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IMPACT EVALUATION OF A MAJOR RESIDENTIAL EFFICIENCY PROGRAM: THE IMPORTANCE OF MARKET TRANSFORMATION

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Background

Energy-Efficient Manufactured Housing

In the Pacific Northwest, about 40% of new electrically heated homes are HUD-code manufactured homes (commonly called "mobile homes"). The U.S. Department of Housing and Urban Development (HUD) sets national energy-efficiency construction standards for manufactured homes that preempt them from local building codes. Until October 1994, a relatively low efficiency requirement established in 1976 by HUD was in place for manufactured homes.

The Bonneville Power Administration (Bonneville) is required to acquire cost-effective energy efficiency to meet the electricity needs of the Pacific Northwest. Because electrically heated manufactured homes are so common and are relatively inefficient, Bonneville, utilities, state energy offices, and others have conducted a series of programs since 1982 to upgrade their efficiency (1). Because of the preemptive national code, these programs have all been voluntary for manufactured homes.

Bonneville and the regional utilities and manufacturers created the Manufactured Housing Acquisition Program (MAP) in April 1992 after conducting projects for ten years to determine the cost of manufactured home energy-efficiency upgrades, predict and measure energy consumption, and establish a regional partnership. The program was phased in over several months; since October 1992, all electrically heated manufactured homes produced in the region have been built to MAP specifications.

A 1987 study (2) showed that payments to manufacturers for energy-efficiency upgrades were likely to have more financial leverage than incentives to buyers. This is because both manufacturers and the dealers who sell the homes mark up the cost. MAP took advantage of this leveraging by providing a payment directly to manufacturers, rather than the consumer, thus reducing the costs that would be marked up. The concept underlying the MAP payment is that it may be cost-effective for utilities to invest in manufactured housing energy efficiency beyond the level that the average buyer can justify. The MAP payment is intended to bridge the gap between the consumer's and electric utility's cost-effectiveness level. A recent study (3) discusses this concept and its application in MAP.

In addition, MAP was intended to produce permanent changes in the manufactured housing market, inducing market transformation. The program was intended to be in place for four years, during which the utilities would acquire energy savings from MAP homes. All parties anticipated that the changes brought about by the program would become institutionalized and, after the program

(a) Pacific Northwest Laboratory is a multiprogram national laboratory operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-ACO6-76RLO 1830.

ended, homes produced by manufacturers and purchased by consumers would be more energy efficient than they would have been without the program.

When MAP was being designed, HUD was in the process of upgrading its 1976 manufactured housing efficiency standards. Scheduled to go into effect in October 1994, halfway through MAP's planned lifetime, these standards raised the average efficiency level and triggered a renegotiation of the MAP contract between utilities and home producers. Utilities argued that they should not pay manufacturers for the efficiency upgrades that had become mandatory through code changes.

Evaluation Purpose

Bonneville contracted with Pacific Northwest Laboratory (PNL) to conduct an evaluation of MAP's regional impacts. The original purpose of the MAP evaluation was to determine the electrical energy savings attributable to MAP and the levelized cost of the energy savings *acquired* under MAP. The task of identifying control homes, with which to compare MAP homes, was complicated by regional efficiency programs spanning ten years prior to MAP that undoubtedly increased the average efficiency of the manufactured housing stock.

The HUD-code upgrade, adopted in 1993, and consequent negotiations to revise MAP contract terms placed additional demands on the program evaluation. Specifically, utilities needed information about the value of electricity savings from MAP homes relative to the *new HUD code*, probably even more than they needed information about program impacts relative to the original HUD code. Consequently, the evaluation methodology needed to lend itself to extrapolation to conditions other than those under which the original program functioned.[b]

As a result of these circumstances, the evaluation purpose was expanded. The analysis was tailored to estimate savings under alternative baseline conditions. It was also designed to permit estimating savings relative to the new HUD code and explore market transformation effects.

Methodology

Sample Design and Data Collection

We conducted our analysis to estimate energy savings by selecting two samples: manufactured homes constructed to the MAP specifications and homes built prior to MAP. As noted, data were not readily available on a true control group of homes because 1) MAP applied to all new electrically heated homes in the region and 2) homes built at any time in the decade prior to MAP were already influenced by regional efficiency programs. To estimate energy savings, we selected a "baseline" sample of homes constructed during the three months immediately prior to MAP, but not built under the regional manufactured home Super Good Cents (SGC) consumer incentives program. The efficiency levels of these homes differed enough from MAP homes to allow us to develop our energy use estimation model, but this sample of homes was not intended to define the efficiency levels of homes that would have existed without MAP and its precursor programs.

Information collected on MAP and baseline homes included the amount of insulation in the ceilings, walls, floors, windows, and air ducts, and window and floor area. A telephone survey was used to collect home characteristics and owner demographic and attitudinal information for both the

(b) Partially to meet these needs, three investor owned utilities (IOUs) contracted with a consultant to conduct a program evaluation separate from the one that we conducted.

MAP and baseline homes. Home occupants were asked to sign a form that would allow the utility to provide PNL with billing data on their home.

In all, 167 MAP interviews were completed and signed utility release forms were obtained from utilities for 134. For the baseline homes, we completed 183 interviews and we obtained 123 signed utility billing release forms.

Energy Savings and Cost-Effectiveness Analysis

A three-tier process was used to analyze the energy consumption of both MAP and baseline homes. We used multiple approaches to enhance the validity of the estimates, compare the results from different methodologies, and gain insights into the factors related to energy consumption. We selected the approaches to take advantage of the whole-house electric billing data available on each home.

The primary approach used regression analysis to analyze monthly energy consumption, taking into account significant factors, including home and occupant characteristics, that influenced electricity usage. This analysis provided a much better understanding of what affected energy consumption and allowed us to control for more factors. We used the regression results to estimate energy consumption under "normal" weather conditions for each climate zone and to estimate energy savings associated with MAP.

The estimated energy savings effects of MAP were dependent on the characteristics of homes with which MAP homes were compared. As discussed earlier, our baseline homes were constructed immediately prior to the beginning of MAP and were likely to be affected by prior regional efficiency programs. Consequently, baseline energy use was likely to reflect years of industry efficiency improvements. The manufacturer and survey data permitted us to extrapolate our results to reflect different baseline home characteristics.

We assessed the *energy savings acquisition* cost-effectiveness of MAP through a procedure specified by Bonneville (4) comparing the levelized price of the energy saved with the levelized avoided cost of Bonneville's alternative electricity resource. The *regional system cost test* (equivalent to the Total Resource Cost test) was used. Bonneville's current cost-effectiveness limit is 4.3¢/kWh (1993$) (4). The adjusted regional system cost cannot exceed this limit for MAP to be cost-effective. Utility and consumer costs were included and adjusted by four indirect cost effects: capacity, seasonality, on/off peak, and resource life. The total cost adjustment was -0.85¢/kWh.

Determining the characteristics of homes that would have been built in the absence of MAP was a difficult analytic task. For initial analysis purposes, we used our baseline homes as the starting point for estimating savings.

Market Transformation

The market transformation effects of MAP are the indirect effects that the program has had on increasing the general efficiency level of manufactured homes and the residual effects that the program will have on efficiency levels after the program ends. As noted earlier, during the development of MAP, HUD increased its national efficiency standard. The level of this standard was influenced to some extent by Pacific Northwest programs prior to MAP and by MAP itself. There was some evidence that HUD selected a standard that was tighter than it would have been otherwise because of regional efficiency programs.

No information was collected as part of this evaluation to predict how much residual influence MAP would have on efficiency levels after the program ended. Rather than systematically predict the residual effect of MAP, we examined reasonable bounds on this effect.

Findings

Home and Home Owner Data

Most of the MAP and baseline homes were located in zone 1. The relatively small number of homes analyzed in zone 3 (e.g., we had billing data for less than ten zone 3 baseline homes) significantly reduced the certainty of any statistics for this climate zone. To derive regional averages, we used population distributions from (5) and (2).

Overall, a larger proportion of baseline homes were single-section homes.[c] A significantly larger share of baseline homes used some non-electric space heating. As expected, the average thermal conductance, U_0, for baseline homes than for MAP homes. Our data showed that the efficiency of baseline homes was substantially higher in climate zone 3. This may have been an artifact of the sample; a 1987 study (2) found no such geographic variations in 1986.

Survey results indicated that 91% of MAP home buyers knew that their homes were built to high efficiency levels, suggesting that information was reaching consumers effectively. MAP home buyers were twice as likely to say that their home had lower energy bills than they expected.

Energy Analysis and Findings

Our initial analyses led to development of a detailed regression model. The model we used was similar to a conditional demand analysis in that it utilized appliance inventories to explain total kWh consumption, but it was formulated around the anticipated thermal-physical relationships because MAP was designed to affect space conditioning energy use.

The final form of the model was estimated using a robust (iteratively reweighted) least-squares regression. The dependent variable was kWh of electricity use per day during the billing period analyzed. Coefficients for all variables (except the number of freezers) had t-statistics greater than 3.1 and the adjusted R-squared was 0.625 with 2,130 degrees of freedom. The variables in the regression included the following: number of occupants; number of freezers; number of dishwashers; whether the home was a single- or multi-section home; income categories; whether the home was occupied during the daytime; climate zone location; whether the home had air conditioning; whether the home had a heat pump; and interaction terms that included whether the home was a MAP or baseline home, the building envelope load coefficient (UA), cooling degree days (CDD), heating degree days (HDD), and the proportion of heat supplied by a non-electric fuel.

The regression equation allowed us to estimate the acquisition energy savings attributable to MAP. MAP's primary effect was to reduce UA and, through this effect, space-conditioning energy consumption. Because the efficiency of electric resistance furnaces and heat pumps differs, our model allows estimating different UA effects for these different heating systems. Most characteristics of MAP and baseline homes and home occupants were essentially the same, so they had no effect on differences in energy consumption between MAP and baseline homes. One characteristic that did differ, however, was the use of non-electric backup heating (such as woodstoves). Occupants of non-MAP homes were twice as likely to use backup heat as MAP home occupants. Reduced use of non-electric backup heat might be an unintended effect of MAP. Although we had no information suggesting that MAP caused occupants to reduce their use of non-electric heating, our model did permit estimating this effect if we assumed that this difference was an unintended consequence of MAP:

(c) Manufactured homes usually are produced in standard-size sections and joined at the home site. In the Pacific Northwest, most are double-section homes, but some homes are constructed in three or more sections.

Table 1 compares several energy savings estimates. Before MAP began, Ecotope, Inc., conducted a simulation model analysis to estimate MAP energy savings for homes heated with only electric resistance furnaces and constructed with insulation levels consistent with common practice. These estimates are shown in column 2.

TABLE 1. Comparison of Energy Savings Estimates, kWh/yr

(1) Climate zone	(2) Pre-program simulation estimates	(3) PNL estimate using pre-program assumptions	(4) Raw billing data	(5) PNL estimate: MAP had no effect on backup heat	(6) PNL estimate: MAP affects backup heat
1	9,090	4,900	2,300	2,600	2,300
2	11,960	6,800	1,400	3,600	3,600
3	13,870	7,800	270	3,800	2,300
Region	10,540	5,800	1,800	3,100	2,700

By inserting in our model the pre-program U-values used in Ecotope's simulation and the MAP U-values, and analyzing only electric resistance heating, we were able to estimate energy savings for comparison with the pre-program estimates. These estimates are shown in column 3. For homes with electric furnace heat only, our estimated energy savings (column 3) were about 55% of the pre-program estimates (column 2), assuming that comparison homes were built to the efficiency levels assumed prior to the program.

Column 4 shows the estimated average difference in electricity use between MAP homes and our baseline homes, based on the raw billing data. These values were not adjusted to reflect long-term weather conditions, the influence of MAP and previous programs on efficiency levels of our baseline homes, sample differences in home characteristics unaffected by MAP (e.g., home size), and the use of non-electric backup heat that occurred during this period. Contrary to expectations, the estimated savings were highest in climate zone 1, the mildest region, and lowest in zone 3. The regional average savings were 1,800 kWh/yr. These savings were considerably less than the estimates presented in column 3 because of the presence of non-electric backup heat, use of heat pumps, and high efficiency levels observed in our baseline homes built immediately prior to MAP.

Columns 5 and 6 present two sets of energy savings estimates intended to bound the most likely value. For both cases, we assumed that the average baseline U_o would be 0.098 (6, p. 11). Results in column 5 reflect the assumption that MAP had no effect on the use of non-electric heat; the backup heat usage assumed for both MAP and non-MAP homes was the level observed in our non-MAP homes sample. Column 6 reflects the assumption that MAP *did have* an effect on occupants' use of non-electric heat; the backup heat usages assumed were the different amounts reported by the MAP and baseline home occupants surveyed.

A review of these results suggests how different factors affect estimated energy savings. The efficiency level assumed for comparison homes was very critical. Most of the difference in savings between columns 4 and 6 could be attributed to U_o differences for the baseline homes. The estimates from the raw billing data in column 4 were highly distorted by the high efficiency levels observed in homes built immediately prior to MAP. These homes were undoubtedly more efficient than they

would have been in the absence of the SGC program and MAP, and using them to estimate MAP's effects would understate the effect of the program. The savings presented in columns 2 and 3 were relatively high because they did not take into account the influence of heat pumps and non-electric backup heat. Finally, if MAP did have an effect on the use of backup heat, then its effect was relatively small. The difference between columns 5 and 6 resulted directly from whether MAP was assumed to reduce the use of backup heat or not; if it did, this effect reduced estimated savings by about 13% regionally.

Cost-Effectiveness Results

We assessed the cost effectiveness of MAP based on the levelized cost of *acquiring energy savings in homes built under MAP*. The levelized costs presented in Table 2 are adjusted for our estimates of the effects of heat pumps and backup heat on energy savings. Table 2 presents six estimates of regional levelized costs. The first two correspond to the original MAP, in which the utilities paid manufacturers $2,500 for each MAP home; the baseline efficiency level reflects a U_0 of 0.098. Columns 1 and 2 present levelized costs based on the different assumptions about program effects on backup heat discussed earlier.

Columns 3 and 4 present corresponding results based on the design of MAP after the new HUD code was implemented in October 1994. The baseline home U_0 was assumed to be the new HUD-code level, 0.079, and utilities paid manufacturers $1,500 for each MAP home.

Regionally, the original MAP was cost effective. During this first phase, the levelized cost of electricity savings was about 0.5¢/kWh higher if MAP were responsible for less use of non-electric backup heat. After the new HUD code went into effect and MAP was renegotiated,

TABLE 2. Regional Average Levelized Acquisition Costs, ¢/kWh

Original MAP (1976 HUD code)		Revised MAP (1994 HUD code)		Both MAP phases	
Assumed MAP effect on backup heat use		Assumed MAP effect on backup heat use		Assumed MAP effect on backup heat use	
(1) None	(2) Reduced	(3) None	(4) Reduced	(5) None	(6) Reduced
2.97	3.43	3.36	4.83	3.00	3.76
Note: Bonneville's cost-effectiveness threshold is 4.3¢/kWh.					

program levelized acquisition costs increased. Assuming that MAP did not change the use of backup heat, the savings purchased through acquisition were still cost-effective; assuming that MAP did cause a shift to less use of non-electric heat, the acquisition costs were 4.83¢/kWh, which exceeded the cost-effective level.[d] For both program phases combined, MAP was cost-effective compared with Bonneville's required threshold.

(d) Our analysis suggested that the threshold of 4.3¢/kWh would have just been met by a payment of $1,260 per home if MAP did not affect the use of backup heat and $1,866 per home if MAP did affect the usage. The actual payment was $1,500.

These results did not account for any of the energy savings attributable to the market transformation effects of the program, particularly in homes produced after the program ends.

Market Transformation Assessment

MAP was designed to have significant, long-term effects on the manufactured housing market. It demonstrated that very energy-efficient manufactured homes could be built, dealers could sell them, and buyers would purchase them. MAP affected several market participants: manufacturers, suppliers, home dealers, and buyers. It applied to all manufacturers in an entire geographic region. The program was intended to provide an initial boost to the market and then either be terminated or redesigned. All these features were consistent with prerequisites for demand-side market transformation programs, making MAP one of the largest market transformation programs so far.

The scope of our evaluation, however, did not include a comprehensive assessment of the market transformation effects of MAP. The energy savings impacts and cost-effectiveness results presented earlier captured only the direct consequences of acquiring energy efficiency in MAP homes and provided no information about MAP's market transformation effects.

Major market transformation consequences expected of MAP that would have an effect on cost effectiveness included the following: 1) reduced energy conservation measure costs, 2) increased energy code requirements, and 3) residual increases in typical efficiency levels after MAP ends.

No data were collected in this study on the first effect. However, a survey of window costs suggested that during MAP, vinyl window costs decreased about 5% from their costs prior to MAP (personal communication, David Baylon, Nov. 1, 1994).

There was some evidence that the second effect occurred, and HUD adopted a more efficient energy code, in part because of regional programs including MAP. HUD was kept informed about Bonneville's programs as the HUD code was being developed and adopted. Very likely, regional program experiences helped justify HUD's adoption of an efficiency level that was 14% more efficient than the level proposed by the industry (7).

The third effect, post-MAP persistence of higher efficiency levels, cannot be assessed accurately until the program ends. However, we examined this effect conceptually. Figure 1 illustrates the potential market transformation effects.[e] The cumulative market shares for different space heating energy use levels are shown under different conditions. Curve AA shows the market shares under the 1976 HUD code. A small share of homes is built to the lowest efficiency level (consuming the largest amount of energy for space heating), most are in the middle efficiency range, and a few are built to higher efficiency levels. Curve DD shows the market shares under MAP. The curve is relatively flat; no homes consume more energy than the maximum allowed by MAP and a few consume less space heating energy. Curve BB illustrates what the energy consumption distribution might have looked like under the new HUD code if MAP had never been implemented. The maximum heating energy use is less than the 1976 HUD code maximum, and the rest of the homes consume less. Curve CC illustrates one view of how the market might look after MAP ends. Because MAP influenced the efficiency level adopted by HUD, the maximum energy use is less than under the HUD code if MAP had never been implemented. The minimum energy use is at the lowest levels under MAP because some manufacturers would continue to offer and some consumers would continue to buy super-efficient homes after MAP ends.

(e) Note that the numbers shown in Figures 1 and 2 are only illustrative.

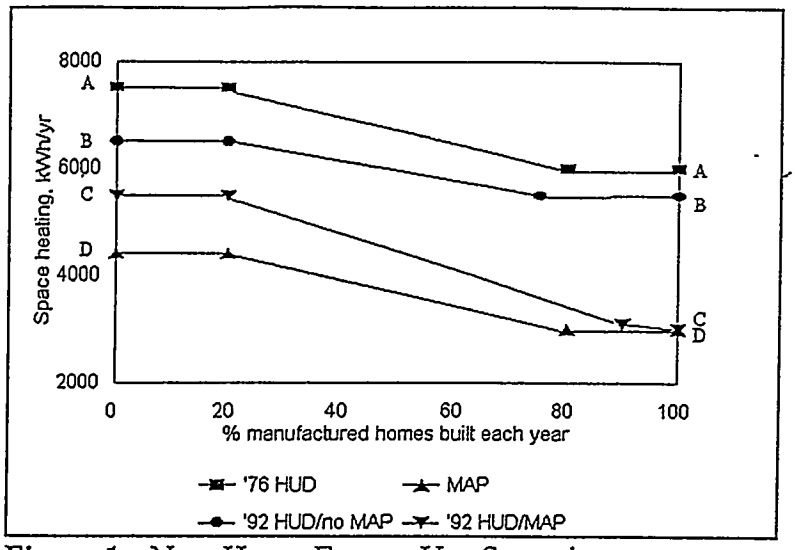

Figure 1. New Home Energy Use Scenarios

Figure 2 uses the same graphical representation to show MAP acquisition energy savings and market transformation savings. The area between curves AA and DD corresponds to the acquisition savings. These savings, however, are for only those homes built during the program. The area between curves BB and CC represents the savings from homes constructed after MAP ends. These savings would occur in all homes built for some period after the program ends.

The energy savings and cost-effectiveness results presented earlier took into account only the acquisition savings attributable to MAP (the difference between curves AA and DD), i.e., energy savings for only those homes constructed during the program. Because MAP was intended to transform the manufactured housing market for energy efficiency, baseline efficiency levels would probably increase during each year of the program. In fact, the new HUD code went into effect halfway through MAP and direct program savings immediately decreased. The terms of the program were renegotiated and, as our earlier results suggested, the acquisition savings from the program were no longer cost-effective. However, this judgment about cost-effectiveness is inadequate because market transformation effects are ignored. Both program phases and the overall program could be cost-effective if the market transformation energy savings shown in Figure 2 were accounted for. These savings represent the efficiency increases that would remain in homes built after MAP ends.

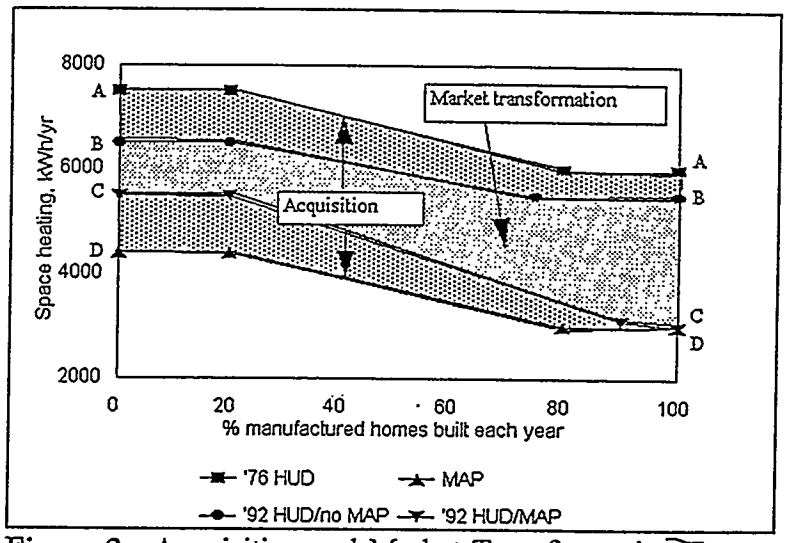

Figure 2. Acquisition and Market Transformation Energy Savings

Because the program had not ended when this analysis was conducted, we could assess only speculatively the market transformation energy savings attributable to MAP. To derive a conservative savings estimate, we assumed that homes built for only five years after the program ended would be more efficient because MAP had been implemented. Instead of trying to determine the market transformation savings, we conducted a simplified sensitivity analysis of various levels of savings.

Table 3 shows program utility levelized costs (instead of regional system costs)[f] as a function of the percentage decrease in average U_o relative to the difference between the HUD-code level (0.079) and the MAP level (0.054). For every 20% decrease in the difference between the HUD-code and MAP thermal efficiency level, the program levelized costs would decline about 13%. Although we don't know exactly what measures consumers would continue to purchase after MAP ends, consumer response to vinyl windows has been very positive. Assuming that consumers continued purchasing only vinyl windows after MAP ends, the program utility levelized cost, including both acquisition and market transformation effects, would be about 1.5¢/kWh. Note that this analysis conservatively takes *no* credit for MAP increasing the new efficiency level adopted by HUD.

TABLE 3. Effect of Market Transformation on Utility Levelized Costs

Residual Efficiency Improvement					
0%	20%	40%	60%	80%	100%
2.59¢/kWh	2.20¢/kWh	1.90¢/kWh	1.64¢/kWh	1.43¢/kWh	1.26¢/kWh

Conclusions

Our program evaluation shows that strictly in terms of the direct acquisition of energy savings, MAP overall meets Bonneville's regional levelized cost test. Cost-effectiveness, however, is highly dependent on what baseline home energy-efficiency characteristics are assumed. Ten years of regional efficiency programs have undoubtedly increased the efficiency level of homes against which to measure MAP energy savings. Under the most reasonable assumptions about the average efficiency of homes in the absence of MAP, the program appears to be cost-effective.

Cost-effectiveness also depends significantly on what amount of backup, non-electric heat is used. We assume that backup heat is present in some homes, and this causes the estimated energy savings to be considerably less than pre-program estimates, which assume the use of no backup heat. We also examine the effect of assuming that MAP has reduced the use of backup heat, thereby reducing the cost-effectiveness of direct electricity savings. If this effect has occurred, this unintended consequence of MAP has a marginal effect on cost-effectiveness, but does not change the conclusion that the program is cost-effective.

The program was revised significantly part-way through its life cycle because HUD adopted a tighter national code, and levelized costs of acquired savings increased after the program was modified. We maintain, however, that the program needs to be evaluated as a whole, and cost-effectiveness assessments must take into account the market transformation impacts that have occurred.

Our preliminary investigation of the market transformation effects suggests that MAP is partially responsible for reductions in material costs and an increase in the national HUD-code requirements. More significantly, MAP is likely to have a significant residual effect on the energy effic-

(f) Utility levelized costs are presented in the market transformation case because the utility is considered to have had the effect of changing the market and consumer behavior so that consumers are willing to pay the full additional cost of energy-efficient homes.

iency of manufactured homes purchased in the Pacific Northwest. Although these effects cannot yet be estimated with confidence, reasonable assumptions suggest that market transformation effects reduce overall program costs to less than 1.3¢/kWh from the utility perspective.

Despite the generally favorable cost-effectiveness results from our evaluation, two IOUs and Bonneville have decided to end MAP earlier than originally planned. A study conducted for three IOUs indicated that program savings were less than our estimates and far less than the pre-program estimates. Although the decision to terminate the program early was due largely to financial pressures, debate about program cost-effectiveness unfortunately has not benefited much to date from solid evidence about market transformation effects.

For future programs, this evaluation suggests that the role of market transformation has to be better integrated from the beginning. First, if a program is intended to have significant market transformation effects, then a strategy for assessing these effects should be established early on and integrated into the program evaluation. Second, a strategy for transitioning from the acquisition stage into the post-acquisition stage of market transformation programs needs to be established up front and agreed to by all participants. Attempts are currently underway to design a program to implement after MAP's acquisition stage ends, but all parties would have benefitted if the general form of this next stage had been laid out earlier.

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