Transforming the Market for Residential Windows: Design Considerations for DOE's Efficient Window Collaborative

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Market adoption of recent, commercially available technological advances that improve the energy performance of windows will lead to immediate economic and energy savings benefits to the nation. This paper is a scoping study intended to inform the design of a major DOE initiative to accelerate market adoption of these windows in the residential sector. We describe the structure of the U.S. residential window market and the interests of the various market players. We then briefly review five recent market transformation initiatives. Finally, we summarize our findings in a list of considerations we believe will be important for the DOE's initiative to transform the U.S. residential window market.

INTRODUCTION

The window is a defining feature of buildings. Traditionally, it has been a large and unavoidable contributor to space-conditioning energy requirements. Commercially available technological improvements can reduce these requirements dramatically (Arasteh 1995). The rate at which these technologies penetrate the market for residential windows will have measurable impacts on national energy use (Frost et al. 1996). In order to secure the substantial national economic and environmental benefits that would result from more rapid market adoption of these technologies, DOE has initiated the Efficient Window Collaborative (EWC).

The EWC is a voluntary partnership of all players in the residential window market, ranging from glass and window manufacturers to utilities and state and local building code officials. The goal of the EWC is to double the market share of highly energy-efficient windows by 2005. To meet this goal, the EWC will foster a variety of initiatives to transform the market for residential windows.

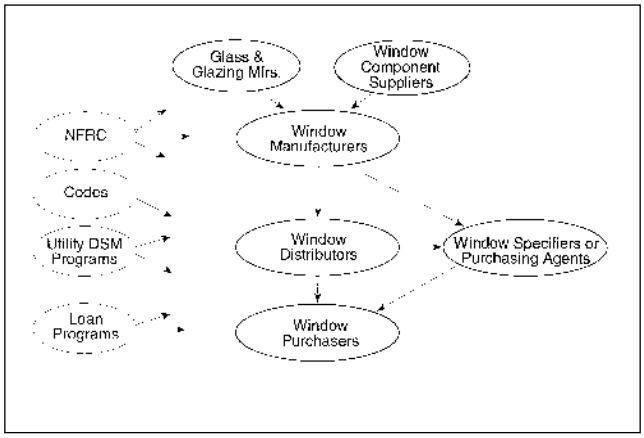
This paper is a scoping study to identify program design issues for future EWC initiatives. It is not a proposal for any particular initiative, but is instead an effort to identify key issues that will be useful in guiding the Collaborative's discussions leading to specific initiatives.

This paper is based on and organized around two key premises. First, as described in the next section of the paper, a successful initiative must recognize and take advantage of the unique features of today's residential window markets. This requires an appreciation for the nature of the business of making, selling, and installing windows, focussing on the financial interests of the various market players. Second, as described in the second section following this introduction, the 1990s have already witnessed several so-called ''market transformation'' initiatives for energy-efficient technologies other than (but sometimes including) windows (Nadel & Geller 1994). We review several of these initiatives in order to extract the important lessons they hold for future initiatives. In the final section of the paper, we synthesize these findings into a series of design recommendations for future EWC initiatives.

THE MARKET FOR RESIDENTIAL WINDOWS

The market for residential window can be thought of as consisting of six primary market players (see Figure 1): (1) Glass and glazing manufacturers, including float glass and plastic manufacturers, glazing coaters, and those who assemble insulating glass products from these substrates; (2) Window component manufacturers, the most important of which are vinyl and aluminum lineal extruders; (3) Window manufacturers who assemble finished windows out of glass (insulating, tinted, coated, or standard) and other components; (4) Window distributors, including independent building material dealers and sales representatives of window manu-

Figure 1. *Structure of U.S. Residential Window Industry*



facturers; (5) Window specifiers or purchasing agents, such as architects and engineers, remodeling contractors, and to some extent custom home builders; and, finally, (6) Window purchasers, including production home builders, home owners, and rental property owners. Overlaid across these players are a variety of additional stakeholders, including state and local building code and enforcement agencies, industry trade groups and organizations (including, for example, the National Fenestration Rating Council or NFRC), and utility DSM and loan programs for residential new construction and retrofits.

Glass Manufacturers

Windows are assembled from two major components, glass and framing materials. Glass is purchased from glass manufacturers who also sell to curtain wall and storefront fabricators in the commercial building sector, and to mirror and automotive glass fabricators. The U.S. glass manufacturing industry is highly concentrated and has been very stable. The most recent entrant two years ago entered an industry that had consisted of only five manufacturers for over 30 years. The glass market is essentially self-contained and national in scope, although there are many international business alliances and exchanges of technological know-how. Glass imports, predominantly from Canadian glass manufacturers (some of whom are owned by U.S. manufacturers), account for a small fraction of overall sales.

All six manufacturers produce standard glass, tinted glass, and glass coated with low-emissivity (low-e) films. They have an interest in low-e glass to the extent that it can be sold for a greater profit, as a value-added product, or increase their market share. However, all manufacturers also make un-coated glass products and pricing in the industry is very competitive; hence, the relative profitability of the two products is not well-known, although one would expect value-added products would be more profitable. Float glass production lines run continuously and are only infrequently shut-down for repairs and upgrades; the entire line is replaced at the end of its useful life (on the order of about 15 years).

Insulating glass (IG) manufacturers take coated glass and assemble it into a sealed unit, called ''insulating glass.'' In the early 1970s, most windows were single glazed units, with IG capturing only about 20% of the market, mainly in northern tier states. Today, the great majority of windows sold (~90%) use insulating glass. Some IG manufacturers also make and coat their own glass, some coat purchased glass, still others work only with purchased coated glass. IG units are sometimes filled with inert gases (such as argon or krypton) to further reduce thermal conductance. IG manufacturers have a keen interest in increasing the market adoption for more energy-efficient windows (i.e., windows with coatings and gas fills).

Window Component Manufacturers

Windows have been traditionally framed with either wood, vinyl, or aluminum. Today, there are also fiberglass and engineered thermoplastic frames, as well as composites, such as vinyl- or aluminum-clad wood. Wood frames are usually milled by the window manufacturer. Vinyl and aluminum ''profiles'' are usually purchased from independent firms, called lineal extruders, who do not make windows. Since vinyl and fiberglass (and wood) have superior thermal properties compared to aluminum, vinyl and fiberglass lineal extruders have a keen interest in expanding the market for energy-efficient windows.

Manufacturing multi-paned windows involves the use of spacers to hold the panes of glass apart and, in the case of IG, sealants to maintain air/moisture-tightness. The primary variation among spacers relates to their ability to minimize thermal short-circuits, which if un-checked increase heat loss and lead to additional condensation on the room-side surface. Traditional aluminum spacers are being replaced by a variety of ''warm-edge'' spacers with lower conductance. These spacers are found mostly in higher efficiency windows. However, most manufacturers offer both standard and premium grade spacers, so their interest in energy-efficient windows (like that of glass manufacturers) depends in part on the relative mark-ups their products are able to command. They, of course, are also interested in promoting the condensation-minimization benefits of their warm-edge products. Failed seals are the primary source of failure for IG units. However, sealant manufacturers argue that the design of IG units and the degree of quality control exercised in the production process are more important than the type of sealant used.

Window Manufacturers

Manufacturing windows involves assembling insulating glass units, or individual glazings into a frame with associated hardware (hinges, latches, etc.). Window manufacturers can be roughly divided by the choice of framing material. In the U.S., wood has been historically the premium grade framing material. Wood has excellent thermal properties, but also commands the highest price. Aluminum is typically lower in price and has poorer thermal properties (although the thermal properties of aluminum frames can be improved with thermal breaks). For many years, the industry was organized around either wood or aluminum window manufacturers, resulting in two rival industry trade groups, the National Wood Window and Door Association or NWWDA and the (originally) Aluminum Architectural Manufacturers Association or AAMA.

The use of vinyl as a framing material is comparatively recent. Vinyl has gained market share, initially in the window

replacement market, at the expense of aluminum and to a lesser extent wood, spurred in part by concerns about energy costs and building energy codes. Vinyl has thermal properties comparable to wood, but costs comparable to aluminum. Building energy codes have been largely responsible for the conversion by aluminum window manufacturers to vinyl windows. (Aluminum window manufacturers can relatively easily re-tool their manufacturing processes to produce vinyl windows.) The significance of this shift in framing material is reflected by the change in the name of the industry trade group to the American Architectural Manufacturers Association. Today vinyl windows are manufactured both by traditional wood and aluminum window manufacturers. Some wood window manufacturers now offer products that combine wood with vinyl in a single frame. Both wood and vinyl window manufacturers, as well as manufacturers of aluminum windows with thermal breaks, have an interest in expanding the market for energy-efficient windows.

The window manufacturing industry is extremely diverse. There are a small number of large, national firms, which collectively account for perhaps 20-30% percent of window sales. There are also a moderate number of medium-size regional firms accounting for 30-50% of sales. Finally, there is a huge number ($>$2000) of small firms with highly localized markets, but collectively a comparatively small market share ($<$20%).

Competition among window manufacturers is fierce. There is substantial entry and exit among smaller firms with competition tending to center (naturally) around price, features, and product quality (see discussion below on window purchasers). Historically, energy-efficient windows have been offered primarily by the larger regional and national firms, in part because they are in a better position to underwrite the additional start-up costs associated with manufacturing energy-efficient windows. Given the intense price competition among smaller manufacturers, gaining the expertise to manufacturer and raising the capital necessary for investment in energy-efficiency window-making capacity is more difficult (although, as mentioned earlier, the conversion by aluminum window manufacturers to vinyl frames has been straightforward).

Window Distributors

Residential windows are sold through two main distribution channels, building material distributors, which typically offer windows from more than one manufacturer, and window manufacturer's sales representatives, which sell only one manufacturer's windows. Neither type of distributor sells energy-efficient windows exclusively.

Building material distributors consist of national chains, regional chains, and individual outlets. The windows they sell include both those of national manufacturers, as well as those of local or regional manufacturers. The windows are generally purchased by custom home builders, remodelers, and home owners.

There are two types of exclusive window manufacturer's sales agents, those representing national or regional window manufacturers, and those representing individual, local window manufacturers (e.g., windows are both manufactured and sold at the same site). The windows sold by exclusive sales agents are generally purchased by production home builders. Hence, the volume of windows sold per customer is generally higher than that for building material distributors.

The price premium for energy-efficient windows depends on local conditions and is complicated by many issues (e.g., framing material, window type, brand name, purchase volume). Market share is a useful indicator: In the Pacific Northwest, where energy-efficient windows command a fairly high market share, the retail price premium is on the order of $1-3/square foot of window (Lubliner 1994). In other parts of the country where the market share for energy-efficient windows is lower, the retail price premium can be as high at $10/square foot. Selling more energy-efficient windows is of interest to distributors to the extent they can profit from the mark-up on the manufacturer's price. Since the manufacturer's price premium is only on the order of $0.50–1.00/square foot for energy-efficient glass, higher retail price premiums reflect the additional cost of handling special orders, such as shipping, inventory, and handling costs, as well as no doubt some amount of profiteering by the retailers selling premium windows.

Window Purchasers (including specifiers and purchasing agents)

Over the last ten years, as new housing starts have declined, window purchases for remodeling have overtaken window purchases for new construction. Today, slightly more than half of all residential windows are sold to contractors or home owners for remodeling existing homes. Windows sold for new construction are dominated by sales to production, as opposed to custom, home builders. Interest in energy-efficient windows among window purchasers can be directly related to the business, aesthetic, and thermal comfort preferences of each class of purchaser, as affected by their personal experience and general knowledge regarding energy-efficient windows. These insights are not new and have been addressed in numerous studies of the market barriers to energy efficiency (See Golove & Eto 1996 for a recent survey of these issues).

Contractors, custom builders, and architects, acting as agents for home owners, often have a tremendous influence on the selection of windows for remodeling or the new home.

However, their knowledge of the energy-efficiency and thermal comfort properties of energy-efficient windows (and of related issues associated with installing windows properly) may be limited. If they are working on a labor plus materials basis or fee basis, their choice of window will not necessarily be constrained by the higher initial cost of energy-efficient windows. In this situation, the home owner should, in principle, be the final arbiter in the window purchase decision. On the other hand, the choices offered to the home owner are likely to be limited to those the agent is familiar with installing or has some monetary incentive to install (possibly offered by the window distributor). Utility DSM programs have succeeded in offering financial incentives to custom builders to install energy-efficient windows in new construction.

In a remodeling or custom-build situation, the home owner will typically be motivated by aesthetic, operational, and thermal comfort concerns regarding a window. Information to inform their decision can come from a variety of sources, including the architect, contractor or custom home builder, the window distributor, word-of-mouth, and any independent research the home owner may have undertaken. Energy-efficiency has only recently been added to the calculus of this decision. The cost premium associated with energy-efficient windows is a major deterrent to increased purchases. Utility DSM programs have been successful in addressing this barrier through incentives. However, utility programs have historically only targeted new construction.

Production builders are motivated by the profit associated with building homes at lowest cost consistent with a marketable product. They are weakly interested in the energy-operating costs and physical comfort of the home, except to the extent that it enhances or at least does not detract from the marketability of the home. They are highly motivated by windows that look good, cost little, are easy to install, and do not require call-backs. Energy-efficient windows can meet aesthetic criteria, but cost more, and require somewhat more careful installation to maximize their energy-saving potential. Utility DSM programs, which can in principle off-set some of the first-cost premium, have not historically been successful in enlisting production builders (Vine 1995). Instead, building codes have been the most important driving force for increasing the energy efficiency of windows in new construction.

LESSONS LEARNED FROM RECENT MARKET TRANSFORMATION INITIATIVES

Market transformation is an ill-defined term that has come to mean many things to many people. For some, it refers to DSM programs that promise greater savings at lower cost. For others it refers to influencing energy-efficient technology markets upstream of the ultimate consumer. For still others, it refers to lasting, not temporary reductions in market barriers to energy efficiency. Our goal is not to add to this discussion. Instead, we will briefly review five well-publicized programs that have been held up as models for future market transformation programs: (1) the Super-Efficient Refrigerator Program (SERP) implemented in the US; (2) the Energy-Efficient Refrigerator Procurement (EERP) implemented in Sweden; (3) the Energy-Efficient Window Procurement (EERP) also implemented in Sweden; (4) the Model Conservation Standards (MCS) Program implemented in the Pacific Northwest; and (5) the Superwindow Demonstration Project also implemented in the Pacific Northwest. Our review is not comprehensive nor is it intended to replace or update existing published evaluations. Instead, we seek to learn the important lessons they may hold for future efforts to accelerate the market adoption of energy-efficient windows.

Super-Efficient Refrigerator Program

The SERP program was one of the first to be touted as a market transformation program (see Feist et al. 1994). The program involved a pooled set of funds from utilities ($30 million) offered through a competitive solicitation to a manufacturer (Whirlpool was the winner) that would produce a premium grade refrigerator more efficient than any currently on the market. In addition, the utilities agreed to promote the refrigerator through DSM rebate programs whose design would be coordinated centrally and thereby made consistent across participating utilities. The rationale for the program was a perception that manufacturers faced too much market risk to justify the R&D and production investments required to bring new, more efficient products to the market.

No official evaluation of the SERP program has been published but anecdotal evidence suggests that it has not been successful in transforming the market for energy-efficient refrigerators. First, preliminary signs indicate that Whirlpool intends to discontinue the product following the end of the program. Higher initial costs compared to other, almost as efficient, models, coupled with the tremendous variety of features differentiating models, which complicates cost comparisons, have led to only modest sales within the service territories of the participating utilities offering rebates and even fewer sales in service territories where rebates are not offered. Second, no other manufacturers appear to be offering similarly high-efficiency models. Third, while the program demonstrated that refrigerators far more efficient than the current federal standard could be built, recent moratoriums on standards suggest that it may be some time before new refrigerator standards are promulgated.

A critical short-coming of the SERP program appears to have been the inability of the program to address fundamental aspects of consumers' reluctance to purchase the more efficient units. A rebate lowers first cost immediately, but may or may not overcome other related barriers that influence a consumer's decision to purchase energy-efficient products. These related barriers include the risk associated with the performance of the refrigerator not well-known to the market and in some cases lack of the basic knowledge that, because of its higher efficiency, the operating costs of the SERP refrigerator would be substantially lower than those of its competitors. Unless the lower price, backed by a utility's implicit certification (or endorsement) of the energy efficiency of the product leads to a lasting (rather than temporary) reduction in the market barriers facing the adoption of a product, removal of the discount will likely lead to a return to purchasing patterns prior to the program. The inability to achieve these lasting reductions in the minds of consumers appears to be the logic underlying Whirlpool's decision to withdraw the SERP refrigerator from the market.

Much also appears to have been complicated by the competitive pressures and market share considerations underlying the pricing strategy adopted by the manufacturers of SERP and other less energy-efficient refrigerators, as well as the existence of utility rebates for non-SERP units. There is also anecdotal evidence that SERP units were not aggressively marketed by retailers who instead promoted non-SERP units that were more profitable to sell. Clearly there were a number of other factors besides price and energy performance driving the purchase of these products. These undoubtedly include non-energy performance features (size, other amenities, and configuration), as well as the retailer's business conditions (mark-up or profitability of the units, stocking and inventory issues, and the knowledge, credibility, and sales incentives of the retail sales staff).

Energy-Efficient Refrigerator Procurement

The EERP involved a competition similar to the SERP in which a pool of funds was offered to manufacturers who competitively bid an efficient product to meet a small but now growing market niche in the Swedish refrigerator market for small (by U.S. standards) combination refrigerator-freezers (Nilsson 1992). The offer consisted of a guarantee to purchase a large number of winning units through an aggregation of large purchasers of refrigerators.

Unlike SERP, initial reports suggest EERP has successfully transformed the market for refrigerator-freezers in Sweden. Sales of the winning unit are up and extend well beyond the units accounted for by the original aggregation of bulk purchasers. Other manufacturers now offer comparable units.

EERP was able to take advantage of three unique features of the Swedish market for refrigerator/freezers. First, the participants in the procurement were the owners or landlords for large residential rental housing units, which they equip with refrigerator/freezers. The procurement participants account for 80% of purchases of this type of refrigerator made by this class of purchasers (i.e., apart from individual purchasers). The participants were thus able to guarantee the winning manufacturer a significant share of the market for refrigerator/freezers. The utilities participating in SERP could only guarantee consistent promotion and rebate levels for SERP units, not sales.

Second, the procurement appears to have been successful in lowering market barriers traditionally thought to inhibit landlords from making energy-efficient equipment purchases whose energy bills are paid for by tenants. It did this by taking advantage of the participant's impending need to replace existing units in residences, concerns regarding the phase-out of CFCs, and interest in being recognized publicly for the pro-environmental implications of their decision to participate.

Third, the procurement targeted an appliance that currently had little or no market share (larger refrigerator/freezers), but that was expected to be increasingly popular among Swedish purchasers. Thus, the procurement was able to add energy efficiency at an early stage of the market introduction of new type of appliance. In doing so, it established a de facto standard for other new entrants to the market.

Energy-Efficient Window Procurement

The Swedish EEWP followed closely and shared many of the design features pioneered in the EERP (Persson 1993). Landlord owners of large residential housing units were once again targeted and a competitive solicitation was held. Two window manufacturers were selected and guaranteed sales of windows amounting to less than 2% of the Swedish market for windows. Unlike EERP, the landlords also received financial incentives to reduce the first cost of the windows.

The EEWP, too, appears to have successfully transformed the market for residential windows in Sweden. The manufacturers report sales well beyond the original purchase guarantee and other manufacturers are offering comparable high-efficiency products. Sales have increased despite a dramatic downturn in the total number of windows sold.

The developers point to several successful features of the procurement. For example, one of the units targeted by a landlord for window replacements was older and comparatively less energy-efficient than the stock. The window replacements were accompanied by major renovation work. The increased thermal performance of the windows led to

additional cost savings in the HVAC equipment installed as part of the renovation. In addition, the new window reduced noise from the outside. In another example, the reduced downdrafts from the windows allowed radiators under windows to be removed. Cleaning costs savings expected from not having to dust the radiators added to the cost savings from not having to replace or service the radiators.

Finally, there is a large market for future window replacements. Sweden undertook an ambitious building program during the 1950s to address a housing shortage. The windows in the one million homes built during this period are all slated for replacement in the near future. It remains to be seen whether the new models introduced as a result of the procurement will capture a significant share of these sales.

Model Conservation Standards

The Model Conservation Standards (MCS) program was a comprehensive effort led by BPA and other utilities in the Pacific Northwest to accelerate the adoption of the next generation of building standards through aggressive promotion of advanced building technologies, combined with improvements to the energy-efficient building industry infrastructure. Demonstrations, technical assistance, and financial incentives—the traditional scope of DSM programs—were complemented by extensive builder training and unprecedented support to state and local building code officials. Subsequent revisions to the energy codes in the Pacific Northwest testify to the success of this comprehensive strategy to transform the market for new construction.

Several aspects of the MCS program are noteworthy. First, as with traditional DSM programs, demonstrations, technical assistance, and financial incentives were designed to lower the perceived risks, information costs, and cost premiums influencing the market adoption of new technologies. What is unique is the region-wide coordination of these efforts. This perspective was particularly appropriate given the regional nature of the construction market in terms of prevailing construction practices and the suitability of particular energy-efficient technologies.

Second, the addition of builder training recognized that changes to the construction industry itself were necessary to ensure effective installations and lasting improvements in building practices. Without these improvements, eventual changes to building codes, which historically reflect prevailing practice, would have been vigorously opposed.

Third, direct support financing the salaries of additional and training for code officials directly addressed the historic resource constraints faced by enforcement officials and the consequent field evidence on the lack of compliance.

Superwindow Demonstration

The SD was a pilot demonstration project undertaken by the Bonneville Power Administration to document the measured energy-savings of highly energy-efficient windows in the Pacific Northwest (Jackson 1994). The program paid for 40% of the cost of replacing windows in 100 existing homes with energy-efficient, superwindows. Savings are being evaluated by a variety of methods.

Initial results from the project have found slightly lower than expected savings from the superwindows as compared to the windows they have replaced. This resulted in part from underestimating the thermal properties of the original windows. Preliminary calculations suggest a payback time of 14 years.

Unlike the previous four initiatives, at this time, the SD is primarily a demonstration and research project designed to gain experience with a technology not yet widely adopted in the region. Accordingly the bulk of the effort to date has been devoted to creating a highly defensible record to document performance unambiguously. There are, however, preliminary signs that the program has had an influence on regional window manufacturers. Some vinyl window manufacturers are believed to have been influenced by the program to develop lower-priced superwindows.

INSIGHTS FOR FUTURE RESIDENTIAL WINDOW MARKET TRANSFORMATION INITIATIVES

The five market transformation programs all hold important lessons for future initiatives to accelerate the market adoption of highly efficient residential windows. We focus on seven specific observations emerging from our review.

Overcome market barriers in a lasting fashion. The SERP program apparently did not lower the retail price of the super-efficient refrigerator (even with the rebate) sufficiently to capture a significant share of the market. For a comparable effort to succeed in the windows market, either the price reduction or enhancement in performance caused by the program must be lasting. If it is not lasting, it must be complemented by a concerted effort to reduce the underlying non-financial market barriers to adoption of high efficiency windows. Failure to achieve either lasting reductions in cost or the related non-financial market barriers means that the market will likely ‘‘backslide’’ following termination of the program. For windows, this suggests special attention be paid to providing convincing evidence of the superior performance of energy-efficient windows (including, especially, their non-energy benefits such as increased thermal comfort

and reduced condensation) in order to demonstrate their lasting value or benefit to consumers.

Focus on increasing market share for existing technologies. Part of SERP's high first-cost resulted from the design objective to introduce a refrigerator not currently available in the market. One might conclude from this experience that, while there is potential for promoting near-commercial window technologies, it may be more important to accelerate market adoption of already-commercial technologies. For example, an alternative to introducing a more advanced window technology might be additional manufacturing R&D to lower the production cost associated with windows of current efficiencies, and thereby lowering their first cost premium. Another possibility would be simply to increase the availability and usefulness of information documenting the benefits to consumers of highly energy-efficient windows.

Target bulk purchasers. Both EERP and EEWP involved a coordinated bulk purchase. A guaranteed market no doubt contributed to the manufacturer's certainty regarding their ability to recoup the investment required to produce the new units. Equally importantly, in order to create a lasting market, EERP and EEWP both appear to have successfully lowered the market barriers facing owners of large multifamily residential buildings by successfully convincing them not only of the value of energy efficiency, but also of the other attributes of the product (e.g., CFC-free), as well as providing a tangible way for purchasers to enhance their public image through participation. Future window initiatives should consider large window purchasers (e.g., production home builders or public housing authorities), assess the barriers inhibiting their purchase of energy-efficient windows (e.g., uncertainty regarding buyer interest or government procurement regulations), and develop a targeted approach to overcoming them. A related strategy involves stresses the non-energy benefits of energy-efficient windows, such as improved thermal comfort and appearance (i.e., reduced condensation).

Piggy-back on emerging market trends. EERP targeted a product whose market share was small but expected to grow (i.e., larger refrigerator/freezers). In doing so, the program set a standard for new entrants both in terms of price and features. For the windows market, there may be a close analogy in vinyl, fiberglass, or composite frame windows, whose market share is expected to grow over time compared to aluminum or wood-only frame windows.

Adopt a regional approach. The MCS was a highly coordinated regional approach, involving all market players in the construction industry in the Pacific Northwest. This approach seems especially warranted for new construction and remodeling, which exhibit strongly regional characteristics. Window markets, therefore, should be examined on a regional basis.

Plan for the long term. The MCS program paved the way for new building codes through extensive training or ''re-tooling'' of the construction trades in energy-efficient construction practices. Without a competent infrastructure that views energy-efficient windows as standard practice, market adoption will be hindered by poor installations and high transactions costs. At the same time, training takes time and, therefore, it is not realistic to expect changes in standard practice overnight. Undoubtedly, perceptions regarding the inevitability of changes to the building code will contribute to the speed of this transition.

Develop and disseminate measured performance and related certification procedures. The SD program illustrates the importance of documentation for addressing the perception of risk associated with the claims of energy savings from new products. The NFRC certification process is a major step in the right direction. In addition, a large, well-documented field demonstration has great potential for substantiating manufacturers' claims in a highly visible and believable manner. It also helps manufacturers gain experience and underwrite some of the re-tooling costs associated with producing more energy-efficient windows. In the case of SD, disseminating the field experience widely is only in its initial phases.

CONCLUSION

Technologies for reducing residential window energy requirements are already commercially available. Widespread adoption of these products will yield large economic and environmental benefits to the nation and improve the thermal comfort of US residences. Lessons learned from related market transformation efforts, if applied to windows, hold the promise of accelerating the adoption of highly energy-efficient window products. The key to transferring these lessons to the window industry successfully lies with identifying innovative ways to tap and coordinate the interests of window market participants toward a common and mutually beneficial goal.

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REFERENCES

Arasteh, D. 1995. ''Advances in Window Technology: 1973-1993.'' K. Boer (ed.) *Advances in Solar Energy, An Annual Review of Research and Development*. Boulder, CO: American Solar Energy Society, Inc.

Feist, J., R. Farhang, J. Erickson, E. Stergakos, P. Brodie, and P. Liepe. 1994. ‘‘Super-Efficient Refrigerators: The Golden Carrot from Concept to Reality.’’ *In Proceedings of the ACEEE 1994 Summer Study on Energy Efficiency in Buildings*. 3:67–76. Washington, DC: American Council for an Energy Efficient Economy.

Frost, K., J. Eto, D. Arasteh, and M. Yazdanian. 1996. (To appear.) *In Proceedings of the ACEEE 1996 Summer Study on Energy Efficiency in Buildings*. Washington, DC: American Council for an Energy Efficient Economy.

Golove, W. and J. Eto. 1996. *Market Barriers to Energy Efficiency: A Critical Reappraisal of the Rationale for Public Policies to Promote Energy Efficiency*. LBL-38059. Berkeley, CA: E. O. Lawrence Berkeley National Laboratory.

Jackson, M. 1994. ‘‘ ‘Superwindow’ Retrofits Show Significant Energy Savings.’’ *Home Energy*. September/October. Berkeley, CA: American Council for an Energy Efficient Economy

Lubliner, M. 1995. *Pricing of Energy Efficient Windows in the Pacific Northwest*. WSEO #95-026. Olympia, WA: Washington State Energy Office.

Nadel, S., and H. Geller. 1994. ‘‘Market Transformation Programs: Past Results, Future Directions.’’ *In Proceedings of the ACEEE 1994 Summer Study on Energy Efficiency in Buildings*. 10:187–198. Washington, DC: American Council for an Energy Efficient Economy.

Nilsson, H. 1992. ‘‘Market Transformation by Technology Procurement and Demonstration.’’ *In Proceedings of the ACEEE 1992 Summer Study on Energy Efficiency in Buildings*. 6.179–6.188. Washington, DC: American Council for an Energy Efficient Economy.

Persson, A. 1993. ‘‘Energy-Efficient Windows: Technology Procurement Helps Manufacturers and Market Meet’’ *In Proceedings of the Energy Efficiency Challenge for Europe, ECEEE 1993 Summer Study*. 1:349-360. Oslo, Norway: European Council for an Energy Efficiency Economy.

Vine, E. 1995. *Utility Residential New Construction Programs: Going Beyond the Code*. LBL-36603 Berkeley, CA: E. O. Lawrence Berkeley National Laboratory.