Deep Energy Savings in California Homes: A New Vision

Robert Knight, Rebecca Brown Alex Shim and Scott Fable, Bevilacqua-Knight Inc.

ABSTRACT

Since 2010, California has been conducting one of the world's largest and most valuable experiments in achieving high energy savings in existing homes through "whole-house" energy efficiency upgrades. Driven by the state's global warming solutions policies and the need to create jobs to stimulate a depressed economy, several hundred million dollars were allocated under a combination of utility levies and Federal stimulus funding to state and local government agencies. Vital advances were made in building a foundation for future success. But as in other similar programs around the nation, the growth of public participation has been slow. In this paper we seek to identify the principal barriers, lessons learned, and major changes needed to provide a viable pathway to the state's single-family home energy upgrade goal of an average 40% energy savings in all homes by 2020. Conclusions of this study include the following:

- California must reconcile its energy efficiency programs with its ambitious climate goals
- Those goals will require an unprecedented commitment to large-scale programs
- A initial infrastructure of trained contractors, standards, and support has been built
- Existing programs still fall far short of the state's climate and employment goals
- The most significant barriers to success are institutional and financial, not technical
- Incremental, evolutionary changes in energy efficiency programs will not suffice
- Legislative, regulatory, design, administrative and technical innovations will be needed

The principal conclusions and many details of these findings appear to be transferable to other residential energy upgrade programs nationwide.

Introduction and Background

The Climate Imperative

California's "Climate Solutions Act" (Assembly Bill 32) became law in 2008 and is now being implemented by several State agencies led by the Air Resources Board (ARB) and including the Public Utilities Commission (CPUC) and California Energy Commission (CEC). The AB 32 carbon emission goals and timing are based on the findings of the United Nations Intergovernmental Panel on Climate Change (IPCC). Among the initiatives supporting AB 32, the Public Utilities Commission's Energy Efficiency Strategic Plan [CEESP, 2011] sets a target for the state's entire existing housing stock to achieve an average energy efficiency savings of 40% from 2008 levels by the end of 2020. This amounts to a reduction of some 30 billion kWh and 2.5 billion therms; renewables such as rooftop photovoltaics are subject to separate goals.

By 2050, the state's AB 32 carbon reduction goal is increased to 80% of 1990 levels, requiring unprecedented future savings requirements in all energy sectors including all existing

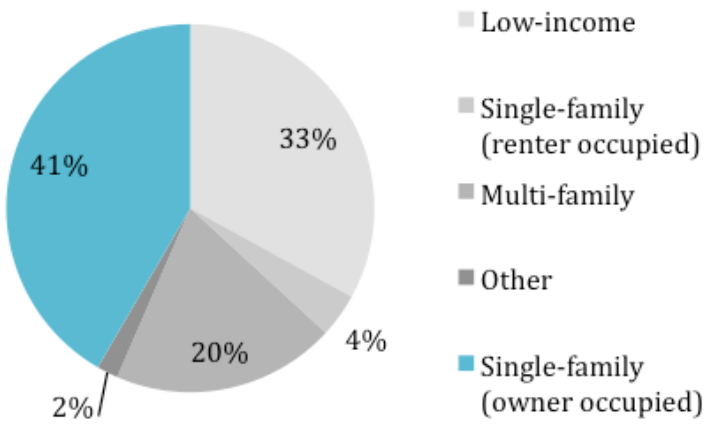
housing units.[1] This ambitious policy is a pathbreaking experimental prototype for future climate change legislation in other states and at the national level. It sets the stage for this paper's focus on what is likely to be required to achieve the carbon reduction contributions targeted for energy use in existing single-family homes. Other sectors of the housing stock, including low-income and multifamily units, are to be treated in other initiatives and are not considered in this analysis.

Home Energy Upgrade Program Support

The CEESP established broad home energy retrofits as the centerpiece of the state's strategy to help meet the AB 32 existing-home goals. CPUC authorized the four large California investor-owned utilities (IOUs), which serve about 85% of the state's housing, to allocate over $115 million to these new "whole-house" programs for 2010-12. As startup programs, their collective market penetration goals for that period were well below one percent of the single-family homes served by the IOUs. These goals were recognized as the maximum attainable in the initial years, with the expectation of later program refinements based on that initial experience to reach the far larger 2020 goal.

Among the 11.5 million dwelling units served by the California IOUs, about 4.8 million meet CPUC program eligibility requirements as single-family, detached, owner-occupied, and non-low income.[2] The chart below illustrates the significance of this part of the housing stock.

California housing stock distribution by type[3]



Source: RASS Saturation Tables [KEMA 2009]

These utility-funded retrofit programs were dramatically amplified by even larger Federal, state, and local allocations of Federal economic stimulus funds, largely to educate the public, test innovative approaches, increase rebates and financing choices, and stimulate demand for the utility retrofit programs. Collectively, these home energy retrofit programs are of

[1] State carbon reduction goals established by Executive Order S-3-05 and later included in AB 32
[2] One of the state's largest publicly owned utilities, the Sacramento Municipal Utility District, also fielded a major home energy upgrading program not under the CPUC's jurisdiction.
[3] The limitations of the state's Residential Appliance Saturation Survey (RASS) database for 2009 make this housing stock breakdown approximate although adequate for this study's purposes.

unprecedented financial scale. They provide a broad range of activities including rebates, contractor training, certification, mentoring, marketing, and quality assurance. Until recently some programs provided up to $9,000 in combined utility and Federal stimulus (ARRA) rebates, although these were somewhat reduced in early 2012 due to exhaustion or reassignment of some initial funding. In some areas below-market interest rates for home upgrade financing were added.

Accomplishments to Date

The 2010-12 whole-house programs have made substantial progress. Nearly 500 contractors (and far more individual trainees) have been trained, technically certified, and admitted to the programs. Intensive public education has raised consumer awareness and understanding. The generous cash rebates have influenced many homeowners to sign up. Several innovative deployment experiments have been fielded, and overall program momentum has increased. This is a crucial step, providing an essential foundation for future growth. However, the market penetration, energy savings levels, and rates of increase have been well below the early market penetration trajectory needed to meet the state-specified 2020 goals.

There are many reasons for this initial shortfall, such as the public's lack of understanding of the full range of benefits, the depressed economic situation, substantial cost of such improvements, inadequate financing options, high contractor costs of program compliance, and complexities of program regulation—among other challenges. These initial program results suggest a need for substantial program review and reconsideration, not just refinement.

California's results are similar to those of other states and localities fielding comprehensive whole-house programs. These programs, typically aligned with the visionary Federal DOE/EPA *Home Performance with Energy Star*[4] initiative, range from less than one year to over ten years in operation to date. They now include over 30 state and local utility-sponsored ventures with relatively similar program concepts typically involving contractor training, public outreach, quality standards and enforcement, home-by-home forecasted savings, and consumer rebates and/or other incentives. Based on the authors' communications with these program implementers and sponsors, market penetration and energy savings are generally well short of the ramp-up momentum needed to reach global carbon reduction depth and timing targets.[5] This suggests that this study may have broader applicability despite California's many unique characteristics.

Whole-House versus Traditional Energy Efficiency Programs

The whole-house home energy upgrading programs of interest here are not the norm. In California, as well as nationwide, most residential energy efficiency funding is directed at more traditional single-measure installations such as insulation, HVAC equipment, and appliances in both single and multi-unit housing. However, it is increasingly recognized [cf. CPUC 2012b] that such conventional "widget" energy efficiency approaches cannot reach the needed carbon reduction goals due to their need for a sequence of separate programs with collectively high administrative costs, slow market penetration, suboptimal combinations of piecemeal

[4] http://www.energystar.gov/index.cfm?fuseaction=hpwes_profiles

[5] Population and new housing construction forecasts, both for California and the nation, indicate that the current housing stock and its energy use will overshadow the effects of new construction for generations to come.

improvements, and lack of consistently adequate scope to meet the targets. The newer comprehensive whole-house programs are much more promising for reaching high levels of energy savings per home, and are the natural successors to those "widget" programs both in single and multi-unit buildings and including both subsidized and market-rate programs.

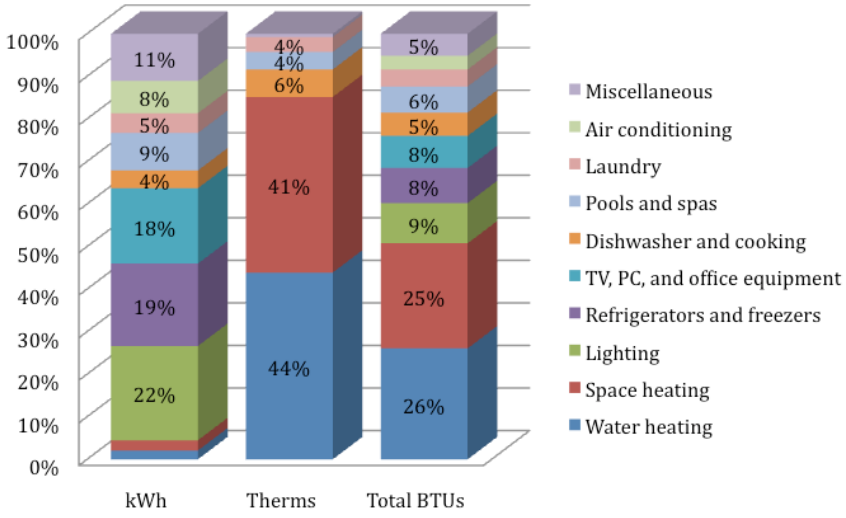
Whole-House Programs versus Savings Goals

The California whole-house programs, like most others elsewhere, focus on savings opportunities in water and space heating, ventilation, and air conditioning (HVAC), with emphasis on building and duct tightness, insulation, and mechanical systems upgrading. Interim results of the California programs are showing estimated energy savings to be averaging around 30%, although early small-sample reviews, using year-to-year energy bill data comparisons adjusted for weather fluctuations, are suggesting some overestimates of savings in the simulation modeling used for those savings projections. Instead of the 30%, actual average savings in these programs to date could be 15% or less.[6] Further study is needed to confirm this early finding.

These energy savings estimates are well below the state's 40% target. However, even the 15% estimate of average home energy savings could be adequate for now, given that the program is in its startup phase, with many less intensive retrofits, and focuses almost entirely on HVAC and water heating. These uses account for only about half of the average California home's energy use, as shown below. It is hardly possible to achieve 40% savings in total home energy use through improvement of only about half of that usage.

The overall average breakdown of California home energy use suggests a need for broadening of the scope of the current whole-house programs to cover lighting, appliances, cooking, other plug loads, and miscellaneous functions at high rates of savings in order to reach a 40% average. This further emphasizes the longer-term challenge to be faced in seeking the state's much higher savings goals by mid-century.

Residential Energy End-Uses for Single Family Homes



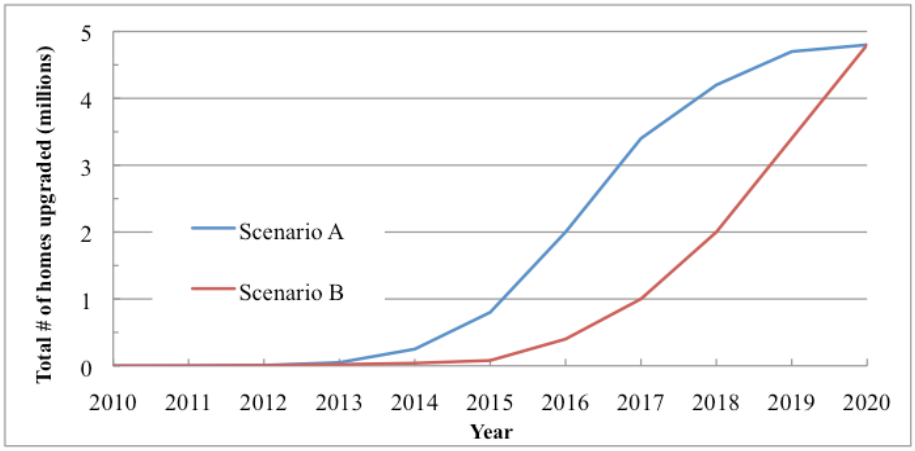
Source: RASS Saturation Tables [KEMA 2009]

[6] Unpublished field data sampling analyses by the authors plus anecdotal results by others

Understanding the Required 2012-2020 Home Retrofit Trajectory

This analysis focuses on the state's 40% average energy savings target for the 4.8 million program-eligible single family homes served by the California IOUs. We illustrate below a range of scenario examples for reaching that 2020 target, starting with the 2010-12 efficiency program cycle. These trajectories need not be precise to demonstrate the general levels of acceleration that will be needed to meet 2020 goals for those single-family retrofits. The two extreme scenarios in the graph below represent alternative hypothetical 100% market penetration curves from 2010 to 2020, covering only the 4.8 million homes eligible for the current CPUC retrofit program.

Examples of cumulative home retrofit market penetration scenarios



Two-year retrofit volumes implied by the above scenarios

	2010-2012	2013-2014	2015-2016	2017-2018	2019-2020
Scenario A	7,500	250,000	1.7 million	2.2 million	600,000
Scenario B	7,500	35,000	350,000	1.6 million	2.8 million

As the two scenarios illustrate, the CPUC goal for 2020 could be reached in different ways. These scenarios illustrate two extreme strategies—ramping up quickly now or somewhat more gradually over the next several years. But as the table shows, in either case later years will necessarily involve extremely large-scale achievements on the order of a million or more homes retrofitted per year—a scale-up of several orders of magnitude. Home retrofits to date and forecast through 2012 are essentially invisible on this scale. This suggests that gradual program refinements or focusing improvement on only the HVAC and water heating components cannot suffice.

With this perspective, it is important to consider a broader range of improvements to create a process that can respond to the very high levels of intensity and scale called for by the state's atmospheric carbon reduction goals. In addition, these 4.8 million homes are only a minority of the state's 13.4 million housing units. New programs are needed to address similar energy savings goals for the state's remaining 8.5 million multifamily, low income, and rental homes as well as the owner-occupied single-family non-low income homes not served by the IOUs. These market segments are likely to be even more challenging.

Envisioning a Successful Future

The present whole-house energy retrofit programs in California and elsewhere have provided an essential initial step in moving from traditional piecemeal energy efficiency measures to the introduction of more integrated retrofit models with much higher energy savings potential. What is needed now is learning from the experience of these initial home upgrading programs and necessarily developing improvements in virtually every aspect. Given the disparity between achievements and trends to date versus the strategic state goals, it is likely that many of those improvements must be radical rather than incremental. In this paper we suggest some of the most important changes needed and how they might be achieved and integrated into an overall strategy for 2012-20.

The remainder of this paper will present a view of the current barriers and range of solutions needed, based on the authors' long-term direct involvement in the California retrofit programs. This vision encompasses an unprecedented level of public engagement, urgency, public agency and utility commitment, legislative action, new and flexible regulatory innovation, new delivery business models, intensive program support, local government and community organization involvement, practical research, and attraction of private capital and financing models. The suggestions offered here are only examples; there are undoubtedly even more specific opportunities and improvements beyond those we suggest here. Not everything can be implemented immediately, so the vision includes recommended priorities and a division between immediate feasible improvements and later more far-reaching changes.

Dimensioning the Solution

In the remaining sections of this paper we examine each major element of the home energy upgrade program process and suggest possible refinements and alternatives that may be necessary to reach the state's 2020 goal. We divide those program elements as follows:

1. The policy environment and barriers
2. Program design and implementation
3. Workforce development
4. Public education and marketing
5. Project Financing
6. Administration and reporting
7. Quality assurance and control
8. Research and development

Each of these solution elements is treated in the following sections. Specific barriers and potential solutions are presented in summary form. These details are intended only as catalysts to broader discussion and consensus in developing the advanced strategy and programs needed.[7] Facing the limitations of reality, not every recommendation can be successfully achieved—but all must be considered and attempted, with high-level governmental and utility support.

[7] These barriers and potential solutions are examined in greater detail in the authors' forthcoming study on this topic for the California Energy Commission's PIER (Public Interest Energy Research) program in the fall of 2012.

Element 1: Improving the Policy Environment

This is arguably the most urgent improvement category, in contrast with the general tendency to focus on technical barriers. Institutional barriers appear to be the most damaging to long-term success in reaching the state's climate and employment goals. Such barriers arise from the historical accumulation of policies driven heavily by risk aversion. In an environment of rules developed to minimize financial and legal risks rather than to maximize energy efficiency program success, barriers to that success tend to be created through efforts to eliminate even the smallest perceived operational risks. A major shift in institutional values is needed to more effectively balance those risks against the greater risk of program failure due to the extreme risk-elimination efforts that currently create barriers to broad participation. Without that shift, more ambitious comprehensive savings strategies such as the home energy upgrading initiatives will continue to be overburdened with excessive policy and procedural limitations.

Some specific examples include the current approach to cost-effectiveness of the utility investments of ratepayer funds in energy efficiency programs. The CPUC applies cost-effectiveness tests only to each IOU's complete energy efficiency portfolio, which must meet minimum standards to avoid financial penalties.[8] However, the risk of such penalties encourages the utilities to minimize their investment in poor-scoring programs—including home retrofits, which derive most of their value to consumers and society through benefits other than energy cost savings [cf. Knight 2006]. The dominant "Total Resource Cost" (TRC) test ignores virtually all benefits beyond wholesale utility power procurement savings, despite evidence that such non-energy benefits as job growth and resulting social safety net cost savings may greatly outweigh the value of the electricity and gas procurement savings. The TRC also overstates the relevant costs, by including the large share of homeowners' retrofit investments that are committed for non-energy reasons such as comfort, health, and home value [cf. Knight 2006].

Other biases of the current TRC approach include arguably excessive discount rates and net-to-gross savings reductions, all resulting in TRC benefit/cost ratios for these retrofit programs nationwide well under the 1.0 needed to justify their "cost-effective" adoption. This situation virtually prevents such programs from adoption in many states, and if unchanged will prevent their success in California. This will result in continued inadequate contributions of the housing sector toward the climate goals.

Other institutional barriers include lack of compatibility between the related programs of different state agencies. A California example is the inherent conflict between the CEC's emerging "HERS II" home energy rating process and the CPUC's utility-run home energy upgrade program procedures. These closely related state agency initiatives in home retrofits use different analysis and reporting requirements and costs that may increase the already difficult and costly administrative complexity for the home energy retrofit contractor, client, and program implementers. All these institutional barriers to success can be reduced only with strong executive-level commitment in the key agencies and utilities. Finally, at the legislative level, initiatives are needed for public disclosure of energy usage and ratings, potentially leading to mandated home energy assessments and eventual upgrades at time of sale.

[8] California policy is enlightened in this respect. Many states further inhibit innovations such as home retrofits by requiring that every program—or even every energy efficiency measure—must achieve a passing (1.0) TRC score.

Element 2: Program Design and Implementation

This improvement category offers many specific opportunities to make home energy upgrade programs operate more efficiently and effectively for all participants. Most difficult yet crucial is the creation of a strong top-down sense of urgency and commitment to program success rather than the present fragmentation of program guidance due to "silo effects" of topically specialized policies and protocols within utility organizations, similar to the regulatory problems cited above in Element 1. The present extreme risk-avoidance strategy must be replaced by more realistically balanced risk management in areas such as data accuracy, contractor error, and customer satisfaction. This may require legislative initiatives as well as regulatory changes.

Largely due to process inflexibility, promising program innovations are sometimes rejected without testing. Small scale field test studies should be much more widely used to test potential program improvements. Some examples of possible field tests include menu-based rebates, use of community organizations in marketing, neighborhood-focused mass retrofits, and the use of now widely available smart meter data to screen homes and simplify audits.

Design of rebates and other incentives must also be simplified. The present system ties each home's rebate to a modeled percentage-savings forecast, which requires extensive rules, training, and verification efforts in addition to significant contractor training, time, and cost. One possible alternative is the use of a menu of point-weighted measures rather than modeled savings, backed by sampling studies to estimate program-wide savings. Such alternatives would be acceptable to homeowners while dramatically reducing administrative costs for all parties, ultimately reducing retrofit costs and inconvenience for homeowners.

Other possible improvements include a gradual reduction in incentive levels over time, as recently suggested in a regulatory decision [CPUC 2012b]. This would reward early adoption and is already used in the state's solar PV programs. Yet another need is for improved alignment of the interests of contractors and homeowners as well as programs. For instance, contractors could be required to provide energy savings guarantees, backed by insurance, thus encouraging a greater emphasis on reliable quality and energy savings. This could greatly increase consumer confidence while further reducing program quality assurance effort and cost.

Element 3: Workforce Development

Contractors struggle with the demands of home energy upgrade programs. Too often the focus is on burdening all contractors with excessive reporting, verification, and field practice oversight, at high cost to all parties, as a way to eliminate the errors of a few. This approach ignores more realistic quality and safety safeguards and results in an adversarial relationship that hinders contractor participation and success. Instead, it is essential that programs embrace the participating contractors as their principal allies, not incompetents or truants. The ultimate goal must be to transform the entire residential contracting industry, which will require an unprecedented partnership between the industry and the utilities/regulators to assure the many changes needed in standard practice.

The residential contracting industry—including all specialties as well as general contractors—is dominated by very small companies. They typically need economical training and mentoring in not just technical assessment and retrofit skills and certifications but also marketing, sales, energy analysis and modeling, and a broad range of business administration and management capabilities. Such training, along with equipment procurement financing and direct

marketing aid, must be expanded in scope and made far more widely and easily available. Utility program implementers as well as high school and community college vocational training programs should be engaged in this workforce upgrading effort along with commercial training providers. Barriers such as the present HERS II program's limitations on who may provide home assessment training and how, must be reconsidered.

To increase contractor capacity as needed for program scale-up, we must go beyond supporting only conventional contractor models. A broader range of business models must be developed and encouraged: Examples include contractor aggregators, individual raters and rater organizations, contractor alliances, and franchises providing centralized support. Retrofit programs must be innovators here in partnership with the contracting industry and others.

Element 4: Public Education and Marketing

Comprehensive home retrofit marketing in California and often elsewhere has presented the program as a stand-alone venture, not only the most costly option but also disconnected from all other utility guidance and programs for single efficiency measures. This makes the concept harder to understand and accept, especially due to its high participant costs, relatively low energy bill savings, and dependence on its ability to correct non-energy problems such as noise, dust, and discomforts that the homeowner is accustomed to living with. It may be more effective for whole-house upgrades to be marketed within an integrated progression including the many simpler and more economical options for the homeowner, including no-cost behavioral changes. This strategy would be much clearer, and could also help owners stage a retrofit in logical steps over several years to manage cost.

That integration could be further enhanced by a web-based public engagement system, along with active use of new social media, to instill a sense of shared challenge and action. Further momentum could be added by engaging and incenting community organizations to leverage their connections to specific homeowner groups. Other improvements should include flexible and substantial cofunding of contractor marketing costs, as done in some programs in other states. These examples illustrate the more general principle of leveraging and assisting contractors and community organizations as principal marketing agents in preference to mass marketing by the program sponsors or implementers.

Element 5: Project Financing

Home retrofit cost vies with institutional obstacles as the most serious class of program barriers. In addition to rebates or other incentives, innovative financing is urgently needed to reduce overall participant cost and engage many more homeowners. Efforts are in progress to reduce interest rates and liberalize borrower qualifications, but these measures have only marginal effects on consumer payments. On-bill loan payment or financing has similar limitations, and in California's cost and savings environment the on-bill loan payments will typically be higher than the retrofit's energy bill savings. This is typically justified by the homeowner's perceived non-energy benefits, but for many homeowners the additional monthly cost is prohibitive despite their desire for those non-energy benefits.

Loan-loss reserves funded by government or utility programs may improve retrofit loan interest rates if banks choose to participate, but those savings will be small. Energy efficiency mortgage refinancings and programs such as the Federal Housing Administration's 203(K) mortgage underwriting will also be useful but unlikely to greatly increase market adoption. The

aborted national PACE ("property-assessed clean energy") financing concept could also reduce interest rates and has the added advantage of being attached to the property tax account and transferrable to subsequent owners along with the continued benefits. All possible efforts should be made to reinstate the PACE program through national legislative action or legal recourse.

Many other efforts are in progress both in California and nationally to improve home retrofit financing options. But to achieve the extremely high levels of participation required under the California climate-driven goals, the economic constraints of most homeowners must be addressed. Millions of homeowners in California, as elsewhere, simply cannot afford the optional new payment stream for a home energy upgrade, no matter how well justified by the range of benefits. Some form of public cost offsets such as liberal tax credits—or even mandated retrofits—are likely to be required, possible politically only under extreme circumstances such as some possible future highly visible climate crisis.

In any case, retrofit costs to reach the state's 2020 goal for these 4.8 million homes will be in the range of $100 billion if not higher. Public financing options can meet only a small share of that market need. The retrofit goals will require new forms of access to large-scale private investment capital, as has been done in the rooftop solar market with no homeowner capital and guaranteed long-term cost savings. Even with such investment models, major economies of scale and individual retrofit cost will be needed to make major reductions in the consumer's payment obligations. Retrofit program designs and delivery requirements are likely to have to be greatly simplified to reduce costs adequately for any market-transforming financing strategy to work.

Element 6: Administration and Reporting

The current programs have required far too much overhead cost and delay for contractors as well as program administrators, adding to consumer and contractor resistance to participation. A new attitude of partnership between program sponsors and contractors must be developed, requiring substantial streamlining of program administrative requirements and delivery rules as noted earlier. For example, quality assurance and control protocols must be simplified while continuing to assure public safety and satisfaction. Some details of that simplification were provided in earlier sections of this analysis.

There is some early evidence of model-forecasted energy savings inaccuracies, not only for appropriate incentive allocations but also to meet the state's cost-effectiveness requirements. Programs should routinely monitor actual bill savings versus modeled savings forecasts and make adjustments to the modeling tools and their use as warranted. Also, contractor experience confirms that their customers are typically more motivated by the various non-energy benefits than utility bill savings, suggesting that less emphasis on predicting exact energy savings may be advisable. Loosening the present tight connection between each home's forecasted energy savings and the associated rebate could greatly reduce administrative costs and ultimate reduce retrofit costs as well as improve contractor margins. As noted earlier, menu-based point systems are one example of this. Random sampling could be used to confirm energy savings on an aggregate basis instead of what now amounts to a research project on every home. Life safety, especially with combustion appliances, will always be crucial but it may be possible to minimize or avoid detailed analysis of every home's energy efficiency deficiencies and solutions.

Element 7: Quality Assurance and Control

Adequate QA/QC is essential, but current requirements are often excessively costly and intrusive due to overly complex and slow protocols with little compensating value or need. A broad range of specific improvements can be made if regulatory and utility sponsors will agree. For example, detailed and consistent retrofit quality installation practices must be provided. Contractors and raters must be made better informed of those proper practices, through more technical training, certifications, mentoring, and internal quality management instruction, with sampling-based assistance and enforcement.

Combustion safety is already a justifiably major focus of program QA/QC practices, but existing 100% field verification processes appear to be excessive and unduly costly. Combustion safety assurance could be strengthened with analyst-signed test reports, random field verifications, and active non-punitive hotline-type assistance backed by well-publicized severe sanctions, including legal action, for serious or repeated violations. More generally, expert technical advice on all safety and quality-related issues must be made more available through online references and tutorials plus personal field support, and a robust feedback mechanism should be used to monitor homeowner satisfaction or complaints.

Element 8: RD&D Needs

There is far too much that we don't know, but need for transforming program design and operation. Substantial RD&D has been done in specific technology topics but many other RD&D needs have not been addressed. A broad range of such needs must be pursued immediately. The following four categories of RD&D needs offer some examples.

Program cost-effectiveness. Existing mandated tests, particularly the widely used TRC, do not consider the full range of home retrofit benefits, proper retrofit cost attribution, net-to-gross savings, and discount rates. New or substantially improved tests must be developed and tested without further delay. Some essential RD&D needs here include field data studies to quantify buyer motivations, home-value effects, health and safety benefits, upkeep savings, and societal gains such as employment, social service economies, and climate protection.

Program design improvements. Definitive studies of simulation model accuracy are needed to assure more reliable energy savings forecasts. Alternatives to field use of such simulations, such as use of smartmeter data and bill disaggregation, should also be developed and compared. Similarly, pilot-test comparisons of alternative approaches to rebates and other homeowner incentives, such as point-based retrofit menu choices, are needed to permit program refinements that reduce administrative costs for all parties.

Technology improvements and innovations. To achieve the breadth and depth of energy savings needed to meet ambitious goals, RD&D on new technologies must be broadened and accelerated. Some special opportunities include plug load controls, smart appliances, economical deep insulation products and techniques, ductless heating and cooling, combined space and water heating, lighting controls, and home energy automation systems, Examples of longer-term high-impact opportunities include assessment of DC power distribution and use in homes, magnetic refrigeration, and self-adaptive energy management controls.

Institutional process needs. The most important RD&D needs in institutional processes are studies of the current organizational decisionmaking models and their results, with the goal of identifying feasible changes and strategies for such changes in both the near and long term. Also needed is research and testing of innovative energy efficiency program delivery models for programs as well as contractors. Finally, a collaborative research effort is needed to develop and maintain a strategic home retrofit roadmap for the coming decade, involving all aspects of the process as outlined in this paper.

Conclusions

Major Strategic Findings

This paper's assessment has described evidence of an orders-of-magnitude gap between current single-family home energy retrofit program potential in California and the state's climate-change goals for those homes. In addition, the remainder of the existing-housing sector is yet to be addressed. The unprecedented scale of this challenge leads to a broad range of changes needed to close that gap.

Perhaps the most important finding of this analysis is that high-level commitment to home retrofit program success must be strengthened in both the utilities and the state agencies involved. Despite extreme difficulties, it may be possible to reach the CPUC existing-home energy reduction goals if the necessarily unequivocal high-level commitment can be secured from the utility and regulatory agency leadership. That commitment must be adequate to overcome the barriers now evident in the regulatory and utility program management processes. Specific institutional barriers must also be removed: Examples include biased cost-effectiveness tests, lack of flexibility in program refinement, and overly risk-avoidant decisionmaking in lieu of a practical balancing of risk, hedging strategies, and success.

Technical innovations, high cash and other economic incentives, and program design refinements are also needed but are not enough to create market transformation and the degree of up-scaling required. The high cost of deep retrofits prevents most homeowners from participating; new financing and delivery-cost models must be developed, probably involving a combination of institutional investment and major new governmental incentives for homeowners as well as investors.

A broad range of research, development, and demonstration needs must be addressed to answer key questions where lack of factual knowledge is hindering program success. Much of the needed RD&D focuses on "soft" issues rather than technology. Examples include analysis and development of solutions to institutional barriers, cost-effectiveness test issues, financing shortfalls, and energy savings estimation uncertainties. These RD&D needs should be given high priority by state as well as Federal agencies, and must include strong private sector involvement.

Regulators and implementers must treat contractors less as adversaries and more as partners in this effort. Current programmatic complexity for contractors, such as complex simulation modeling, data reporting, excessive quality assurance protocols, and energy rating system complications, must be reversed. Increased direct support to contractors is needed in equipment purchases, training, and cofunding of marketing initiatives.

California is providing other states and the Federal government with a model for the kind of climate protection-driven energy efficiency policies that may be needed nationwide. But all states must reconcile the challenges of energy efficiency program process and funding with bold

carbon reduction goals. Much can be done to begin building momentum now; delay would risk loss of economic gains, needed job growth, and reduction of climate-change risks. The collective challenges are obviously immense. Only comprehensive changes in the full range of home energy retrofit program elements can succeed in adequate up-scaling of market acceptance.

Recommended Top Priorities

The most urgent needs for new initiatives in home energy retrofit programs will and should be the subject of much debate. As a starting point, we present recommendations based on this paper's review of needs and options, as a catalyst for such debate and resolution. These recommended changes are summarized below for both immediate program improvements and more extensive longer-term restructuring.

2012-13 Top Priorities (for immediate implementation).

- High-level agency and utility commitment to radical program improvement
- More extensive training/mentoring, including management, sales, and marketing
- Increased program incentives to contractors for education, equipment, and marketing
- Marketing incentives for community organizations to reach their constituencies
- Immediate job approvals followed by streamlined QA/QC protocols
- Separation of home energy ratings from utility retrofit program operations
- Improved simulation modeling accuracy or replacement with other means of estimation
- Shift of energy savings modeling duties from contractors to program staff services
- Continuous reassessment of program trajectory and rapid adjustment of design as needed

2013-15 Top Priorities (for more difficult longer-term changes).

- Intensified study and implementation of improvements in cost-effectiveness metrics
- Integrated marketing of whole-house retrofits with all other residential programs
- Rebates based on point-scores of measures and declining over time
- Use of smartmeter data with streamlined diagnostics and analysis to identify home problems without modeling and improve accuracy of savings forecasts
- Creation of financing models including private capital/leasing/PACE and tax credits
- Improved HERS II or alternative system for streamlined high-volume energy ratings
- Continuous program reassessment and modification as needed, through 2020

In this paper we have proposed a need for comprehensive restructuring of virtually all aspects of current whole-house energy efficiency programs, far beyond incremental refinements of a few elements. To open a discussion on implementing that finding we have derived a broad array of specific actions to help California bridge the looming gap between its current home energy efficiency upgrade program accomplishments and the state's ambitious climate protection-driven goals as well as urgent employment needs. We urge serious discussion and reconciliation of such goals and actions, in other states as well as California.

The difficulty of that reconciliation cannot be overestimated, even if states adopt somewhat lesser goals for their housing sector. But the weight of scientific evidence put forward by the International Panel on Climate Change and other groups is increasingly incontrovertible.

California's Global Warming Solutions Act (AB 32) implementation has squarely faced that challenge by setting goals and assigning responsibilities to all sectors, including the housing stock. Now we must find practical solutions, including the potential contributions of whole-house energy upgrades at the universal scale needed.

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