100,000 in 1979, to well over 2,000,000 in 1985 (Fig. 4.3). Approximately 422,000 of the units were produced in 1986 (Table 4.1). Of the 12 million households in the U.S. that heat with fuel oil, almost one-fourth have this new technology. Since every replacement burner has it, full market penetration depends only upon the replacement rate for oil burners. Assuming a 12% level of fuel savings over the pre-existing technology, an annual energy savings of almost 0.14 quads is projected by the year 2,000.

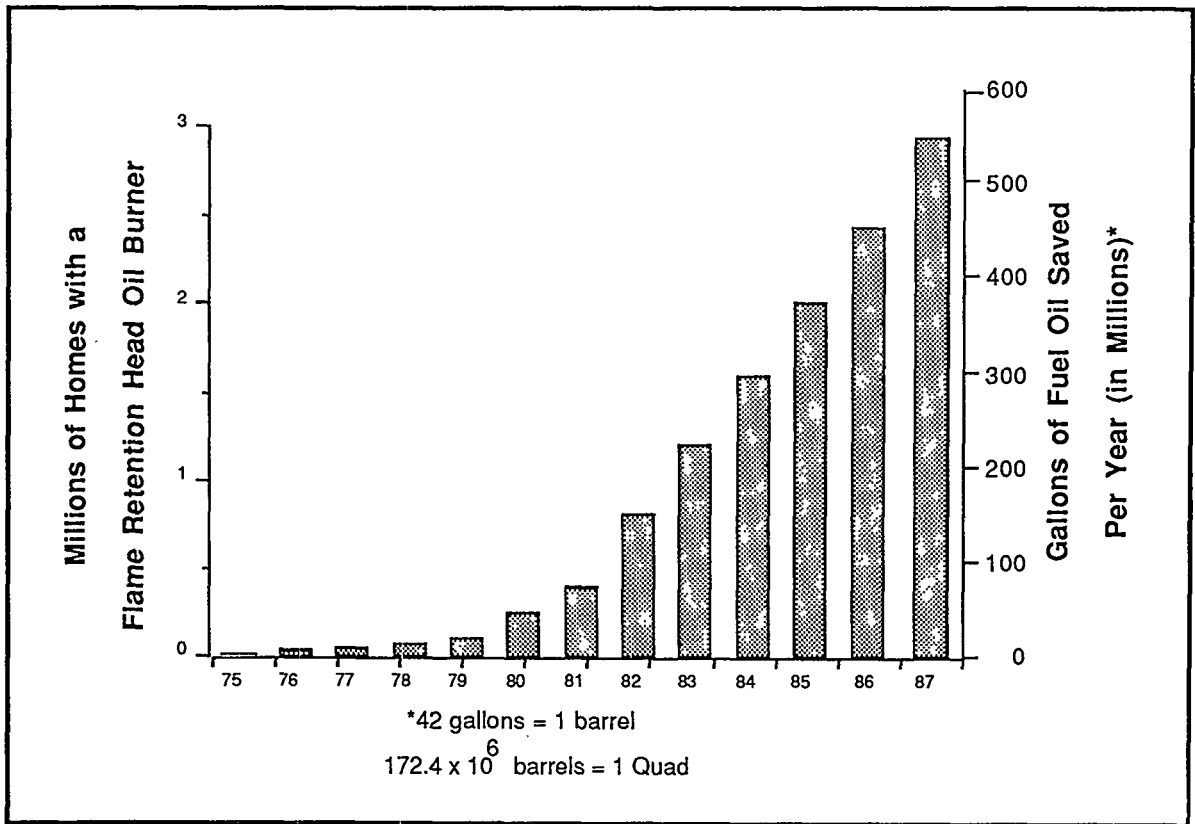


Fig. 4.3. Market penetration of flame retention head oil burners.

Table 4.1 Sales of retention head oil burners in 1986

Type of Equipment		Number Sold
New equipment	oil warm-air furnaces	201,000
	oil boilers	126,000
Retrofits	oil furnaces and boilers	95,000
Total		422,000

Nationwide, new construction tends to employ electric heating or gas furnaces, not fuel oil. Oil furnaces and boilers comprised approximately 8% of 1986 new heating equipment, while natural gas was 59%, electric warm air was 10%, and electric heat pumps were 23% (Mantho, 1987). A total of 3.9 million new furnaces and boilers were installed in 1986. The primary market for this technology is New England homes, where new existing fuel oil furnaces and boilers are used with greater frequency than in any other region.

Requests for the brochure and fact sheet peaked in 1982, and have fallen as fuel prices have declined.

#### **4.4.5 Facilitating Factors**

The FRHOB is a low technology, standard item, easily installed and serviced. The timing of this project was critical. When the project was initiated, fuel oil costs had risen to \$1.00 a gallon in some areas and were still increasing. There were also some localized shortages of fuel oil, and threats of impending scarcities.

#### **4.4.6 Future Directions**

The flame retention-head oil burner technology may also be applicable as a substantial energy conservation measure in commercial and industrial oil-fired boilers and furnaces. The potential for developing these markets should be explored.

#### **4.4.7 Sources of Information**

##### Interviews

Bill Graves, Project Manager, Brookhaven National Laboratory, Upton, New York, September 1987.

John Kauser, Hydronics Institute, Washington, D.C., August 1987.

Danny Lim, DOE Project Manager, Washington, D.C., September 1986.

Margaret Mantho, Fuel Oil and Oil Heat, Washington, D.C., August 1987.

Mark Urban, The Carlin Company, Windsor, Ohio, July 1987.

Bud Wooster, R.W. Beckett Corporation, Elyria, Ohio, July 1987.

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Hoppe, R. J. and W. L. Graves. 1982. Field Tests of Refit Equipment for Residential Oil-Fired Heating Systems, 51555, Brookhaven National Laboratory, Upton, New York, April.

McDonald, R. J. and R. F. Krajewski. 1980. Flame-Retention-Head Burner Efficiency Test Results and Analysis, BNL 51321, Brookhaven National Laboratory, Brookhaven, Upton, New York, 1980.

### 4.5 DOE-2

#### 4.5.1 The Innovation

DOE-2 is a public-domain, computer simulation program that helps evaluate the energy performance of buildings. Such information helps building researchers and builders to design energy- and cost-efficient buildings. Over time, DOE-2 has evolved into an industry benchmark against which other building simulation programs are compared. Numerous public utilities have used DOE-2 to project potential savings from energy-efficient buildings. The existing version of DOE-2 is being used all over the country and internationally. Use of the DOE-2 program by the buildings industry has contributed to around 20% reduction in direct energy use (DOE internal document). DOE-2 has been employed to assess the energy and cost impact of building technologies, e.g., low-E glazing.

The applications of DOE-2 can be classified into three categories as (Winkelmann, n.d.):

- general applications;
- standards, guidelines, and handbooks; and
- simplified models.

General applications include the design of leading-edge buildings and studies of impacts of new technologies. Applications to standards, guidelines, and handbooks are numerous. DOE-2 is employed in the new ASHRAE 90 standards, California energy standards, and ASEAN standards. Further, DOE-2 has been used in the Skylight Design Handbook, the Foundation Handbook, and the Atrium Handbook. Also, with the help of DOE-2, the ASHRAE TC4.7. method was validated and the ASHRAE CLTD/CLF tables constructed. Simplified models use DOE-2's basic algorithms. Users can write their own algorithms in a Fortran-like language and evaluate their buildings.

#### 4.5.2 Funding

Most of the research on DOE was conducted at Lawrence Berkeley Laboratory (LBL) under the Building Performance Simulation Research Program, with some participation by Argonne and Los Alamos National Laboratories.

DOE has been the primary sponsor of DOE-2, though EPRI, ASHRAE, and the Gas Research Institute have also provided support. Specifically, recent DOE funding of this program at LBL has been:

FY 1986	\$400K
FY 1987	\$300K
FY 1988	\$300K

The private sector has also been involved in the development of DOE-2. EPRI and DOE jointly provided funds to LBL for the development of thermal



storage sizing methods; the University of Texas received funding from ASHRAE to develop thermal component models; and the Gas Research Institute sponsored the gas-fired desiccant and evaporative cooling models.

#### 4.5.3 Time Line

Work first began on DOE-2 at LBL in 1976. In 1978, the first version of the program became available. Over time, many versions of DOE-2.1 have been developed (Cairns and Rosenfeld, 1986). The latest version of the DOE-2 (i.e., DOE-2.1D) has several new features including:

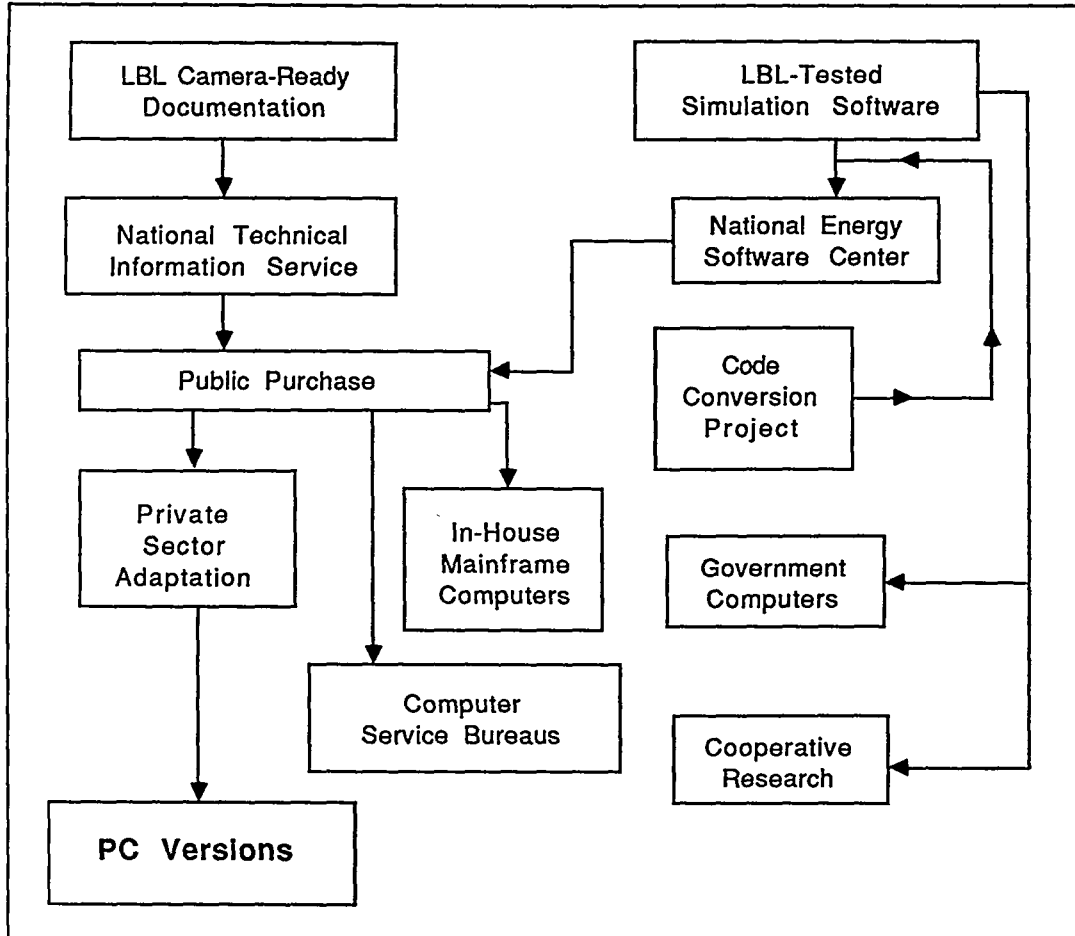
- well defined HVAC functions which will allow users to model innovative HVAC controls without changing the computer code;
- custom libraries that users can create, describing building components, systems, schedules, complete zones, and even whole buildings; and
- improved exterior IR calculation for windows and walls.

The next version of DOE-2 is to be released shortly by LBL (Winkelmann, 1988).

Figure 4.4 outlines the distribution system for DOE-2. DOE-2 is available from four different sources:

- magnetic tapes of DOE-2 for mainframe computers are available from LBL;
- PC version from private firms;
- National Technology Information Service (NTIS); and
- National Energy Software Center (NESC).

In recent years, approximately 300 magnetic tape versions of DOE-2 have been sold annually. The PC version also sells around 300 copies annually (Winkelmann, 1988). According to the National Energy Software Center, ten copies of DOE-2.1C were distributed to domestic requesters during the 18-month period ending March 31, 1987. Every quarter LBL publishes the



**Fig. 4.4. The distribution system for DOE-2.**  
(Source: Winkleman, 1988)

DOE-2 User News. During FY 1987, LBL provided instruction during a five-week training course in different technologies including DOE-2 and PC-DOE.

According to LBL, the use of DOE-2 is fast expanding (Winkleman). The users of DOE-2 range from researchers and academicians to private manufacturers.

Figure 4.5 provides a general overview of the numerous beneficiaries.

PRODUCT MANUFACTURERS	DESIGNERS	RESEARCHERS AND EDUCATORS	AUDITORS AND CODE OFFICIALS
<b>HVAC Equipment Manufacturers</b> (Carrier, Westinghouse, Lennox, Trane)	<b>Government Agencies and Contractors</b> (GSA, U.S. Army, U.S. Navy, U.S. Air Force, NIH, DOE, etc.)	<b>Universities</b> (more than 50 in the U.S.)	<b>State Energy Offices</b> (CA, FL, AL, NY, GA, OR, MN, NC, TX, etc.)
<b>Controls Manufacturers</b> (Robertshaw)	<b>Architectural/Engineering Firms</b> (S-O-M, Heery, Haskell, Kaiser, Bechtel, Steven Winter, etc.)	<b>Professional Societies</b> (ASHRAE, ASME, etc.)	<b>Utilities</b> (BPA, TVA, So. Cal. Edison, B.C. Hydro, etc.)
<b>Product Manufacturers</b> (Owens-Corning, Southwall, Johns-Manville, Birdair, etc.)	<b>Corporate Design Departments</b> (DuPont, IBM, Eli Lilly, Dow Chemical, Raytheon, Ford Corp., BEST, McDonalds, etc.)	<b>National Laboratories</b> (ORNL, PNL, LBL, ANL, NBS, SERI, BNL, LLNL, LANL, SANDIA)	
<b>Industry Organizations</b> (GRI, EPRI, NAHB, AAMA)			

**Fig. 4.5. Beneficiaries of DOE-2.**  
 (Source: After Winkleman, 1988)

#### 4.5.4 Spinoffs

The extensive use of the mainframe DOE-2 computer program developed by LBL has given birth to numerous spinoffs. The chief spinoffs include the availability of DOE-2 for microcomputers and the use of DOE-2 algorithms in the evolution of other buildings evaluation programs.

The microcomputer version of the DOE-2.1C is the exact translation of the mainframe version. It was developed and is sold solely through Acrosoft International of Denver, Colorado. The price of the whole package is \$495. No royalties were paid to LBL since the mainframe version of DOE-2 is in the public domain. It took Acrosoft 6 months to develop the microcomputer version and the first sales of the program were in February 1987. So far, 180 copies of the program have been sold to consulting engineers, utilities, universities, and private contractors who use it for numerous purposes ranging from design of new buildings to calculating energy consumption of buildings and research (Tsai, 1988). Ten to 15% of the sales of the microcomputer version have been overseas. What makes the program especially attractive to foreign buyers is its ability to perform calculations in the metric system. The program is not copyrighted or protected. Hence, the actual number of users may be much greater than the number of copies sold. Dr. Tsai of Acrosoft International identified two areas where efforts need to be concentrated: (1) improving the documentation, and (2) making the input interactive. The nonproprietary nature of the software and large development costs are the main arguments in favor of government support.

ADM Associates of California market a microcomputer software program called ADM-2. ADM-2 is based on the same basic algorithms as the DOE-2, but even ADM acknowledges that it is not the same program and does not have all the capabilities of DOE-2. For example, the application front end of ADM-2 differs from DOE-2. The complete package of ADM-2 sells for \$595 and 100 copies of the program have been sold since sales first began in early 1985. ADM-2 is copyrighted and copy protected. All the research was conducted in-house after source code was obtained from LBL. The uses and users of ADM-2 are similar to those of DOE-2. ADM-2 is developing a PC-version of DOE-2 that is likely to come

out in a year and ADM claims that the new version will be better than the one marketed by Acrosoft. Presently, the development efforts are constrained by resources.

Morgan Systems of California has developed a microcomputer software called TrakLoad. Though it is based on some DOE-2 algorithms, TrakLoad differs significantly from DOE-2. Unlike DOE-2 and ADM-2, TrakLoad is unable to perform hourly simulations. First sales of TrakLoad began in early 1985 and around 400 copies have been sold so far. Two versions of TrakLoad are available with respective prices of \$795 and \$1,485. These versions are technically alike and differ only in reporting capabilities. The program is copyrighted but not write protected. Many users of TrakLoad are former DOE-2 users. TrakLoad is also used in course curricula at some universities. DOE has indirectly helped sales by stimulating demand through the Institutional Conservation Program. In the future, Morgan Systems does not intend to make TrakLoad more conformable to DOE-2 (Krinkel, 1988).

DOE-2.1-C, ADM, and TrakLoad are the main programs that are offshoots of DOE-2. They are advertised regularly in the ASHRAE Journal. (Tri Fund Research Corporation was marketing a program under the PC-DOE brand name, but it has since gone out of business.) The importance of DOE-2 can be gauged from the fact that these companies saw the potential in LBL research and developed these products without government assistance. Of course, none of this would have been possible if DOE-2 were not available in the public domain. DOE-2 may be the most successful program sponsored by the DOE and now it has reached a stage of self-generating growth.

#### 4.5.5 Future Development

DOE-2 is an evolutionary software and it is being constantly updated. There are some complicated features of buildings which DOE-2 only approximates (MacDonald, 1988). As of 1983, there were still deficiencies in documentation of DOE-2 and the program was expensive to run both in terms of time and money (Copeland, 1983). These shortcomings still exist. Continued DOE funding for the program is essential to support research at government facilities, industry, and universities; to develop energy-efficient standards and guidelines; and to provide an analytical tool for new technologies and buildings. LBL expects the DOE-2 to be replaced by advanced software by the year 1992. Until then, LBL expects to improve and maintain the program, adding new capabilities to the program only if public or private funds are forthcoming.

#### 4.5.6 Sources of Information

##### Interviews

Drew Crawley, Pacific Northwest Laboratories, Richland, Washington, July 1988.

David Krinkel, product manager, Morgan Systems, Berkeley, California, July 1988.

Kwok Lam, product manager, ADM Associates, Sacramento, California, July 1988.

Mike MacDonald, Oak Ridge National Laboratory, Oak Ridge, Tennessee, April 1988.

Gene Tsai, product manager, Acrosoft International, Denver, Colorado, July 1988.

Fred Winkelmann, Lawrence Berkeley Laboratory, Berkeley, California, April 1988.

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Government Computing News, various issues.

U.S. Government Accounting Office. 1987. Software Distribution: Review of the Department of Energy's National Software Center, GAO/IMTEC-88-2, October.

Winkelmann, F. "Building Performance Simulation Research," Lawrence Berkeley Laboratory, Berkeley, California, n.d.

## 5. CASE STUDIES OF SEMI-COMMERCIALIZED OBCS INNOVATIONS

### 5.1 DIELECTRIC COATING FOR LIGHTING FIXTURES

#### 5.1.1 The Innovation

Dielectric coatings (which are also called optical interference coatings) are relatively new to the lighting industry, although they have been used for years in cameras, projectors, and other optical instruments. Optical coatings can reduce reflection from camera lens surfaces, increase reflectance of mirrors, and perform other light control functions. The application of dielectric coatings can significantly enhance the reflectivity of anodized aluminum lighting sheeting in lighting fixtures. Optical interference coatings are made by depositing vaporized materials onto the substrate in a vacuum chamber. The materials used for the coatings include metals such as silver and aluminum, semi-conductors such as silicon and germanium, and inorganic dielectrics (nonconductors of direct electric currents) such as magnesium fluoride and titanium dioxide. These coatings have been referred to as thin films because the thickness of a single layer is about 0.1 micron. The coatings of interest to the lighting industry are multilayered with a total thickness of slightly less than 1.0 micron (Rubins, 1981).

#### 5.1.2 The DOE Role

Dielectric coatings were produced in the late 1970's by the Optical Coating Laboratory, Inc., (OCLI) for a variety of applications that did not include lighting fixtures. In 1979 OCLI began an effort to develop optical interference coatings that would increase the reflectivity of prefinished aluminum lighting sheet. At the same time, Lawrence Berkeley Laboratory was assisting the U.S. Department of Energy in planning and encouraging the development



of improved lighting components, materials, and control systems. OCLI received a contract of \$12,000 in DOE funds through LBL, to develop a coating specifically for application to lighting fixtures. OCLI is a well-established, highly respected, large company with a significant share of the optical coating market. It employs over 1,000 people, and has manufacturing plants in Europe as well as the United States. LBL administered the DOE contract on a cost-sharing basis with OCLI. The luminaire design and prototype development was subcontracted by OCLI to John Brass, Lighting Research and Development, Inc., San Rafael, California (Rubins, 1981).

The original objective for the project was to establish the performance and energy benefit of optical-coated, enhanced specular reflectors in conventional roadway luminaires. In January 1981, OCLI and LBL published a joint report which documented the satisfactory performance of the lighting fixtures with the coating.

Omega Energy, Inc., a small private company that was already in the business of manufacturing lighting fixtures with specular reflectors, saw the report and decided to investigate the new coating material. The product Omega Energy had been manufacturing was not performing as well as desired because the laminated silver film coating they were using was not sufficiently durable. In 1986 Omega Energy contacted OCLI and asked to manufacture fixtures with the OCLI dielectric coating. OCLI agreed and today Omega Energy has an exclusive license from OCLI to use the technology. OCLI had attempted to interest larger manufacturers of fixtures in the new coating, without success, before reaching the agreement with Omega Energy. OCLI now supplies Omega Energy with aluminum sheeting covered with the dielectric coating which Omega fabricates into fixtures and sells to end-users.

### **5.1.3 Market Penetration**

Since Omega Energy began fabricating and selling fixtures with the coating material supplied by OCLI, its business has expanded rapidly. In 1986 it sold about 15,000 fixtures mainly in the Northern California area. In 1987 sales reached 50,000 and moved into other regions. In 1988 sales are expected to exceed 120,000 fixtures, with 17 distributors of the Omega product serving most major areas of the United States. Omega Energy expects their sales to double again in 1989, and to continue to expand in future years. Early sales were only for retrofit applications but new construction sales have become important since then. Fixtures are generally custom-designed for clients such as hospitals, office buildings, supermarkets, and industrial plants. Many of the distributors for Omega's fixtures work for energy management companies.

### **5.1.4 Facilitating Factors**

The early use of dielectric coatings in roadside lighting fixtures provided a valuable base of experience for its later use in buildings. The economics are now very attractive, with a payback period between 1 and 2 years. Because more light is reflected by fixtures with dielectric coatings, 30-50% fewer lamps can be used for the same level of illumination, and the number of ballasts can be reduced, too. With the dollar savings from fewer lamps and ballasts, overall costs may decrease by as much as 40%. The dielectric coating is very durable and easy to clean and is backed up by a ten-year manufacturer's warranty. Some utilities offer rebates for the installation of the reflectors.

### **5.1.5 Barriers to Market Penetration**

Although the coated fixtures have short payback times, initial costs are higher. The coated fixtures cost \$50-60 installed, while uncoated fixtures cost

\$35-40. Thus, builders who construct buildings for speculative purposes may be unwilling to pay the higher front-end costs.

### 5.1.6 Future Directions

The annual doubling of Omega Energy's sales of their lighting fixtures with dielectric coatings suggests that this technology will continue along the path to full commercialization. DOE should monitor its market penetration to see if the expected expansion continues. At present, no active involvement is needed.

### 5.1.7 Sources of Information

#### Interviews

Carmen Bisher, Jr., Omega Energy, Inc., Haywood, California, April 1988.

Rudolph Verderber, Lawrence Berkeley Laboratory, Berkeley, California, April and October 1988.

#### Other

Video tape produced by Omega Energy, Inc., Haywood, California.

#### Documents

Rubins, H. L. 1981 Optical Interference Coatings for Improved Luminaire Performance: Final Report, LBL-12176/UC-95, Lawrence Berkeley Laboratory, Berkeley, California.

## 5.2 HEAT PUMP WATER HEATER

### 5.2.1 The Innovation

Water heating accounts for approximately one-fifth of the energy used by households in the U.S. Nearly one-third of these households (or approximately 30 million) use electric resistance water heaters, the primary

competitor to the heat pump water heater (HPWH). According to figures published by the Air Conditioning and Refrigeration Business magazine, these electric resistance water heaters consume the energy equivalent of 750,000 barrels of oil a day. The heat pump water heater consumes only one-half of the energy used by the electric resistance water heater. Thus, the potential for savings in both energy and dollars is substantial.

The HPWH "pumps" heat from the air into a water tank, just as an air conditioner removes heat from buildings. Like an air conditioner, the HPWH uses a compressor, an evaporator, an expansion valve, a refrigerant, and a control system.

At the same time it heats water, a HPWH cools and dehumidifies the air in the room where it is located. This air-conditioning effect can be an added benefit in hot or humid climates. It may also be valuable in restaurant kitchens, hotel laundries, and other commercial establishments generating waste heat and requiring hot water. In a restaurant, for instance, a HPWH can be installed in a location with high ambient temperature. The efficiency of the HPWH rises, the need for space cooling is decreased, and the life expectancy of other nearby equipment may be lengthened as a result of the decreased room temperature. In northern climates the effect could be a disbenefit for use in homes.

The HPWH concept has been around for decades, but until recently, energy prices were too low to justify the higher initial cost associated with heat pump technology. Today, the HPWH has an installed cost of \$800-\$1,200 with a payback period of 2 to 3 years. This compares with an installed cost of \$300-\$500 for an electric resistance water heater. The initial costs for HPWHs may be reduced in some areas by rebate programs, which typically provide \$200-\$500 rebates for the purchase of a water heater.

A standard efficiency calculation would produce the following picture:

The average four-person family has a daily hot water usage of 64 gallons. At the national average electricity cost of \$0.08/kWh, this is a \$400-\$500 annual water heating bill. The typical HPWH uses half the energy of an electric resistance water heater, so the household would save \$200-\$250 annually. This would give a payback of 2.5 years (Geller, 1985).

Large families with heavy hot water use can get a more rapid payback from a HPWH.

Heat pump water heaters also offer peak electricity demand reductions of 0.03-0.46 kW in winter and 0.08-0.29 kW in summer. The space conditioning load impacts of HPWHs are unclear (Dobyns and Blatt, 1984).

### 5.2.2 The DOE Role

In 1976 Robert Dunning, the president of Energy Utilization Systems, Inc., (EUS) approached the Energy Research and Development Administration (ERDA) with a proposal to develop a residential-scale HPWH. Although ERDA had some interest in the HPWH concept, it was not interested in the EUS proposal. ERDA wanted rapid commercialization of the HPWH and believed that a large manufacturer had to be involved to successfully bring the new technology onto the market. EUS was small and it was at that time a consulting firm, not a manufacturing firm.

EUS then approached the National Rural Electric Cooperative Association (NRECA). The NRECA gave EUS a \$5,000 grant to produce a prototype HPWH, which was displayed in February 1977 at the NRECA Annual Meeting.

At about that same time, under directions from ERDA, ORNL published a Request for Proposals to develop and commercialize highly efficient water heating systems. Copies of the RFP were mailed directly to all of the manufacturers in the water heating field. ORNL recommended that proposals

from nonmanufacturers show a link to a manufacturer to facilitate product commercialization.

Only five proposals were received, and none was from a major manufacturer. The proposal selected for funding was from EUS, which stated that Mor-Flo Industries, Inc., one of the nine major water heater manufacturers in the U.S., would provide the water tanks and their shipping cases. EUS did not propose that Mor-Flo be involved in either the design and development of the HPWH or in any commercialization planning and market analysis activity.

The EUS project had two phases. In Phase I, which started in 1977, EUS developed two HPWH versions - an integral model and a retrofit model - and conducted a market study to determine the potential demand for each.<sup>1</sup> EUS also tested various tank and compressor sizes, types of refrigerant, condenser designs, and fan speeds.

During Phase II, which began in 1978 and ran through 1982, EUS produced 100 demonstration units with some assistance from Mor-Flo and sold them at cost (approximately \$600) to 20 utilities that agreed to participate in a demonstration project. EUS also sold an additional 125 units to 65 other utilities that were interested in running their own tests.

Because of difficulties in retrofitting water tanks, the retrofit model proved to be impractical and EUS dropped it temporarily. EUS remedied problems encountered with the integral model, including weak joints in the compressor tubing and fragility during shipping.

Data gathered during the demonstration test showed that the coefficient of performance (COP) for the EUS HPWH in field conditions was approximately 2.0, which meant that the unit used half the energy of a conventional electric resistance water heater. EUS later conducted a lifetime assessment of the

HPWH based on a re-examination of 20 demonstration units two years after installation. It concluded that the HPWH could last 10 years or more (versus an average of 7-11 years for conventional gas-fired and electric water heaters).

No patents arose as a result of the OBCS program. Several related patents were issued decades ago and have now expired. There was simply nothing that arose of a patentable nature.

DOE's support for research and development on the heat pump water heater spanned five years:

1977	-	\$108K
1978	-	\$141K
1979	-	\$330K
1980	-	\$105K
1981	-	\$ 50K

Cooperating utilities contributed approximately 5% of the total costs, through their support for installing, maintaining, and monitoring the demonstration equipment. But, neither the American Refrigeration Institute nor any other trade or professional organization was involved. Though there were some efforts to attract sponsorship from such organizations, none was obtained. There was no industry advisory board, as was observed in other cases such as the supermarket refrigeration R&D program.

Very little R&D is supported by the industry. What R&D is supported is directed toward better maintenance and increased durability rather than improved energy efficiency.

### 5.2.3 Market Penetration

DOE's support of this technology stimulated the growth of a new industry. By the spring of 1980, EUS had established manufacturing facilities in Johnson City, Tennessee. Commercial production of the EUS HPWH began in August 1980 and by the end of 1980, EUS was manufacturing 80 units per month.

Fedders Corporation and E-Tech began marketing their own units during the same year, and several other firms entered the market soon afterwards. By 1982, 12 companies were manufacturing HPWHs, including Rheem Manufacturing Company and State Industries, the two largest manufacturers of water heaters. Production appears to have peaked in 1985 when it is estimated that 8,000 units were sold. By 1986 the annual sales had fallen below 8,000 and manufacturers were dropping the technology from their product lines (Fig. 5.1). Three of the manufacturers active in 1982 had dropped out of the HPWH market by 1984, and only five remained in 1986 (Table 5.1). Of these, E-Tech dominates sales with 5,000-6,000 units sold in 1986 and 1987, representing approximately 70% of the market (Shufford, 1988).

The heat pump water heater has had minimal penetration in the residential market, and is limited in impact to specific regions of the U.S. Availability of the

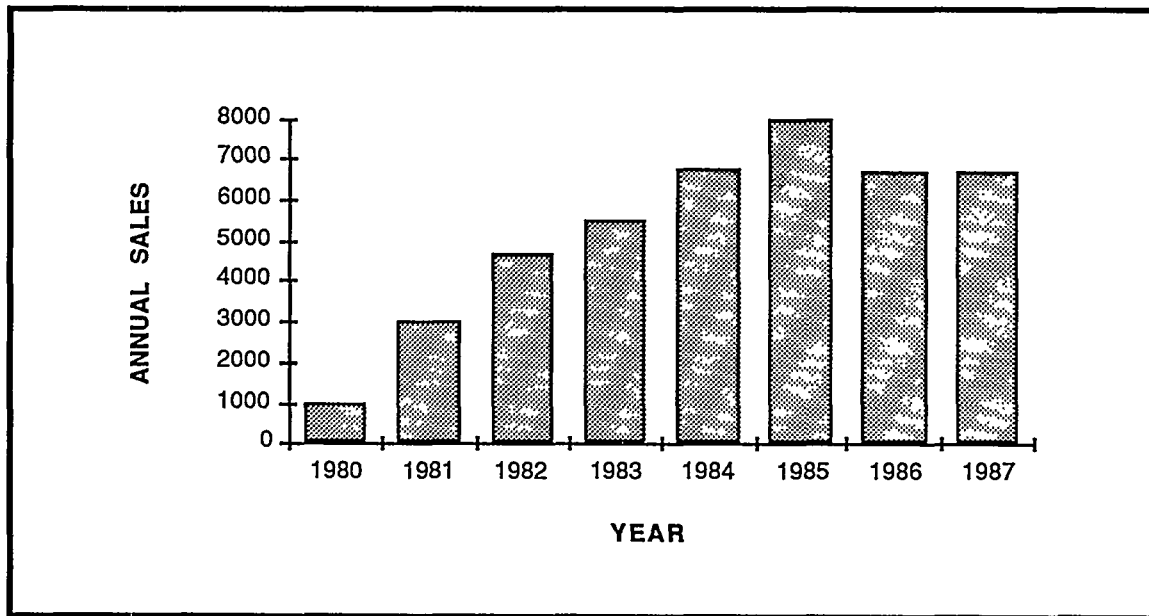


Fig. 5.1. Market penetration of heat pump water heaters.



product has been restricted primarily to the Southeast, California, and Hawaii. Two of the current manufacturers are in Tennessee, and two are in Georgia, indicating the regional nature of the technology's availability.

A profitable spin-off application for the HPWH has been marketed by E-Tech, EUS, and possibly others for the past five or so years - the HPWH for swimming pools and spas.

State Industries has also sold some units to fast food restaurants that do not require prohibitively hot water for washing dishes. E-Tech estimated that their commercial sales totaled only 300 per year in recent years.

EUS has also developed and marketed an improved retrofit HPWH, and sold about 50 units of these in 1986 and 1987. Three basic improvements were made to the old retrofit design: changes in shape, material, and capacity. As opposed to their old rectangular model, the new model is a narrow dome. Because this shape

**Table 5.1 Manufacturers of Heat Pump  
Water Heaters (1980 through 1986)**

1980 (N=3)	1982 (N=12)	1984 (N=8)	1986 (N=5)
E-Tech Energy Utilization Systems, Inc. (EUS) Fedders	American Appliance Manufacturing Corp. Borg-Warner Carrier DEC International E-Tech EUS Duo-Therm Fedders Manoir International Oregon Heat Pump Rheem Mfg. Co. State Industries, Inc.	Borg-Warner DEC Duo-Therm E-Tech EUS Fedders Rheem State	DEC E-Tech EUS Rheem State

gives their new add-on unit a modern look, it is more appealing to the consumer. Another change in shape is the position of the outlet pipe. On the old unit the intake was on one side and the outlet was on the opposite side, whereas with the new unit the intake is on the side and the outlet is on the top. Because heat rises, this new design is more efficient. New construction material has also improved the unit. The old unit was made of painted metal, while the new one is made of molded pvc plastic. This makes the unit stronger and more durable. In addition to these improvements, the capacity of the unit has been doubled. The former design's evaporator capacity was one-half ton, and the new model has a one-ton evaporator.

The new add-on unit costs \$750 and is estimated to cut the amount of power spent on heating water in half for a four-person household. For the Tennessee area with power supplied by TVA, the average cost of hot water is \$120 per person, per year. For a four-person household, then, the unit would pay for itself in a little over 3 years.

In the late 1970's the HPWH looked like a technology that would "take off" as prices came down and cost effectiveness and dependability rose. But it never gained widespread market acceptance when energy prices were high, and the anticipated experience-based price declines have not occurred.

#### **5.2.4 Information Dissemination**

A great deal of information on the HPWH has been published in popular magazines - one of the most important sources of information for the purchasing public. These magazines have a broader circulation and greater readability than any government publication or fact sheet. The DOE has also produced a "Fact Sheet" on hot water heating that describes the HPWH. Nevertheless, a majority of the industry representatives interviewed for this study complained that consumers were ill-informed.

### 5.2.5 Barriers to Further Penetration

Several barriers inhibit further market penetration of the HPWH. Low visibility of energy use for water heating has subdued demand for improved water-heater efficiencies in general. Consumers are largely unaware of the cost of heating water and do not pay attention to their water heater until it needs to be repaired or replaced. The lack of consumer awareness of the energy saved by HPWHs could be alleviated by the addition of an energy metering device to the heater or by better information outreach.

Another major problem is the high initial cost of the product due to small-scale production. The combination of the information and cost problems creates the HPWH industry's dilemma. There is insufficient demand for the product, presumably due to the lack of consumer's knowledge and the high price of the product, for it to be profitable to increase the scale of production. Therefore, the price of the product remains high, which is one of the reasons that there is insufficient demand to begin with. However, any attempt to increase the demand for the product with an informative marketing effort will be unsuccessful due to the high initial cost of HPWHs, and the cost of the marketing effort. This marketing cost would be too large of a burden for these small firms to bear without passing the cost onto the consumer, so the price of the product will increase. This increase in the price of HPWHs, which already is perceived as too high, would make the payback from energy savings longer. Thus, the demand for the product will be lower, which would counter the increase in demand that the marketing effort was to generate.

Plumbers and HVAC service personnel are poorly trained in the heat pump technology. They therefore do not actively promote the product, and qualified servicing is often unavailable. Maintenance requires skills in refrigeration, electrical wiring, and plumbing that often go beyond

the expertise of local service personnel. The HPWH has never had a dedicated distribution channel with the technical expertise to support efficient installation and maintenance. EUS and other manufacturers are now supporting specialized dealers who install and service their HPWHs (Ivey and Smith, 1988); this should reduce the problem of untrained installers.

#### **5.2.6 Facilitating Factors**

The most receptive regions for HPWH marketing have been the service areas of utilities and public programs that offer either rebates or low-interest loans for HPWH purchases. Mandating energy efficient water heating would also generate considerable demand, and there is some preliminary evidence that the California building code (which does give credit to heat pump water heaters) has indeed stimulated the market.

#### **5.2.7 Future Technology Transfer**

Research on shopping behavior and innovation diffusion suggests that there should be a certain group of consumers who would enjoy examining heat pump water heaters, and who might serve as a source of information for friends, neighbors, and acquaintances at those critical times when replacement water heaters are purchased. A diffusion strategy that targets these "innovators" and "opinion leaders" might be especially effective. Previous research suggests that articles in popular magazines would be one way of stimulating awareness on the part of these consumers. Unfortunately, this tactic has not proven effective to date.

One attractive but largely unpenetrated market for HPWHs is the major real estate developer. Developers of subdivisions could install units in large lots. After installation, having a cluster of HPWHs would allow the development of local expertise in maintenance and replacement.

In some locations, the HPWH can compete with gas water heating, because of high local costs for gas. OBCS could assist in the identification of these areas.

#### **5.2.8 Future Directions**

A new product with enormous energy-savings potential is now on the market, and a new industry has been spawned to market it. Industry has stated that the HPWH would not have been developed without DOE support. At the very least, DOE funding accelerated the technology's development.

Although market penetration has not been great, the technology is by no means dead. If energy costs rise again, the HPWH could achieve much higher penetration. A coordinated strategy could result in significant market development if it could effectively tie together utility financial incentives for the residential market with information programs targeting key market segments: innovators and opinion leaders among the buying public and selected commercial businesses and subdivision developers.

#### **5.2.9 Sources of Information**

##### Interviews

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Cindy Gattis, Tennessee Valley Authority, Chattanooga, Tennessee, July 1987.

Berny Middlestat, Dairy Equipment Company (DEC) International, Madison, Wisconsin, August 1987 and June 1988.

James Milhorn, Energy Utilization Systems, Inc., Johnson City, Tennessee, August 1987 and June 1988.

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## **5.3 RADIANT BARRIERS**

### **5.3.1 The Innovation**

Radiant barriers are an example of an existing product applied to an innovative use. Specifically, a radiant barrier is a double reflective aluminum foil which is placed over regular insulation in the attic (called horizontal installation) or mounted underneath rafters (called vertical installation). Radiant barriers reflect the solar heat which passes through the roof back to the atmosphere. They are capable of blocking up to 95% of far-infrared radiation heat transfer. The primary use of this technology is in the southern United States. However, it can be applied internationally along similar latitudes.

### **5.3.2 The DOE Role**

Research on radiant barriers has been ongoing at Oak Ridge National Laboratory (ORNL) and Florida Solar Energy Center (FSEC). Most of the research funding at ORNL has been provided by DOE and TVA, though EPRI and the Reflective Insulation Manufacturers Association (RIMA) have also been significant contributors. The amount of DOE support to ORNL has been \$270,000, while TVA has contributed nearly \$310,000. Radiant barriers research at FSEC has been sponsored chiefly by the State of Florida and DOE. Over the years, the State of Florida has invested around half a million dollars toward radiant barriers research. Work on radiant barriers began at FSEC in 1981 and the first results were published in 1982.

DOE assisted in developing and testing the radiant barriers concept by supporting radiant barriers research both at FSEC and ORNL. All of the DOE-sponsored research was conducted in-house at both of these centers - there was no subcontracting.

Since radiant barriers are not a typical insulation product (insulation defined as having some air between layers of nonconducting material), RIMA was not aware of the radiant barrier concept before DOE research began. In their advertisements, private firms acknowledge the role of DOE, FSEC, ORNL, and TVA in radiant barrier research. However, the energy savings claimed in these advertisements sometimes exaggerate the research results. The bottom line is that radiant barriers would not have been commercialized without DOE's role in testing and development (Karnitz, 1988).

The research on radiant barriers is still ongoing. It has been estimated that in dry, hot summer weather, radiant barriers are capable of reflecting around 90% of the heat. Since the barriers are reflective on both sides, they help keep the heat out in summer and the heat in during winter (Levins and Karnitz, 1986; 1987). Two issues requiring further research are: the effectiveness of radiant barriers in cooler climates, and their performance under conditions of greater humidity. Also, there is some debate about the appropriate installation procedure with ORNL preferring horizontal installation on efficiency grounds and RIMA recommending vertical installation. FSEC and ORNL are looking at the problem of dust accumulation on horizontally-installed radiant barriers (Fairey, 1988).

### 5.3.3 Energy Savings

The potential energy savings from radiant barriers are substantial. Reflective insulation could be used in approximately 22 million homes in the South and may be appropriate elsewhere. Based on research at ORNL, it is estimated that in a typical home in the northern Tennessee Valley, a radiant barrier would reduce annual electric consumption for cooling and heating by 600 kWh and 300 kWh, respectively. At a price of 6¢/kWh this would save



around \$54/year. The investment proved to be cost effective based on an experimental house used in ORNL tests that had an attic area of 1,200 square feet. If radiant barriers are installed by the homeowner, costs range from \$60-\$180 at 5¢-15¢/sq. ft. For horizontal installation by a contractor, the total costs are expected to range from \$150 to \$600. The payback period, for a typical, self-installed home, should not exceed 4 years (Karnitz, 1988). No warranty on energy savings is issued by the sellers; warranties are limited to defective workmanship.

As a pilot project, TVA has installed radiant barriers in 30 homes each in Hopkinsville, Kentucky, and Tupelo, Mississippi. Since radiant barriers are

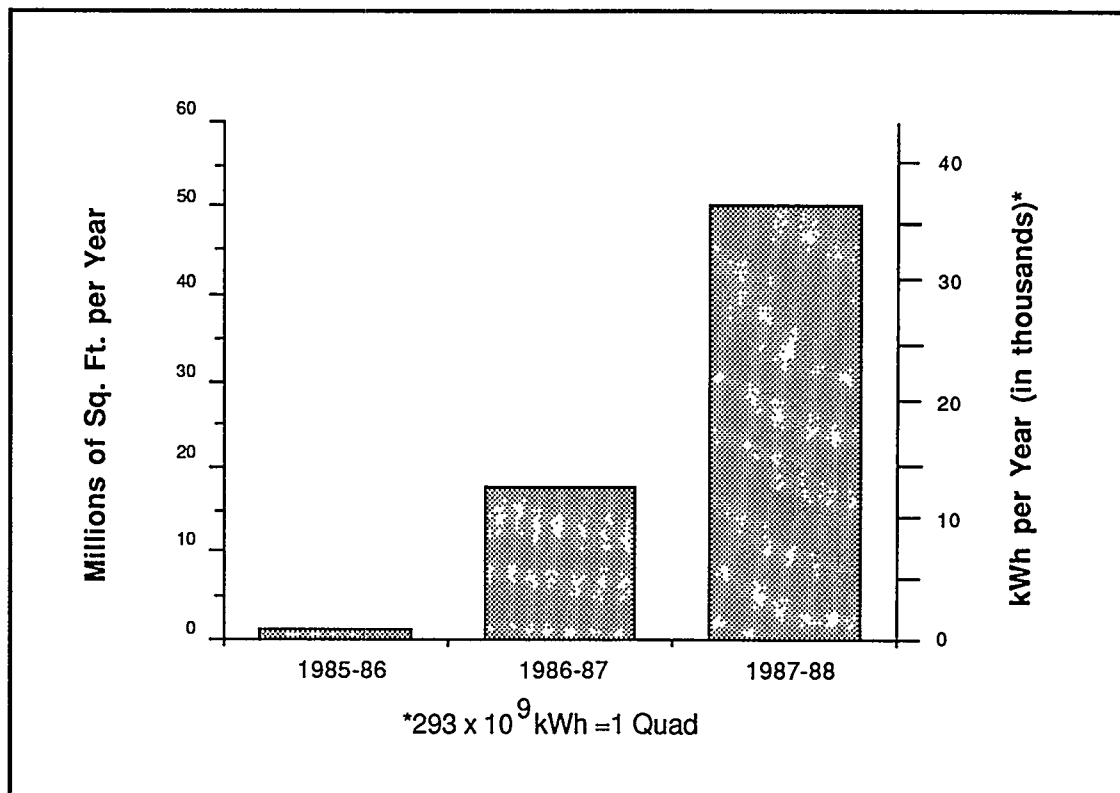


Fig. 5.2. Energy savings from estimated sales of radiant barriers.

nothing more than the conventional aluminum foil applied to a novel use, they do not involve the substantial development and marketing costs typically associated with a new product. As their use becomes widespread, the returns to both public and private investment will be substantial. Figure 5.2 summarizes the energy savings achieved to date.

#### **5.3.4 Market Penetration**

Radiant barriers first became commercially available in approximately 1985. The partnership of a trade organization, in this case RIMA, in the development stage provided ready acceptance by the manufacturers and distributors. Since the technology is easy to install and does not require any specialized materials, it has not been patented. This has resulted in a mushrooming of manufacturers and distributors with varying prices and qualities. The product diversity does not pose problems as long as the foil used is of the same emissivity. Typically, sellers of radiant barriers also carry other types of insulation products such as multilayer insulation and insulation bubble products. The various marketing avenues in operation are shown in Fig. 5.2.

The geographic concentration of the market for radiant barriers has been limited to the southwestern and southeastern United States because performance of the technology has only been tested in similar climates so far. California is another potential market for the product that is likely to open up after hearings by the Bureau of Home Furnishers scheduled for later this year are conducted.

In the first year of commercialization, there were around four firms with sales of one million sq. ft. of radiant barriers selling at an average price of \$70

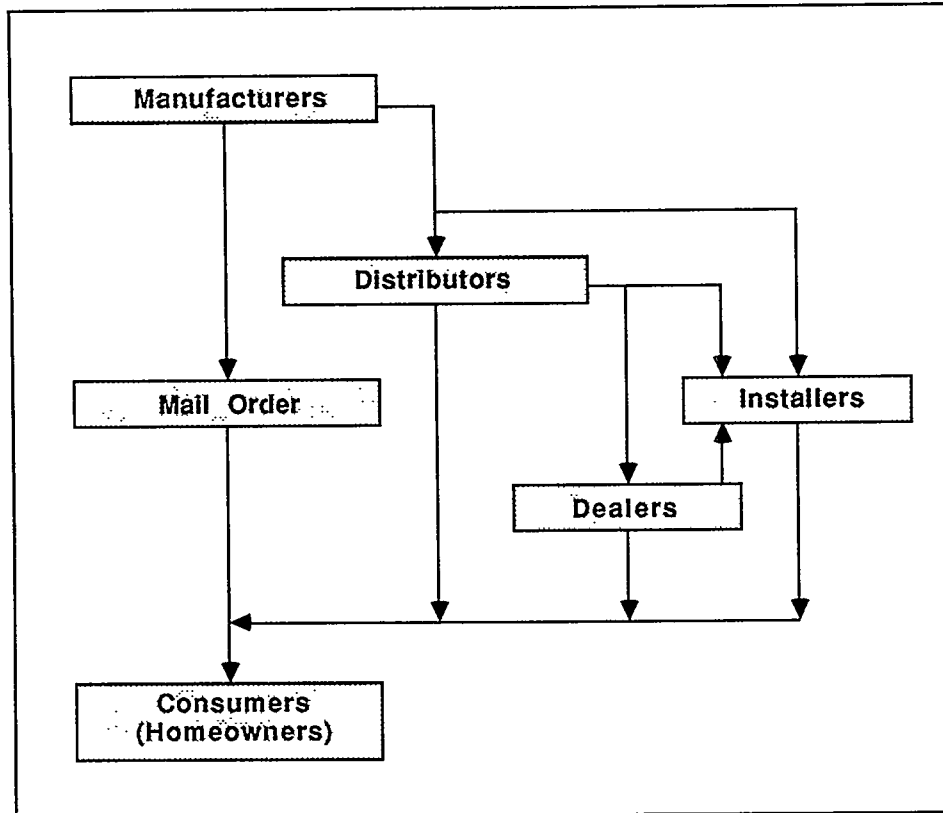


Fig. 5.3. Marketing structure of radiant barriers.

per 1,000 sq. ft. In the second year, sales rose to 15-20 million sq. ft., while the price remained the same. Presently, there are about 25 firms selling an estimated one million sq. ft. of radiant barriers per week at an average price of \$65 per 1000 sq. ft. (Akers, 1988). Assuming the potential market is 22 million homes and the average floor area is 1,700 sq. ft. (U. S. Bureau of the Census, Statistical Abstract of the U.S., 1988, Table 1211) the market penetration of radiant barriers is about 0.1%. The trends in market penetration are shown in Fig. 5.3. The average price is not very representative because some sellers charge almost 10 times more than others (The Oak Ridger, 1988). This huge

variance in price is a cause for concern, since the technology is still in its infancy and being branded as economically infeasible could hurt its future market standing. The reason behind this price variance seems to be the lack of public information about a benchmark price.

The radiant barriers industry faces resistance from competing insulation products such as mineral insulation. Part of this resistance occurs because competitors do not know that radiant barriers are to be used in conjunction with conventional insulation, not as a substitute.

One encouraging development has been that the State of Florida, in its new building code, has made a provision for obtaining credit toward the code requirements for installing radiant barriers. Though the extent of credit is not substantial, it provides the new technology much needed exposure and credibility. FSEC answers around 5,000-7,000 queries about radiant barriers each year. Florida is the only state to incorporate radiant barriers into its building code.

Every commercialization strategy needs to be tailored to the product's unique characteristics. In developing a strategy for radiant barriers, it is important to keep two points in mind:

- Radiant barriers are not a stand-alone product. They are intended to be used in conjunction with other insulation. This makes it harder to convince potential buyers of the additional benefits from their installation.
- Radiant barriers are an "experience" good. That is, the utility of the product can only be determined by its use and not by looking at it. This prevents buyers from verifying the energy savings claims of sellers. Hence, a credible organization (e.g., a government agency) needs to set price and performance guidelines on radiant barriers.

### 5.3.5 Future Directions

It is evident that radiant barriers can result in substantial energy savings in the South, but continued DOE support is essential to determine the efficiency of radiant barriers in cold and moist climates. DOE could also facilitate the commercialization of radiant barriers by providing rough price and performance guidelines. Such a move would go a long way in guarding the public against fraud.

One spinoff from research has been that the use of radiant barriers in conjunction with loose fill insulation can result in prevention of heat loss due to convection. An interesting alternative to aluminum foil may be the use of tinsel as radiant barriers (Karnitz, 1988).

Existing energy analysis software programs for buildings, such as DOE-2, are incapable of adequately evaluating the effectiveness of radiant barriers. Research needs to be conducted so that these programs are capable of testing radiant barriers. This non-sophistication and cost effectiveness of the technology makes it very promising at least in the regions where it has been tested. The non-sophistication of the product is not without its costs, however, in that no firm can patent the technology and thereby protect its investment. Firms are less willing to promote a technology when their rivals will benefit from their promotional activities.

### 5.3.6 Sources of Information

#### Interviews

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## 5.4 WISCONSIN AUDIT

### 5.4.1 The Innovation

The Wisconsin audit is a home energy audit that was initially developed by researchers at Oak Ridge National Laboratory. It has proven to be a successful tool for cost-effectively selecting building-envelope and heating-system retrofits in weatherization programs, offering significant advantages compared to approaches that involve a fixed priority list of retrofit measures (Ternes et al., 1988).

### 5.4.2 Background

The gas heating home energy audit was developed by Lance McCold and David Wasserman at ORNL during 1985 and 1986. It was programmed to run on a personal computer in LOTUS 123 format. The Wisconsin Energy Conservation

Corporation (WECC) provided data on weatherization from Wisconsin and worked with ORNL and the Alliance to Save Energy on a field test during the winter of 1985-86. The field test involved 66 occupied, low-income, single-family houses in and around Madison, Wisconsin. The three primary objectives of the test were to:

- (1) determine the energy savings and the relative benefits from a combination of envelope and mechanical equipment retrofits that were selected following the new audit-directed retrofit procedure;
- (2) determine the energy savings and benefits due to performing infiltration reduction work following a recently developed infiltration reduction procedure; and
- (3) study general occupant behavior and house thermal characteristics and their possible change following retrofit installation.

Funding for the innovation and its field test came from many sources:

- DOE's Office of Buildings and Community Systems;
- DOE's Low-Income Weatherization Assistance Program;
- the State of Wisconsin's Department of Health and Social Services; and
- Wisconsin utilities (Wisconsin Power and Light, Wisconsin Gas, and Madison Gas and Electric).

A total of \$50K to \$60K of DOE funding was spent at ORNL to develop the original version.

Using State of Wisconsin funds, WECC then improved upon the original ORNL version by adding extra features such as a fuel normalization scheme. The result was the WECC single-family audit - version 1.2. Additional versions of the audit were subsequently developed by WECC with internal funds and funding from Wisconsin utilities. Versions in the 2.0 series of the WECC audit included more elaborate infiltration procedures and an audit user's manual. The latest version, WECC audit 3.0, has the capability of auditing one- to four-unit multifamily buildings. The total expenses incurred by WECC in its development efforts were approximately \$120K.

### 5.4.3 Commercialization

The original field test version and version 1.2 are in the public domain. WECC has copyrighted version 2.0 and subsequent versions. The audit is currently being sold to states and utilities in a package that includes training, support, and customization of the audit for local needs. The audit package is priced between \$15,000 and \$20,000. Basically, WECC has a two-tiered pricing structure. Non-profit buyers are charged a lower price than private utilities. The buyers are required to sign a licensing agreement for each copy of the audit purchased. The cost and the complexity of the program and data input requirements prohibit wider use of the WECC audit.

WECC, a non-profit organization, first started marketing the audit to utilities in the middle of 1987. So far, WECC has sold ten licenses - nine to public agencies and one to the State of Wisconsin. The licensees are allowed to make copies of the program for internal use. WECC does not perceive any audits to be directly competing with its own audit though it is aware of a similar mainframe audit developed by the State of Illinois. Pennsylvania Electric (PENELEC), one of the utilities in Pennsylvania that bought the audit from WECC in February of 1988, is using the program in its low-income weatherization program and has concluded that the audit meets its expectations. It is significant to note that even PENELEC does not know of any close substitutes of the WECC audit (Ponzurick, 1988).

### 5.4.4 Future Development

Future audits need to include cooling measures for application in the southern United States. The WECC audit does not perform any cooling measurements. WECC has an audit on the drawing boards that will cater to the



needs of mobile homes, buildings with more than four units, and small establishments like gas stations.

Jeff Schlegel of WECC thinks that there is duplication of effort and resources between the weatherization programs of different states because of a lack of communication and coordination. WECC originally wanted to develop the audit with DOE funds and then place the resulting software in the public domain. Failure to obtain DOE support forced WECC to finance the project with internal funds and to copyright the program to recoup its investment. WECC still has a strong preference to develop a new audit jointly with DOE.

DOE should consider supporting the further development of this audit. However, it should also ensure that the resulting product is available to users at an affordable cost. At a minimum, the government should retain a royalty-free, paid-up, nonexclusive license to the software, and the price for the software when sold to government users should be reduced by at least the amount of the royalty due on a commercial sale.

#### **5.4.5 Sources of Information**

##### Interviews

Mike Gettings, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September 1988.

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## **5.5 COMPUTERIZED, INSTRUMENTED, RESIDENTIAL AUDIT**

### **5.5.1 The Innovation**

The Computerized, Instrumented, Residential Audit (CIRA) is a collection of programs for energy analysis and energy auditing of residential buildings. From a large list of energy retrofits, CIRA can select those that would maximize energy savings and also indicates the sequence in which they ought to be installed. It can be used for houses in different climates, with a variety of economic parameters.

In the CIRA energy calculation model, each retrofit is defined by a change in one or more of the following: (1) the building load coefficient, (2) the furnace or air conditioner efficiency, (3) internal gains, or (4) the heating or cooling distribution losses. To estimate the energy consumed by any given house, CIRA makes use of heating and cooling algorithms developed at Lawrence Berkeley Laboratory, Los Alamos National Laboratory, National Institute of Standards and Technology, and Princeton University. CIRA can present results in both tabular and graphical forms. In sum, the two important functions performed by CIRA are the selection of retrofits and their economic optimization (Sonderregger and Dixon, 1983; Sonderregger et al., 1983).

### **5.5.2 The DOE Role**

All the research on CIRA was conducted at Lawrence Berkeley Laboratory with funds from OBCS. There was no private sector involvement in the development of this technology. Research on CIRA began in 1980 at LBL and the first version was released in 1982. CIRA has not been patented or copyrighted, and LBL has given a license or simply permission to use it to everyone who has applied; thus, the technology is in the public domain.

### **5.5.3 Commercialization**

LBL has been selling CIRA since 1982 at the cost price of \$250. The package includes manuals and computer disks. Burt Hill Kosar Rittelmann Associates of Pennsylvania, a private firm, is marketing CIRA under its own brand name - EEDO. EEDO is the PC version of CIRA and contains 99% of the same program as CIRA. Around 125 copies of EEDO have been sold since sales first began in 1984. The current price of EEDO is \$395 which includes documentation (Shank, 1988). There are no other programs on the market that closely resemble CIRA.

### **5.5.4 Future Directions**

Though software is ever evolving, no further development is planned for CIRA because individual users can modify the program to their own specific needs. There has been no DOE funding for CIRA for a number of years, and none is planned for the near future (Boulin, 1988). Since Howard Ross, the original DOE program manager left his job, the development of CIRA has not been closely tracked by the DOE.

CIRA is a limited commercial success. There have been and continue to be applications of the program in both the public and private sectors. EEDO is still

selling well and Burt Hill Kosar Rittelmann Associates intend to improve the program. The continuing sales of EEDO lend credence to the utility of the program.

### **5.5.5 Sources of Information**

#### Interviews

Gene Boulin, DOE, Washington, D.C., August 1988.

Mike MacDonald, Oak Ridge, Tennessee, April 1988.

Bill Mixon, Oak Ridge National Laboratory, Oak Ridge, Tennessee, August 1988.

Ed Shank, Burt Hill Kosar Rittelmann Associates, Butler, Pennsylvania, August and September 1988.

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## **5.6 HOTBOX METHOD FOR TESTING HEAT TRANSFER THROUGH WALLS**

### **5.6.1 The Innovation**

A Hotbox is a device consisting of two boxes that are mounted on each side of a wall to measure the ability of the wall to transfer heat. Temperature controls are set on one of the boxes and the readings on the other box give the extent of heat transfer through the wall (for details, see Achenbach, 1979).

Hotboxes have been around for quite a long time. The first Hotbox was developed in the 1930's at the Pennsylvania State University and the Massachusetts Institute of Technology. This Hotbox was capable of conducting static temperature tests on walls. Currently, there are approximately 60 Hotboxes in operation in different parts of the U.S. and Canada with sizes varying from 3' X 3' to 9' X 12'. Only three of the existing Hotboxes are capable of analyzing dynamic temperature variations; others called steady state devices analyze set temperature changes through walls.

The biggest Hotbox (9' X 12') is at the National Institute of Standards and Technology (NIST). This Hotbox has a higher degree of accuracy than others and will ultimately be able to measure the transfer of humidity and variations in temperature. DOE's main role has been in sponsoring a dynamic test method capable of measuring temperature variations. Steady state Hotboxes have been built and calibrated, and are no longer undergoing technical development. Dynamic temperature experiments, on the other hand, are relatively new. They have been conducted on two different wall systems by the NIST. Work is also being conducted on humidity measurements.

Hotboxes are applied in testing the thermal performance of whole wall systems. The Hotbox method leads to better information on different whole wall systems which increases economic efficiency by recommending correct amounts of insulation.

There are no direct energy savings generated from using Hotboxes. Like appliance labelling programs, home rating systems, design models, air infiltration testing methods, and other OBCS supported activities, Hotboxes have been promoted in an effort to narrow the information gap surrounding the energy performance of alternative building technologies.

The main centers of Hotbox research are: the National Institute of Standards and Technology; National Research Center, Canada; Jim Walter Technology Center; and Construction Technology Laboratory, Illinois (CTL). The chief funders of Hotbox research are OBCS, the Department of Commerce, and the Canadian Government. There have been no direct spinoffs or patents from this technology (Courville, 1988).

### 5.6.2 Hotbox Applications and Users

Hotboxes are used for many purposes. Industry and government laboratories use Hotboxes to test the thermal performance of particular wall systems such as prefabricated and superinsulated walls. Government laboratories use Hotboxes to develop test methods such as the dynamic test method for testing heat transfer through walls. Researchers also use Hotboxes to verify mathematical models of heat flow. Government labs use Hotboxes to referee disputes among builders or construction companies by examining the energy saving claims made by different companies. Scientists and researchers on sabbatical leaves are also allowed to conduct experiments at the NIST Hotbox (Taylor, 1988).

The CTL Hotbox is the only Hotbox that does dynamic testing on a contractual basis (Van Geem, 1988). CTL charges \$5,000 per Hotbox run. This figure is slightly above the industry average, but CTL claims that they conduct more detailed analysis than others. Currently, the installed Hotboxes are operating at less than full capacity.

Final consumers (for example, homeowners) do not typically know whether or not a particular wall system has been tested by a Hotbox. They simply experience the thermal performance of wall systems (Birch, 1988).

### 5.6.3 The DOE Role

DOE has facilitated the development of Hotboxes on a number of fronts. It has provided half of the construction and operating costs for the NIST Hotbox. Though the exact numbers are unavailable, DOE and NIST have jointly spent between two and three million dollars on the NIST Hotbox (Taylor, 1988). DOE also provided a quarter of a million dollars to CTL. These funds were provided at the same time that DOE was sponsoring similar research at NIST. DOE support facilitated the development of the Hotbox at CTL. In addition to supporting the costs of constructing Hotboxes, DOE took the lead in funding a round robin on Hotboxes. In round robins, sample(s) of one or more materials are tested at different research locations, and performance tests are compared. The NIST Hotbox is seen as the standard for calibrating different Hotboxes. DOE also supported a horizontal Hotbox at the Roof Research Center at ORNL.

Hotbox results are available to users - builders, construction companies, and architects - through ASHRAE's Handbook of Fundamentals. DOE is sponsoring a compilation of Hotbox calculations on different wall systems which will be published for use by builders. Thus, DOE has had a role in stimulating the use of Hotbox testing, even though it has had little direct role in the commercialization of the Hotbox itself.

The objectives of DOE were: (1) to provide industry with a benchmark apparatus to evaluate wall systems, (2) to provide industry with a capability to measure heat transfer through superinsulated walls, (3) to facilitate the standardization of wall systems, and (4) to test how real-world data fit laboratory calibrations. These objectives have all been accomplished for steady state Hotboxes. Work is progressing on the development of a Hotbox capable of measuring dynamic temperature settings and the transfer of moisture.

The following is the time-line of events in the development of the Hotbox method. The following events occurred at NIST:

- 1978 - NIST Hotbox conceptualized.
- 1983 - NIST Hotbox built.
- 1985 - NIST calibration was completed.

At CTL:

- 1979 - CTL Hotbox installed.
- 1985 - CTL introduced the Guidebook of Performance on 21 wall systems.
- 1988 - Second draft of test procedures for dynamic performance of Hotboxes.

The next milestone for DOE is to test the dynamic stability of Hotboxes to examine moisture transfer through walls.

#### 5.6.4 Conclusions

Unlike many of the other innovations examined in this report, Hotboxes are not a consumer good. Builders and construction companies, to whom they are targeted, do not have a recurring need for them because they can have a particular wall system tested on a Hotbox and then build numerous structures with the same wall specifications. Hence, an average user would not generally need to use a Hotbox very frequently. Also, Hotboxes do not have any direct energy savings, so the returns to DOE's investment cannot be adequately measured. Nevertheless, DOE played an important role in facilitating the use of Hotboxes, and was instrumental in the emergence of the NIST Hotbox as the industry calibration standard. By reducing uncertainties surrounding the thermal performance of different wall systems, DOE has helped builders and construction companies more accurately assess the advantages of energy-efficient buildings. In the future, DOE needs to sponsor a standardized dynamic Hotbox test for testing the performance of wall systems. Such standardization will lead to lower costs per run and consequently greater use of Hotboxes.



### 5.6.5 Sources of Information

#### Interviews

Douglas Birch, National Institute of Standards and Technology, Gaithersburg, Maryland, May 1988.

George Courville, Oak Ridge National Laboratory, Oak Ridge, Tennessee, April 1988.

Sam Taylor, Department of Energy, Washington, D.C., June 1988.

M. Van Geem, Construction Technology Laboratory, Stokley, Illinois, June 1988.

#### Documents

Achenbach, P. R. 1979. "Design of a Calibrated Hot-Box for Measuring the Heat, Air, and Moisture Transfer of Composite Buildings," ASHRAE Report no.: ASHRAE/SP-28.

## 5.7 TRACER GAS TESTING WITH THE AIR INFILTRATION MEASUREMENT SYSTEM

### 5.7.1 The Innovation

The Air Infiltration Measurement System (AIMS) consists of two small cigarette-sized cartridges - a sender tube (the source) and a receiver tube (the sampler). The source is a gas-charged device that emits an inert perfluorocarbon tracer gas (PFT) into the air at a constant rate through a silicone rubber plug. The sampler is a glass tube with a charcoal-like absorbent material that "passively absorbs" the PFT tracer gas over the duration of the test.

One PFT source with a sampler costs \$50 and is enough to test 500 square feet of a building. The source is placed within 2 feet of an outside wall, usually on a piece of furniture. The sampler is placed at least 2 feet from any wall, ceiling, or floor and 6 to 8 feet from the source. The source and sampler are prepared and sent out by a laboratory and then deployed by a researcher,

builder, or homeowner for a known amount of time. The instructions for use can be followed by the untrained layman. When the test is over, the source and sampler are sent to the laboratory for analysis with gas chromatography. Knowing the duration of the test, the amount of gas, and the volume of the house, one can calculate the effective air infiltration rate in air changes per hour and the air flow between zones of a building.

Blower door testing also is used to measure air infiltration but it gives different results and serves different purposes than AIMS. Blower doors measure the tightness of the building envelope and give an instantaneous measurement of leakiness or tightness in terms of an equivalent leakage area. Thus, in contrast to AIMS, blower door techniques do not measure infiltration rates. The blower door results can be incorporated into simulation models, for which the user makes assumptions about climate, wind conditions, and other factors affecting infiltration, to estimate an average long-term natural infiltration rate. The most useful application of the blower door technique, however, is as a diagnostic tool to determine how much additional infiltration reduction is needed, to locate leakage sites while the building is being weatherized, and to provide an index of the change in building leakage performance before and after retrofit. AIMS does not serve such diagnostic purposes; instead, it measures effective infiltration rates over extended periods of time including the effects of mechanical ventilation, exhaust fans, door and window openings, and other occupant-controlled activities (DuPont, 1987).

### 5.7.2 The DOE Role

AIMS was developed as a practical technique by Russell Dietz at Brookhaven National Laboratory with support from the U.S. Department of Energy in the early 1980's. Patents on the technology, however, are held

privately by AIM, Inc., a firm that was created by the individuals who invented the concept before Brookhaven became involved in its practical development.

For a few years, Brookhaven National Laboratory analyzed AIMS results for users of the testing system, processing about 1,000 samples per year. In 1985, the company holding the patent (AIM, Inc.) sold an exclusive license to the National Association of Home Builders (NAHB) for selling and processing the testing system in applications involving three-story and smaller buildings. This license will expire in 5 years. AIM, Inc., retained rights for applications to larger commercial buildings. NAHB now processes about 8,000 samples per year. Several research organizations - including the Harvard School of Public Health, Princeton, Battelle, and Brookhaven - still process their own samples for internal research purposes.

NAHB wanted to set up their own testing laboratories as a service to the building industry. NAHB membership includes builders, building subcontractors, architects, and building product manufacturers. NAHB found that more time, effort, and money than anticipated was required to set up their testing laboratory. Brookhaven staff offered a good deal of assistance to NAHB and NAHB is still working closely with other laboratories to improve the technique.

### **5.7.3 Market Penetration**

Most users of the technique are researchers at utilities interested in air infiltration and indoor air quality issues. AIMS is seldom used by builders or building inspectors.

#### 5.7.4 Facilitating Factors

AIMS is less intrusive, time-consuming, and costly than earlier tracer gas infiltration measurement techniques, yet its accuracy can be nearly as high. Opportunities for testing in commercial buildings are largely untapped, and a vanishingly small percentage of residences has been tested. Blower door testing is more widespread than AIMS testing, but as noted above, the two techniques serve different but complementary functions. The National Institute of Standards and Technology is currently in the process of developing a protocol (ASTM/E-6) for testing with a generic version of AIMS. If approved, the ASTM/E-6 protocol will be a consensus standard for a proper and reproducible measurement procedure.

#### 5.7.5 Barriers to Further Penetration

To date, delays in receiving AIMS analysis results of several months or longer have been typical. In addition, analysis with gas chromatography is a complicated process and some users have received inaccurate results. The accuracy of AIMS is influenced by temperature, air mixing, and occupant activities. One of the key assumptions behind AIMS measurement is that the tracer gas is perfectly mixed and evenly distributed throughout the area. Since air flow within a house is seldom uniform, placement of AIMS monitors can strongly affect test results. Results also may be affected by the constancy of the emission rate, by how and where samples are taken, and by the length of the measurement period. Sherman (1987) suggests that inadequate mixing of gases may invalidate AIMS measurements and that the technique significantly underpredicts the average infiltration rates predicted by models.

### 5.7.6 Future Directions

The variety of potential sources for error in AIMS measurements suggests that further refinement may be needed before the technique will produce consistently accurate results. Thus, the AIMS techniques still has some technical problems and is in a very early stage of market penetration. DOE could aid in the commercialization of this innovation by sponsoring work that would improve the consistency and accuracy of results and reduce processing delays. At that point an information outreach program would be in order.

### 5.7.7 Sources of Information

#### Interviews

Russell Dietz, Brookhaven National Laboratory, Upton, New York, April 1988.

Jim Kolb, Oak Ridge National Laboratory, Oak Ridge, Tennessee, April 1988.

Robert Kedl, Oak Ridge National Laboratory, Oak Ridge, Tennessee, April 1988.

Andrew Persily, National Institute of Standards and Technology, Gaithersburg, Maryland, May 1988.

#### Documents

"Passive Infiltration Monitor." 1986. Energy Auditor and Retrofitter, p. 25, September/October.

du Pont, P. 1987. "The AIMS Monitor: Measuring Infiltration, Not Tightness," Energy Auditor and Retrofitter, January/February.

Sherman, M. H. 1987. "Analysis of Errors Associated with Passive Ventilation Measurement Techniques," LBL-23088 Preprint, Lawrence Berkeley Laboratory, Berkeley, California.

## 5.8 FOOTNOTES TO SECTION 5

<sup>1</sup>In the integral model, the unit was characterized by a heat pump and a water tank packaged as a single unit and a heat pump condensing coil immersed in the water tank. The retrofit unit consisted of: 1) a helix-shaped

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condenser to be screwed into the lower resistance element hole of an existing water tank, and 2) a separate compressor that stood apart from the water tank.



## 6. GUIDELINES FOR SELECTING A TECHNOLOGY TRANSFER STRATEGY

This section provides a general framework for DOE to use in designing technology transfer strategies for particular R&D projects. Questions of interest include: how often have various strategies been successfully used by OBCS, and under what circumstances is a particular technology transfer strategy appropriate?

Although our sample of innovations is small and not necessarily representative of all the successfully commercialized results of OBCS R&D programs, it does provide some preliminary insight into the questions noted above. This section also draws on findings from past studies.

### 6.1 HOW OFTEN IS EACH STRATEGY USED?

Figure 6.1 characterizes each of the five fully-commercialized case study innovations in terms of the strategies that were used to commercialize them. Figure 6.2 does the same for the seven semi-commercialized innovations. One strategy dominates the more successful case studies - contracting R&D to industrial partners - but other strategies have also led to full commercialization. No single strategy dominates the seven semi-commercialized innovations.

In total, six of the 12 innovations were commercialized through R&D contracting to industrial partners, and in five of these six instances, the industrial partner was a small firm. Major manufacturers were typically sought as partners, but did not respond. Section 7.2 describes in greater detail the scenario of events that characterizes the contracting approach.

Generating end-user demand was a primary strategy used to achieve the full market penetration of two innovations studied here. With the super-



	<b>CONTRACTING R&amp;D TO INDUSTRIAL PARTNERS</b>	<b>INFLUENCING KEY DECISION- MAKERS</b>	<b>WORKING WITH BROKER ORGANIZATIONS</b>	<b>GENERATING END-USER DEMAND</b>
Low-E Windows	<b>Subcontracts to Small Firms</b>	Roundtable & Private Meetings with Key Actors	LBL Presentations at Meetings & Trade Shows	News Releases
Solid-State Ballast	<b>Subcontracts to Small Firms</b>			
Supermarket Refrigeration Compressor System	<b>Subcontract to Small Firm</b>		Involvement of the Food Marketing Institute	<b>Distribution of Report to Every Major Supermarket Chain</b>
Flame Retention Head Oil Burner		<b>Training Program for Service Personnel</b>		<b>Booklets &amp; Fact Sheets Distributed Through Existing Networks</b>
DOE-2		<b>Software marketed privately and through NESC and NTIS</b>	Use in ASHRAE and other Standards and Codes	

**Bold Lettering Represents the Primary Strategies**

**Fig. 6.1. The technology transfer strategies applied to the fully-commercialized innovations. (Note: neither industrial consortia nor licensing strategies are used in the 12 case studies.)**

market refrigeration compressor system, DOE sought to generate interest by providing supermarket chains with credible performance data. For the flame retention head oil burner, consumer demand was stimulated through the distribution of fact sheets. In several other cases, this "market pull" strategy was employed as a supplement to other approaches.

Trade, professional, and regulatory organizations have been involved as major players in six of the case studies. In two instances, a single trade association played an instrumental role - RIMA in the case of radiant barriers, and the Food Marketing Institute for the supermarket refrigeration compressor system.

	<b>CONTRACTING R&amp;D TO INDUSTRIAL PARTNERS</b>	<b>INFLUENCING KEY DECISION- MAKERS</b>	<b>WORKING WITH BROKER ORGANIZATIONS</b>	<b>GENERATING END-USER DEMAND</b>
<b>Dielectric Coating</b>	Subcontract to Large Firm (OCLI)	Exclusive License between Omega Energy and OCLI		
<b>Heat Pump Water Heater</b>	Subcontract to Small Firm	Contacts with Electric Utilities	Articles in Popular and Trade Magazines	Fact Sheets
<b>Radiant Barriers</b>			Involvement of the Reflective Insu- lation Manufac- turers Association	
<b>Wisconsin Audit</b>		Further R&D and Marketing by Wisconsin Energy Conservation Corp.		
<b>CIRA</b>		Marketing of a version of CIRA (EEDO) by Burt Hill Kosar Rittelmann		
<b>Hotbox Method</b>	Development work by CTL & NIST		ASHRAE Handbook	Information for Contractors, Builders, and Architects
<b>Tracer Gas</b>		Technology marketed by NAHB through an exclusive license with AIMS		

Bold lettering represents the primary strategy(ies).

**Fig. 6.2. The technology transfer strategies applied to the semi-commercialized innovations. (Note: neither industrial consortia nor licensing strategies are used in the 12 case studies.)**

Efforts to influence key decision-makers have been used to promote eight innovations. All three software packages have relied upon this strategy, by placing the software in the hands of a key public agency or private firm to develop a distribution system.

None of the case studies involved an industrial consortium or licensing from DOE or a national laboratory to industry. An informal inventory of OBCS technology transfer activities in 1986 and 1987 did not uncover a single instance of these strategies. The cost of establishing industry consortia is probably a major deterrent to the industrial consortium strategy. Another stumbling block is the tendency for consortia to disintegrate over time. Patent policies and procedures, in turn, have made it difficult for DOE laboratories to obtain patent waivers and, therefore, the ability to license technologies. As these procedures become more expeditious, licensing may become a valuable strategy for OBCS. Recent changes in patent policies could potentially expedite the move of products to the marketplace, but much depends on implementation.

## **6.2 WHEN IS EACH STRATEGY MOST APPROPRIATE?**

There are many factors that affect the appropriateness of one technology transfer strategy over another. The nature of the R&D results being transferred, the potential applications, the producer and consumer markets, existing barriers to adoption and use, and DOE's goals and resources are among the factors that should be considered. These factors are discussed below. It should be noted at the outset, however, that the total context must be considered when designing a technology transfer strategy; the role of each factor cannot be thoroughly understood in isolation from the others. As will become clear, it is sometimes difficult to quantify and measure key factors, which inhibits the development and application of general rules.

### 6.2.1 Nature of the R&D

During the early, exploratory stages of a research program, when technical uncertainties are great and market opportunities are unclear, collaboration with a trade or professional association, or support of an industrial consortium are both appropriate technology transfer strategies (Fig. 6.3). Risks are often too great to gain the participation of a single industrial partner in a joint venture or cost-shared research. DOE's exploratory R&D programs often involve research conducted at national laboratories and universities. When breakthroughs occur as the result of such research, and when potential markets are identifiable, licensing enables private companies to develop the final products to meet the needs of their intended markets. Several of our case study innovations were initiated by DOE

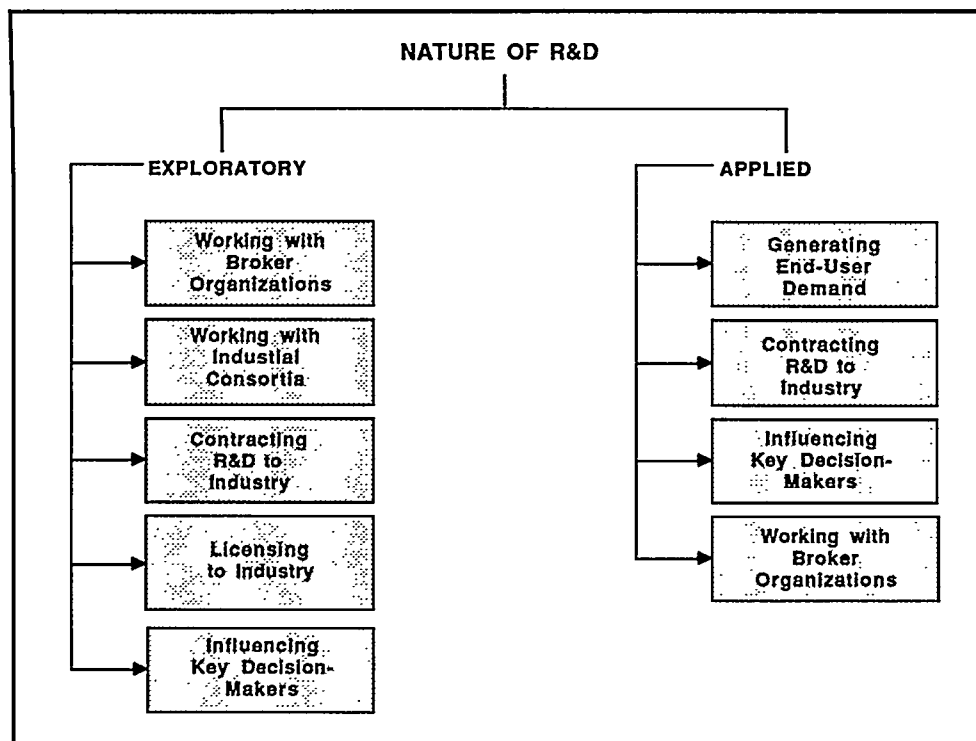


Fig. 6.3. Strategies for different types of R&D.

as exploratory R&D projects, but the initial phases of contracted research were product-oriented and not of a basic nature (e.g., solid-state ballasts, low-E windows, and the heat pump water heater).

As a technology matures and the R&D moves toward an applied phase, the technical risks are typically reduced by demonstrating the feasibility of the innovation or by learning through doing. However, because the technology has not been completely adapted to industrial applications, a large element of uncertainty remains in the area of advanced engineering development. At the same time, the market potential should begin to clarify. If the technological and market opportunities appear large enough and the potential returns appear to be promising, individual companies would become more willing to make a strong commitment to further develop the technology. At this stage, working with industrial partners is a more appropriate strategy. Also useful is influencing key decision-makers and trade and professional organizations.

Generating end-user demand is generally inappropriate during exploratory research because at this stage the message for end-users is usually unclear. In our case studies, the supermarket refrigeration system and the flame retention head oil burner were both effectively transferred through end-user outreach, and they were relatively mature technologies when the information programs began.

### **6.2.2 Nature of the Technology: Product vs Process**

According to Kamien and Schwartz (1982), "Process innovations are technical advances that reduce the cost of producing existing products, whereas product innovations involve development of newer improved products."<sup>1</sup> OBCS innovations that are "process" oriented include the Hotbox

method and design and decision tools that improve building practice (e.g., audit procedures such as CIRA and the Wisconsin audit and design software packages such as DOE-2). Influencing key decision-makers is the strategy used in these process-oriented case studies. Research of this nature needs the attention of the private sector but would probably not be conducted or widely disseminated without public support. A variety of strategies could be appropriate (Fig. 6.4).

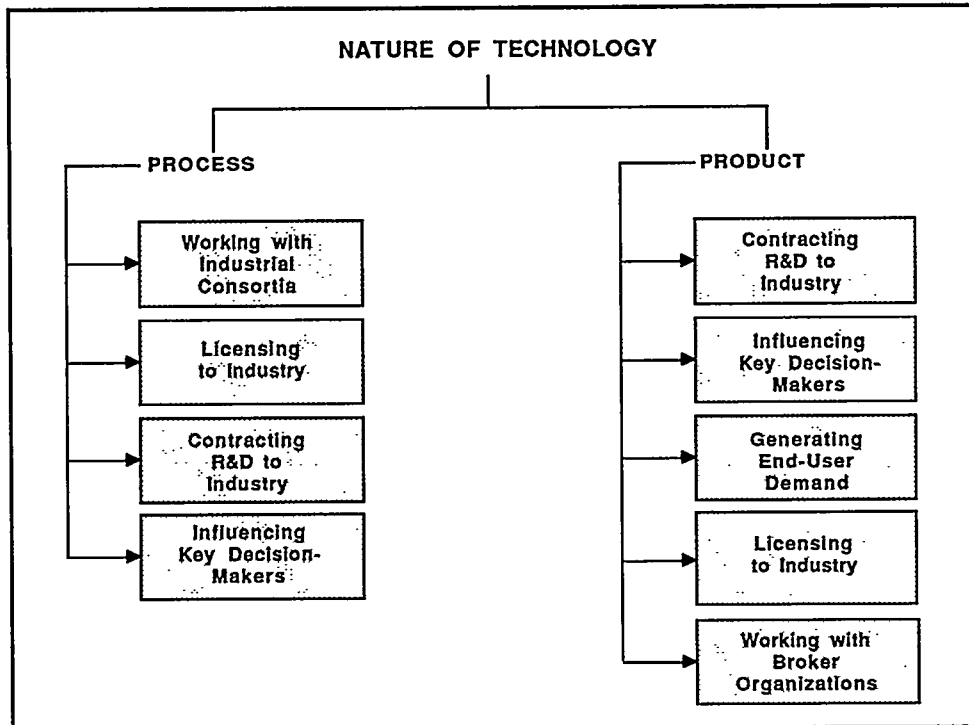


Fig. 6.4. Strategies for different types of technologies.

The primary strategies for product innovations (such as low-E windows and the solid-state ballast) range from contracting R&D to industrial partners

to generating end-user demand. Several of the product innovations also involved process issues such as complex installation and maintenance procedures (e.g., the heat pump water heater, flame retention head oil burner, and microprocessor controlled refrigeration systems). In addition to contracting R&D to industrial partners in these cases, DOE undertook outreach activities to inform practitioners and subsidized the adoption process through training and education.

### 6.2.3 Complexity of the R&D Results

Complex technologies generally have high adoption costs and are therefore more difficult to establish in the marketplace. They are also more difficult to imitate, providing the initial innovating firm with the protection against competitors needed to make a licensing approach valuable.

Several of the innovations studied here are complex both in terms of understanding and use (e.g., the compressor system for supermarket refrigeration). For all the software case studies, the complexities are limited primarily to the internal algorithms - they are relatively simple to use. The radiant barrier is comparatively simple in all aspects: manufacture, use, and understanding.

Influencing key decision-makers and generating end-user demand appear to be particularly relevant for complex innovations because of the high adoption costs. They are less applicable to simple innovations as a subsidy for adoption, but may be important where credible, third-party information is needed about product performance (as with radiant barriers). Contracting R&D to industrial partners dominated as the primary strategy in the case of our more complex technologies, whereas influencing key decision-makers was used most frequently in the less complex cases (Fig. 6.5).

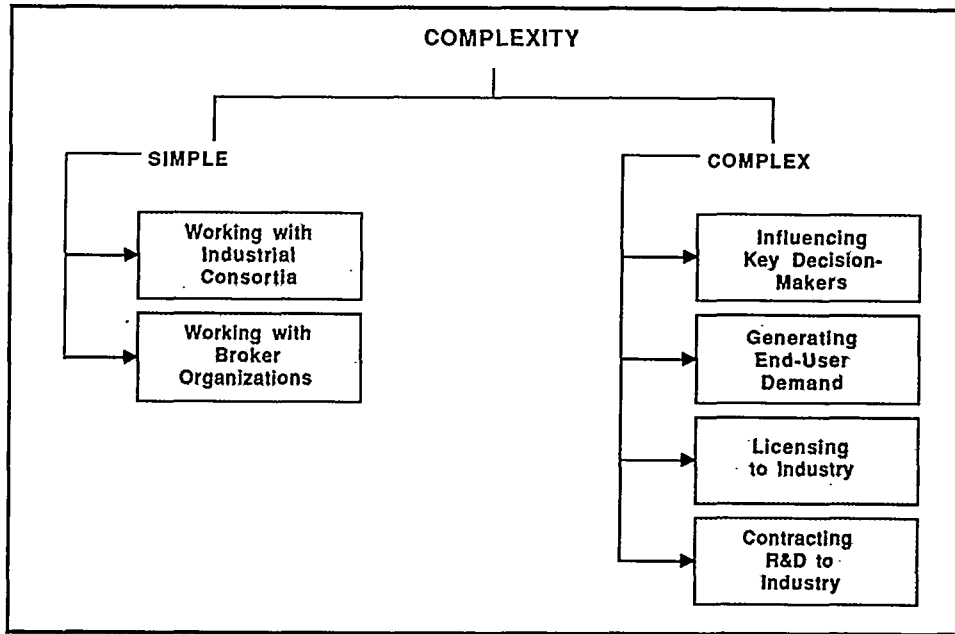


Fig. 6.5. Strategies for R&D results of varying complexity.

#### 6.2.4 Breadth of Applications and Diversity of End-Users

R&D with broad technological applications and diverse potential markets, if conducted through contracts with a single industrial partner, may limit the ultimate availability and use of the results. Industrial consortia, trade and professional associations, and key decision-makers representing the diversity of applications would appear to be more appropriate vehicles for conducting and disseminating the results. Where the results have broad applications but are proprietary, a nonexclusive licensing approach may be appropriate, allowing several or many firms to gain access to the technology.

For innovations with a narrow range of potential applications, contracting R&D to an industrial partner, working with a trade association, or exclusive licensing would appear to be appropriate (Fig. 6.6).

The breadth of applications and diversity of end-users often evolves over the course of an R&D effort. For instance, as R&D progresses from exploratory



to applied research, potential applications often become clearer and narrower. On the other hand, as technologies mature they often develop potential for spin-off applications as understanding of the technology and its alternative uses grow, causing a transition from narrow to broader end-use audiences. This was the case for DOE-2 which now has an expansive range of beneficiaries. Thus, over time the approach to technology transfer may need to change.

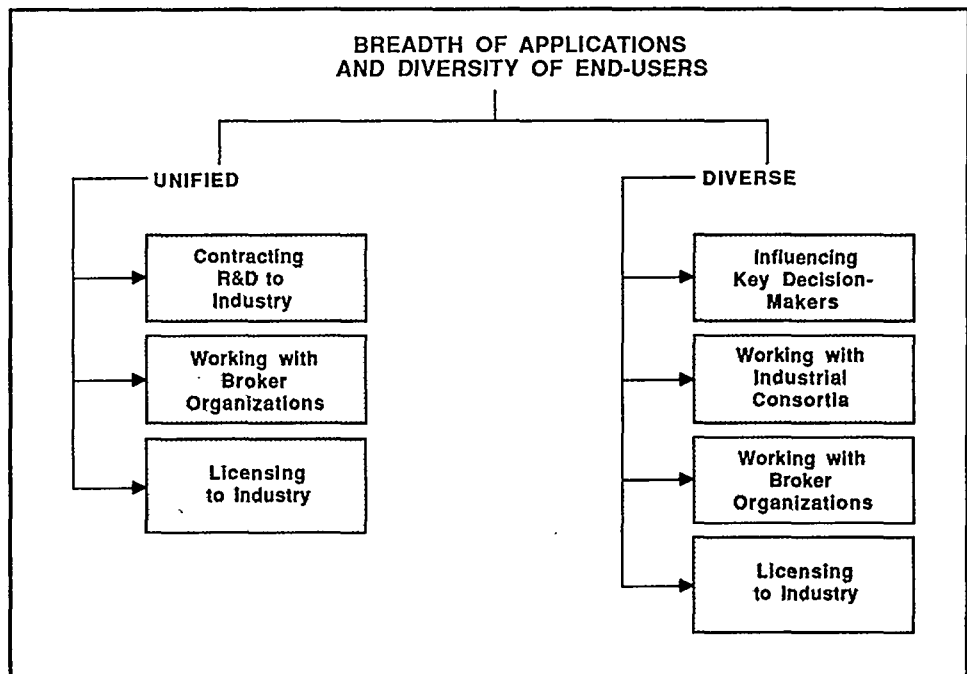


Fig. 6.6. Strategies for applications of varying breadth.

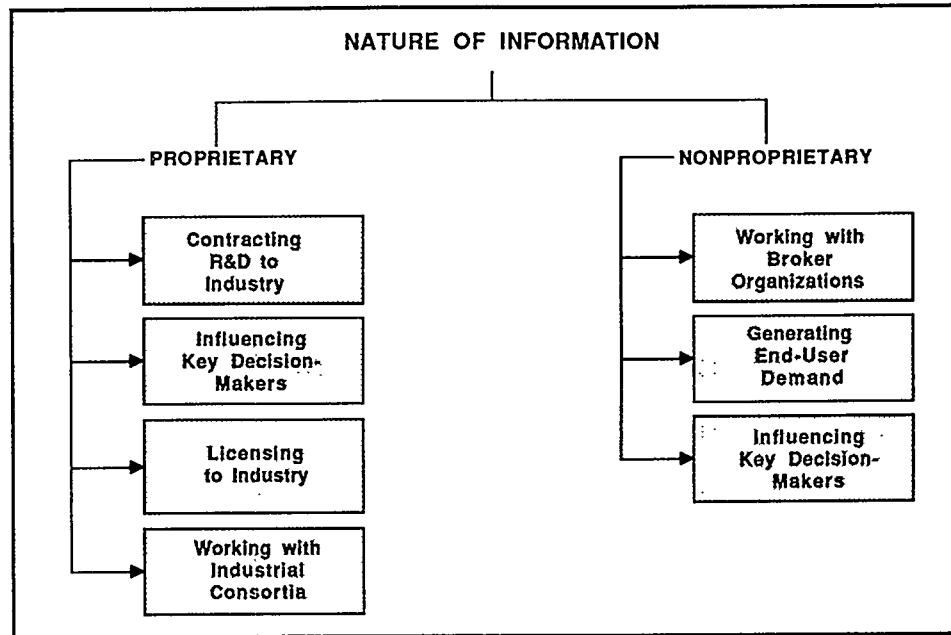
Most of our case studies are so new that spinoff applications have not had time to crystallize. They may never have the time in markets experiencing rapid technological progress, as with CIRA and other computer software. Nevertheless, the audiences for most of the innovations do contain

distinguishable submarkets. The heat pump water heater and low-E windows, for instance, are used in both the residential and commercial sectors. Since the same manufacturers tend to serve all the submarkets, contracting R&D to single industrial partners and working with individual trade associations were effective approaches.

#### **6.2.5 Nature of the Information: Proprietary vs Nonproprietary**

Proprietary information is said to exist when the possessor of the information can prevent others from copying it without permission. Most developments from OBCS-supported research are nonproprietary. Indeed, more than half of our 12 case study innovations are unprotected by patents or copyrights.

Where patents are involved, it is not always clear that the information can be protected, due to reverse engineering and industrial spying. Many of our industrial contacts indicated that patents were not important in their product lines because of these protection problems, and over time, information tends to become less proprietary as rivals invent around patents. Nevertheless, patents and copyrights were closely guarded and influential in several of our case studies: low-E windows, solid-state ballasts, the Wisconsin audit, and tracer gas testing. The most successful of these involved contracting R&D to industrial partners, while the Wisconsin audit and tracer gas were promoted by "key decision-makers." In the future, OBCS should consider licensing as a technology transfer strategy when R&D results are proprietary. Where the nature of R&D is proprietary, dealing with a unified entity such as contracting R&D to industry or an industrial consortium seems appropriate. On the other hand, in cases where property rights are hard to define, as with software, influential key decision-makers may be more effective (Fig. 6.7).



**Fig. 6.7. Strategies for proprietary vs nonproprietary information.**

#### 6.2.6 Nature of Industry

In highly concentrated industries (as is true for the HPWH), it is generally easy to identify leaders and thus industrial partners are feasible potential R&D contractors. Also, since the number of firms is limited, industry consortia may be easier to organize.

On the other hand, in low concentration industries (e.g., radiant barriers), leaders are more difficult to identify because each firm has only a small market share. The following approaches may be more applicable: influencing key decision-makers, generating end-user demand, and working with trade and professional associations. The reason for a large number of possible approaches under low concentration is that, when an industry is disaggregated, there is likely to be no definite entity like a trade or professional organization representing the whole industry or key decision-

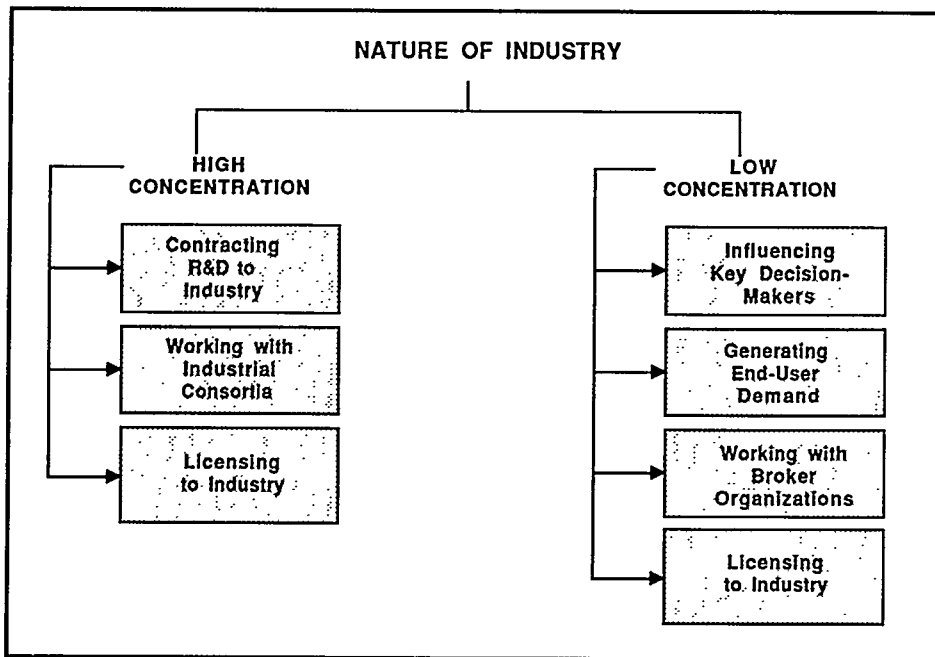


Fig. 6.8. Strategies for different industry structures.

makers. Therefore, a number of technology transfer approaches may be applicable depending on factors such as the nature of the technology and its complexity. Figure 6.8 shows the appropriate strategies for different industries.

Concentration ratios at the industry level were approximated for several of our case studies (see Table 3.1). The industrial partners approach is the only one represented among the four innovations in highly concentrated industries. These innovations are:

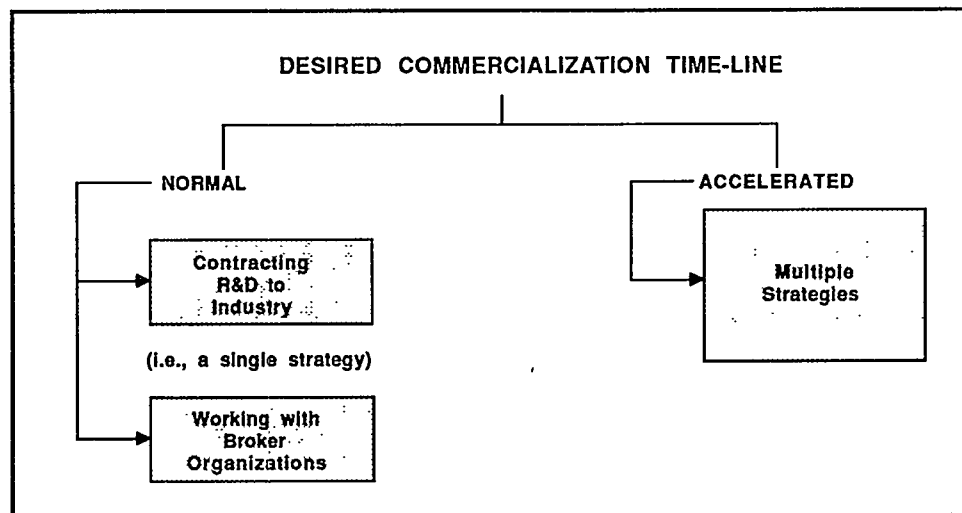
- supermarket refrigeration compressor systems,
- the heat pump water heater,
- low-emissivity coatings for windows, and
- solid-state ballasts for fluorescent lighting.

### 6.2.7 Desired Commercialization Time-Line

Commercialization time-lines vary widely depending, among other things, on the type of technology and the level of effort exerted to achieve commercialization. Easingwood (1988) developed a model to monitor the

diffusion of different innovations, and introduced seven classes of diffusion rates. The time taken to achieve 75% market penetration ranged from 3.5 years under rapid penetration to 28.4 years under low priority. In markets experiencing rapid technological change, there may never be enough time for a technology to achieve full penetration into a market.

If rapid acceleration of commercialization is not important, a single strategy may be more appropriate, such as contracting R&D to industrial partners, licensing, or working with industrial consortia or trade and professional associations. Multiple strategies need to be used if the objective is to strongly accelerate commercialization. However, there is a tradeoff between costs and speed. The amount of acceleration must also be balanced against the losses in areas from where resources must be withdrawn (Fig. 6.9).



**Fig. 6.9. Strategies for different desired time-lines.**

### 6.2.8 DOE Funds Available for Technology Transfer

DOE's technology transfer funds are typically very limited, as is true for most of the innovations studied here. Trade and professional associations have existing networks that can be leveraged when funds are limited. Licensing is also a low-cost approach when the DOE laboratory or university with title to a patent has the legal, marketing, and other resources available to support the effort. Industry consortia are also appropriate with limited funds, but only if they are pre-existing and do not need to be established. Influencing key decision-makers has been used in cases of software with limited resources (e.g., CIRA).

Occasionally DOE's technology transfer resources are considerable, as when a particular commercialization process is of extremely high priority. Multiple strategies may then be most appropriate (Fig. 6.10). Multi-pronged approaches were characteristic of the OBCS case study innovations that were commercialized in the 1970's, when technology transfer funds were more abundant.

Irrespective of the availability of funds, there is always a case for efficient utilization of resources.

### 6.3 FOOTNOTES TO SECTION 6

<sup>1</sup>The distinction between process and product innovations is essential for setting government R&D and technology transfer policy since these innovations may have different effects on market structure (see Lunn, 1986).

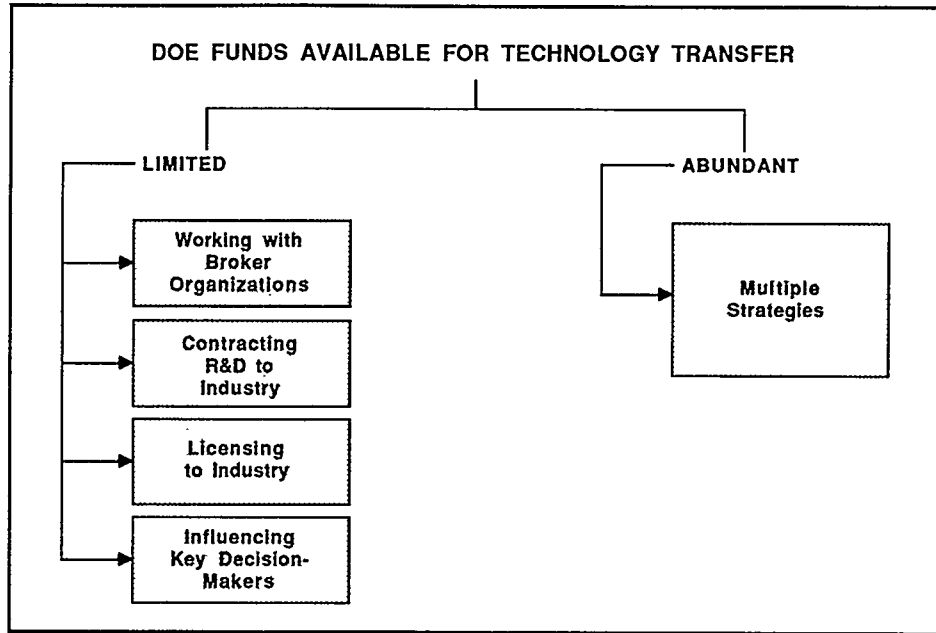


Fig. 6.10. Strategies based on available funds.

## 7. CONCLUSIONS AND RECOMMENDATIONS

### 7.1 THE FUTURE DOE ROLE VIS-A-VIS THE TWELVE INNOVATIONS

The 12 innovations studied in this report vary markedly in terms of the potential future role for DOE. In several instances, the private sector is well on its way to successfully commercializing the innovations, and while DOE might address several minor market imperfections, no major public effort is necessary. Such is the case for the flame retention head oil burner, the supermarket refrigeration compressor system, low-E windows, solid-state ballasts, dielectric coatings, DOE-2, and CIRA. Current market shares for these innovations are either significant or growing rapidly and there are no major technical or market-related problems to be resolved (Table 7.1). The future DOE role in these instances can be narrowly and specifically defined.

**Table 7.1. Summary of market penetration and energy savings for selected case study innovations<sup>a</sup>**

Innovation	Market share of new units in 1987 (%)	Cumulative energy saved by the year 2000 (in Quads)
Flame Retention Head Oil Burner	100 <sup>b</sup>	1.4
Supermarket Refrigeration Compressor System	54	n.a.
Low-E Windows	20	0.1
Solid-State Ballasts	3	0.5
Heat Pump Water Heater	less than 1	n.a.
Radiant Barriers	less than 1	n.a.

<sup>a</sup>"n.a." indicates that energy savings estimates are not available.

<sup>b</sup>100% of the residential market. Market penetration in the commercial sector is much smaller.



Flame retention head oil burners are now used in essentially all new, residential oil furnaces and boilers. But they are used in very few commercial buildings, despite the fact that their cost-effectiveness in certain segments of the commercial sector may be considerable. DOE should work in conjunction with manufacturers to determine the performance of FRHOBs in the commercial sector. If the economies of adoption are judged to be favorable, an information outreach program should be sponsored aimed at oil suppliers and state energy offices, primarily in New England.

Further penetration of the supermarket refrigeration compressor system (and the next generation innovation - variable speed compressors) could be encouraged through strengthening the service infrastructure that installs, repairs, and maintains these systems. Working with the Food Marketing Institute and major manufacturers of refrigeration systems, DOE should help establish a training program to upgrade the skills of refrigeration engineers.

For both low-E windows and solid-state ballasts, the market is growing rapidly and there do not appear to be any major obstacles to its further expansion. Greater public knowledge of both innovations could accelerate the diffusion process, however, and would be a low-cost, effective activity for DOE.

Market penetration of dielectric coatings is likely without significant further public support. DOE monitoring is nevertheless desirable just in case Omega Energy does not continue to experience rapid growth in sales.

DOE-2 has a mature and effective distribution system and has achieved widespread acceptance and use. Nevertheless, it is an evolutionary software program that may require small infusions of DOE support in order to keep it up-to-date.

CIRA also has a well developed distribution system and is experiencing good sales. With further technical work, usage could grow somewhat, but probably not dramatically.

Five of the semi-commercialized innovations have significant unresolved problems that inhibit full acceptance and use. The Hotbox method to test the performance of wall systems is now an established tool. Development of a standardized dynamic Hotbox test, however, would improve the quality and credibility of the performance data being generated, and would lower costs per Hotbox run. Greater dissemination of Hotbox results to contractors and builders would increase their utilization of Hotbox test results. End-users need to become more familiar with the results of Hotbox tests.

For the heat pump water heater, as with the supermarket refrigeration compressor system, inadequate training on the part of the service infrastructure (plumbers and HVAC service personnel) responsible for the installation, repair, and maintenance of water heaters hinders adoption. Encouraging major real estate developers to install HPWHs could result in the development of local expertise in maintenance and replacement. The generation of further end-use demand (particularly among innovators) might also "pull" the technology along.

The non-sophistication and cost effectiveness of radiant barriers makes it very promising as a means of saving energy in the South. To encourage its diffusion and to guard the public against fraud, DOE needs to widely disseminate both price and performance information. DOE should also examine the cost-effectiveness of radiant barriers in cold and moist climates.

Further technical development of the tracer gas testing procedure is needed to produce more consistently accurate results. DOE should review the

situation when the NAHB license with AIM, Inc., expires, to determine whether or not DOE should support this development work.

The Wisconsin audit's high cost to potential users is inhibiting its diffusion. DOE should enhance the current audit by including the analysis of cooling measures and then make the audit available at a less expensive price, perhaps through a carefully designed licensing strategy.

## **7.2 LESSONS LEARNED FOR FUTURE DOE TECHNOLOGY TRANSFER ACTIVITIES**

Of the six generic technology transfer strategies available to OBCS, one dominates as a route to successful commercialization, based on our small sample of case studies. Contracting R&D to industrial partners was by far the most commonly used strategy among the fully-commercialized innovations studied here. A common sequence of events (illustrated by the heat pump water heater, the supermarket refrigeration compressor system, low-E windows, and the solid-state ballast) is for a national laboratory to issue a Request for Proposals for prototype development in hope of attracting a major manufacturer who will cost share. Only small manufacturers (or small research firms with minimal manufacturing capabilities) respond. Through a subcontracting arrangement to the national laboratory, the selected small company is supported (with some cost-sharing) to develop a prototype. The national laboratory evaluates the prototype and either the laboratory or the small firm completes a market study. Field tests and demonstrations are conducted jointly by the laboratory and the small firm.

At this point the DOE involvement typically ends. The small firm that developed the prototype begins commercial production. After a few years, the innovation is then added to the product line of one or more major

manufacturers, either through the purchase of patent rights or through imitation.

In each of the four case studies that followed this pattern, interviews with industry spokespersons indicate that the DOE role was significant. Either the technology would not have been developed without DOE support, or at the very least the pace of technology development, market entry, and market penetration would have been significantly slower.

DOE had an opportunity to support the development of compact fluorescents using a similar strategy, but could not due to inadequate funding. The result is foreign domination of the compact fluorescent market. It is likely that the same fate would have beset solid-state ballasts if DOE had not provided R&D support. In the lighting industry there is little incentive for the major companies to conduct the R&D necessary to develop new technologies, especially if the innovation will require large capital investments. New products are likely to be duplicated by competitors at less cost than was paid by the innovating firm.

Despite the dominance of this one technology transfer strategy, three of the other strategies were shown in the case studies to be effective in specific situations - working with broker organizations, generating end-user demand, and influencing key decision-makers. While the remaining two strategies (involving industrial consortia and licensing) have not yet been used, they would appear to be appropriate under particular circumstances and should be included in the portfolio of alternatives considered by DOE program managers.

DOE's valuable role as a source of information about the performance of new technologies was illustrated throughout our case studies in conjunction with efforts to influence trade and professional associations, key decision-makers, and end-users. Public institutions like DOE are important sources of

information because of the lack of credibility associated with the claims of private firms.

DOE's ability to stimulate commercialization through a training program for service personnel was vividly illustrated in one case study. Examination of several other innovations suggests that inadequate training is a common and critical barrier to technological change in the buildings industry. Highly targeted training efforts supported by DOE and conducted in collaboration with trade associations and major manufacturers should be considered.

### **7.3 SUGGESTIONS FOR FUTURE RESEARCH**

Additional case studies are needed to provide a better empirical basis for assessing the effectiveness of different DOE technology transfer strategies. In particular, much could be learned from case studies of technologies that have failed to achieve commercial success. In addition, future research should explicitly examine end-user demand for energy-efficient buildings innovations. This report has primarily examined "technology-push" approaches to technology transfer; "market-pull" warrants equal attention.

### **7.4 CONCLUSIONS**

Energy-saving buildings innovations have a major potential role to play in improving energy security and international competitiveness. We have examined the process by which 12 technologies sponsored by the U.S. Department of Energy were successfully commercialized, and have suggested strategies for promoting future successes. The tentative lessons offered here provide insight into the complex innovation process and the importance of public support for R&D and technology transfer.

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